Puerto Rican Coral Reef Degradation: Causes and Cures

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Abstract

Puerto Rican coral reefs have been experiencing degradation, and the Departamento de Recursos Naturales y Ambientales wants to protect them. The goal of this project was to identify the environmental and human-related stressors on these reefs in order to recommend ways to monitor their health and protect them. Using archival research, interviews and GIS maps we identified trends in reef health at selected monitoring sites. We concluded that the DRNA should control pollution, prevent mechanical damage, and increase public awareness about the importance of reefs.

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Executive Summary

Coral reefs are a dynamic feature of marine ecosystems around tropical regions of the world. Due to the economic and biological value of coral reefs, it is important that they are sustained for future generations. However, as evidenced by a wide range of symptoms including bleaching and disease, coral reefs are struggling to survive in some locations. It is crucial to halt this trend before the damage becomes irreversible. Organizations, including the Departamento de Recursos Naturales y Ambientales (DRNA) in Puerto Rico, have been trying to identify the environmental and human-related causes of coral reef decline and the extent of the impact on the reefs.

There are two main influences behind coral reef degradation; these are human-related and climate-related factors. Both are detrimental to the reefs, but climate-related causes are harder to control. However, human-related causes can potentially be controlled by an organization like the DRNA. Some of these problems are associated with tourism, fishing regulations, overfishing, storm water runoff, and pollution. Even though several of these factors have been identified, the extent of their impacts has not been thoroughly researched.

The purpose of our project is to identify the environmental and human-related causes of Puerto Rican coral reef decline and make recommendations on how to mitigate these causes. In order for our results to be accurate we had to analyze healthy reefs as well as those that have been damaged. This was done by interviewing experts, conducting archival research and observing the reefs ourselves. We not only investigated the coral reefs surrounding Puerto Rico, but also various other coral reef ecosystems worldwide. We identified and examined the causes of coral reef degradation to better understand and formulate potential solutions to this current problem in Puerto Rico.

In order to pinpoint the exact factors affecting Puerto Rican reefs, we examined the DRNA coral reef monitoring sites through their monitoring reports. We also compiled a comprehensive GIS map using the ArcGIS software and existing map layers provided in the DRNA database to identify trends and possible stressors. Additionally, we conducted background research on past coral degradation problems that have occurred worldwide. In addition to archival research, we interviewed experts specializing in the study of coral reefs, such as members of the DRNA and university professors from the University of Puerto Rico, in order to determine all possible causal factors and ecosystem relationships. We researched the current safeguards that are in place to prevent any damage to the coral reef ecosystems in Puerto Rico. Through observations of fishermen and tourist agencies we evaluated whether or not these safeguards are being followed properly.

After reading through the reports and compiling the GIS map, we were able to identify some general trends. Whenever there was a significant decline in coral cover, there was also a significant rise in algae. The shallower reefs have been negatively affected more than the deeper mesophotic reefs. Over the years there has been a noticeable decline in fish species numbers, while abundance may rise, indicating a shift in ecosystem balance. There is a continuing trend of pollution and pollutant runoff impacting ocean waters. A number of reefs, including the monitoring site at Guanica, are located in close proximity to potential river pollution from agricultural valleys. Lastly, laws and regulations are generally either not known or obeyed. From our observations, we determined that fishing and reef regulations are not always followed.

From these results and our analysis, we can conclude and make multiple recommendations. The DRNA needs to keep track of more variables at their monitoring locations. They should be monitoring levels of a wider range of chemicals including nitrates and phosphorus, bacteria, and specific species of algae. The DRNA should study the interaction between algae and coral reefs to determine the severity of the algae growth at the reefs and whether this growth is causing reefs to decline. Marine Protected Areas must be created or expanded around Puerto Rico in order to stifle overfishing and ecosystem imbalance. Regulations and enforcement must be increased in order to reduce levels of runoff pollution from the Puerto Rico mainland. An effective public awareness program must be implemented in order to facilitate knowledge of coral degradation and preventative measures within the public. The DRNA needs to install more mooring buoys for boats to decrease the amount of mechanical damage from anchors. Lastly, the DRNA should look into the possibility of coral cultivation to combat the negative effects from Puerto Rico's coral degradation.

1.0 Introduction

Coral reefs are an essential part of marine ecosystems around tropical regions of the world. Due to the economic and biological importance of coral reefs, these reefs should be sustained for future generations (Caribbean Coral Reef Institute, 2010; Diaz, 2008; García-Sai, 2008; Lesser, 2007; NOAA, 2012; Riegl, 2001; The Nature Conservancy, 2011; US EPA, 2005). However, as evidenced by a wide range of symptoms including bleaching and disease, coral reefs are struggling to survive in some locations. It is necessary to halt this trend before this damage becomes irreversible. Researchers have been trying to identify the environmental and human related causes of degradation in coral reefs, but so far, no definitive answers have been found.

Coral reef degradation problems have specifically affected the island of Puerto Rico (Caribbean Coral Reef Institute, 2010; Diaz, 2008; García-Sais, 2008). However, some of its reefs are thriving, while others are succumbing to damage from factors like bleaching and disease. If there were no non-environmental and climate-related stressors, Puerto Rico's reefs would have a greater chance of thriving and being full of life. However, conditions in Puerto Rico at this time are inhibiting some of the reefs from flourishing. The coral reefs have an important influence on the Puerto Rican economy; their degradation is negatively impacting the island's tourism and fishing industries and marine ecosystems in general. Thus far, scientists have not been able to identify all the factors that are detrimental to the Puerto Rican coral reefs.

Prior research done by experts has found that specific culprits of reef degradation include climate change, pollution, tourism, overfishing, erosion, regulations and lack of public awareness (Crownover, 2011). In Hawaii's Protection Campaign, for example, researchers found that coral reef ecosystems were being destroyed due to pollution, development, overfishing, and alien species. All research has been used to create local action strategies at various organizations to be used in managing the health and protection of coral reef ecosystems.

Prior research has failed to identify the degree to which each negative influence has impacted Puerto Rico's coral reefs and the overall marine environment (García-Sais, 2008). For example, there is inadequate knowledge on how much and in what ways tourism disturbs the marine environment and whether or not it is a major problem that must be addressed by the Departamento de Recursos Naturales y Ambientes (DRNA). Additional research is needed to determine the key factors that affect the health of the Puerto Rican reefs. The DRNA does not know why some reefs have remained healthy and others have not.

The goal of this project was to identify the non-environmental and climate-related stressors on Puerto Rico's coral reefs. This project's sponsoring agency, the DRNA, is looking to successfully sustain the coral reefs in Puerto Rico. In order to fulfill this goal of identifying the human-related and climate-related stressors, our objectives included identifying trends in specific variables at monitoring sites that may be affecting reef health, determining current DRNA data collection methods for coral reefs, and determining whether other countries' strategies to prevent damage to their coral reef ecosystems would be viable in Puerto Rico. To accomplish our goal and objectives we used various methods such as interviews, archival research, GIS map layer analysis, and direct observations. By completing this project, we have provided the DRNA with potential ways to improve the monitoring system for determining the health of coral reefs and their knowledge of why specific coral reefs are struggling or thriving. Our recommendations are based on the trends we have found by analyzing the available data on coral reefs in Puerto Rico. It is crucial that these reefs are protected because of their importance to Puerto Rico's environment, economy and society.

2.0 Background and Literature Review

This chapter introduces the science behind coral reefs and the causes of bleaching and disease including climate change, tourism, and overfishing. We discuss the research that has been carried out to determine the causes and impacts of bleaching and disease in coral reefs from both human and environmental influences. Given the global nature of these problems, we present representative examples from Puerto Rico and elsewhere.

2.1 Coral Reefs

Coral reefs can be defined as underwater collections of slow growth, wave resistant structures (Life Bio: Stony Brook University, 2011). However, this simple definition fails to delve into the complexity of a coral reef ecosystem. These resistant structures are actually biological communities living off of one another. The life contained within a coral reef ecosystem is so diverse that it is often considered the "rainforest of the ocean" (US EPA, 2005). The coral itself is composed of tiny invertebrate organisms, called *cnidarians* that stay fixed to the surface they are on and do not move from that position (Beckham, 2000, p. 323). The coral polyps are connected by a cement-like calcium substrate that binds the entire reef together. The final product is an intricate network of diverse organisms and structures that occurs through most of the world's tropical and subtropical oceans.

A coral reef is a global phenomenon that occurs in warm water regions of the world's oceans (Thurman, 1993, p. 336). Typically coral can only survive if the temperature of the water does not fall below 64º F year round. Corals also prefer clear waters that are high in salinity and sunlight (Beckham, 2000, p. 323). This results in a distribution of reefs around the equator, staying close to coastal areas. Although these reefs cover less than 1% of the Earth's surface, they support 25% of all fish species on Earth (The Nature Conservancy, 2011). Reefs are specifically located in the Atlantic, Pacific and Indian Oceans, where the Atlantic's reefs are primarily in the Caribbean (Coral-Reef-Info, 2010).

Home to a plethora of these coral reefs is the small Caribbean island of Puerto Rico. This island has more than 300 miles of coastline and has a coastal shelf surrounding it. The shelf serves as a perfect nursery for marine life. As a result, the island is bordered by over 260 square miles of coral reefs. Puerto Rico is also home to a wide variety of local species that are on the endangered species list. Coupled with the fact that all of Puerto Rico's reefs are now considered "at risk," the condition of these reefs and surrounding marine ecosystems is now extremely important (U.S. Fish & Wildlife Service, 2011). Loss of these reefs would be devastating to the local ecosystems and Puerto Rico as a whole.

2.2 Climate Change

Climate change is a global problem affecting the coral reef ecosystems. According to the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (2007), climate change is a long-term change in weather patterns. The Washington State Department of Ecology (2011) believes these changes in weather play a basic role in shaping ecosystems and the cultures depending on them. There is a debate about climate change, but the question is not if climate change is real. Since climate change is a very real phenomenon, the question is rather if humans are responsible for recent climate change or not. Regardless, there are some major naturally occurring events that can be associated with recent climate change.

El Niño and La Niña are two global weather phenomena that are affected by climate change. The Scripps Institution of Oceanography (1997) describes El Niño as a temporary change in the climate of the Pacific Ocean near the equator. This event causes the ocean surface to warm up a few degrees Celsius, which then changes weather patterns. Examples of these weather changes are wet winters in the southeastern US and drought in Indonesia and Australia. Also, the normal area along the equator associated with thunderstorms moves eastward. La Niña, as described by the NOAA (2012), is the opposite of El Niño. La Niña occurs when the surface ocean temperatures of the Equatorial Pacific lower by a few degrees Celsius. This drop influences weather patterns including warmer than normal winters in the Southeast United States and colder than normal winters in the Northwest United States.

These weather changes directly affect Puerto Rico and its reefs. Diaz (2008) predicts in the next 100 years the surface temperature of the ocean water will increase 1.4° to 5.2°C due to climate change. The sea level will rise 34 to 98 centimeters, which will result in greater erosion along the shore. This rise in sea level will result in more pollution flowing into the ocean from top soil and other contaminates coming from the island. Another change is an increase in the frequency of extreme events such as hurricanes. These hurricanes can cause great damage to the reefs. They cause greater erosion, which, as stated before, results in more pollution, and they cause damage from rough seas tearing apart the reefs. A change in the Arctic and Antarctic might also affect the reefs. When the ice caps melt, more freshwater is added to the ocean creating a lower salinity in the ocean water. This can be extremely harmful to the coral, as can be seen in the study conducted by Craig Downs on hypo-salinity's effect on the coral species, *Stylophora pistillata* (Downs, CA, et al, 2009). The study revealed that a decrease in salinity damaged the coral, which lead to tissue swelling, loss of zooxanthellae, and tissue necrosis.

2.3 Coral Reef Damage

Climate change is a factor in coral reef damage; however, coral reefs are delicate structures that can be damaged in many different ways. Coral bleaching and disease, as well as tourism, are commonly identified as the main sources of coral degradation; however, throughout the world different damage is experienced from causes such as mining or even dynamite (Riegl, 2001). In order to understand how to sustain coral reefs, it is important to know how damage occurs in the first place. Without this knowledge it will be impossible to determine solutions to the ongoing environmental problems within these ecosystems. Thus, we will first look at the different causes of coral damage before discussing coral bleaching and disease.

2.3.1 Different Types of Damage

In many areas of the world there are documented cases of damage to coral reef systems. These different causes are both devastating and diverse. One example of such damage is in the Red Sea where the main causes of damage are from dangerous fishing methods and ship groundings (Riegl, 2001). In parts of the Red Sea, shipping lanes are increasingly narrow and dangerous. Ship groundings on a small and large scale are relatively frequent. Bernhard Riegl's study discussed 8 major ship groundings, with 7 of them affecting the windward slopes of the reefs. This damage was extensive with slow regeneration and an estimated total healing time of 100-150 years. Also in this area, the practice of dynamite fishing is impacting the reefs in a very negative manner. Dynamite is used by fishermen to kill and collect fish in the surrounding area. However, this dynamite cannot target solely fish and results in the destruction of everything within a certain radius of the blast. Riegl analyzed 60 reefs and 39 of them showed signs of dynamite damage or scarring. This damage was mainly focused on the leeward slope of the reef and had a severe impact on the coral structure. The research found that damage from dynamite and ship groundings had the same effect on the ecosystem because of the nature of the damage, and because these events often overlapped in the same areas. The article concluded that changes were not only found in the coral structures, but in the fish communities as well.

The report “Status of Coral Reefs in the World” (Wilkinson, 2008) assessed the status of the coral reef ecosystems specifically in Puerto Rico. According to this report, “commercial and recreational fisheries in Puerto Rico land more than 179 edible fish species, as well as many aquarium species. For both jurisdictions, the removal of juvenile fish, queen conch, lobster and herbivorous fish that help maintain healthy coral reefs is of particular concern” (p. 33). This comment alludes to the need to have proper fishing regulations in place to protect the balance of the ecosystem. This report addressed the need to monitor emerging issues such as understanding bleaching and disease and assessing heat tolerant strains of corals, determining the effects of recreational activity on reefs (fishing, anchoring, boating, snorkeling, petroleum, garbage), and identifying non-point sources of pollution. It is also acknowledged that the effects of tourist activities on the coral reefs in Puerto Rico are not well known. As for solutions, this report suggests that the local government alleviate some threats by stricter prevention measures that control nutrients and sediments from development-induced erosion, agriculture and poorly maintained septic and sewage systems from entering the ocean. Other threats from shipping, anchoring and recreational boating can be addressed by installing more navigational aids, and continuing public education and outreach (p. 52).

2.3.2 Coral Bleaching

Coral bleaching is a major symptom and cause of coral reef degradation (Caribbean Coral Reef Institute, 2010). Bleaching is a phenomenon related to the algae associated with the coral. These algae, zooxanthellae, have a symbiotic relationship within the coral structures. The coral provides nutritional compounds and a protected environment, while the zooxanthellae provide organic compounds, oxygen, and removal of wastes. These zooxanthellae also provide the beautiful coloring that reefs are known for through their photosynthetic pigments. Coral system bleaching occurs because these algae are expelled, leaving behind only the white calcium carbonate skeleton. Physiological stress from natural and anthropogenic, or human-caused, variations causes the expulsion of zooxanthellae. Bleaching comes on both a small scale in isolated reefs and through major events that impact entire regions.

Worldwide coral bleaching harms reefs in many locations and in different types of events. In 1998 there was a major coral bleaching event in the reefs of South Asia. This was a major climate-related event that affected the reefs of the Maldives, Chagos, Lakshadweep atoll, Sri Lanka, and in India's Gulf of Mannare. Here, a large percentage of the shallow water corals were bleached. The greatest effects were seen in corals that were less than 10 meters deep. It was determined that increased sea surface temperatures and decreased trade winds that were a result of El Niño caused the event (Rajasuriya, 2002). Increased sea surface temperatures are particularly critical because a variation of only 1 to 1.5 degrees Celsius from the climatological thermal mean can cause bleaching. When these corals exist in shallow waters, they are continuously at risk due to their sensitivity to temperature changes. Another example of such a bleaching event was in 1983 off the Central American coast of the Pacific Ocean (Glynn, 2012). During this event three species of hydrocorals disappeared off the coast of Panama. This event also affected the reefs of Costa Rica, Galapagos Islands, and other eastern Pacific locales. Bleaching to depths of around 12 meters characterized the event, with corals below this depth being unaffected. These events put a global perspective on the issue of coral bleaching that is also occurring in and around Puerto Rico.

In the Caribbean a major bleaching event took place during 2005 (García-Sais, 2008). This event was characterized by above normal ocean temperatures over a period of time which caused thermal stress on the reefs. The region that was most affected was the eastern Caribbean.

During this event 37% of surveyed coral species on the east coast of Puerto Rico suffered 100% bleaching. On the south coast coral mortality was around 50%. This event adversely impacted the coral reefs in Puerto Rico; however, by 2006 some of them had started to regain their color. Other reefs were not as lucky as the bleaching led to coral disease.

2.3.3 Coral Disease

Coral disease is a source of major coral losses. There are over 20 different types of diseases and syndromes that have been identified (Caribbean Coral Reef Institute, 2010). Corals are particularly susceptible to diseases after bleaching events when the reefs are most vulnerable. Disease origins are mostly unknown; however, some diseases are linked to bacteria and fungi from agricultural runoff. Some prevalent diseases in the Caribbean have been white-band, black-band, and yellow-band disease. Black-band disease causes a separation of coral tissue from the calcium carbonate skeleton due to a black mat of filaments that covers the coral. An example is shown in figure 1 below.

Figure 1: Black-band Disease (Caribbean Coral Reef Institute, 2010)

It has been sporadically documented with some cases between 2002 and 2006 off of La Parguera and Mona Island. White-band disease attacks reef building corals by exposing the coral skeleton. An example is shown below in figure 2.

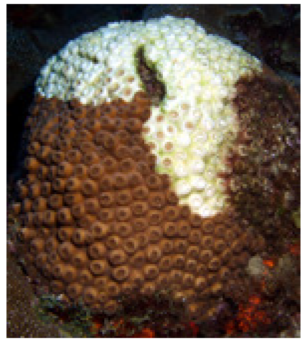


Figure 2: White-band Disease (Caribbean Coral Reef Institute, 2010)

There have been cases between 1995 and 2003 off the coast of Mona Island that affected 15% of the reefs. Finally, yellow-band disease causes yellow patches or rings to be bleached into the coral. An example is shown below in figure 3.

Figure 3: Yellow-band Disease (Caribbean Coral Reef Institute, 2010)

This disease affected reefs off Mona Island between 1999 and 2001 with 50-100% of their tissue being lost. These diseases are tough to fix since most causes are unknown; however, effects from tourism are easier to prevent.

2.3.4 Tourism

Tourism can cause damage to reefs through the boats and machinery used, as well as from the tourists themselves. In South Asia different modes of tourism were associated with site specific reef damage (Rajasuriya, 2002). Trampling and coral removal caused damage to the reefs. In these areas there is a known presence of glass bottom boats used to get views on top of coral, boat anchoring, destructive collecting, and high visitor pressure. When boats visited the reefs, they often dropped anchor without thinking that the anchor might be landing on the coral. These tourists or merchants would take ornamental coral species for souvenirs, causing localized destruction. These boats also added pollution to the environment from exhaust and trash, which can change the chemical makeup that influences the ecosystem. A further effect of reef visitors was broken coral that, over the course of one month, was estimated at 7% of the coral cover. This figure accounted for 17% of susceptible coral cover (Allison, 1996). Some of these impacts may be relevant for Puerto Rico.

In Puerto Rico the effects of tourism on coral reefs have not been studied extensively, but tourism itself has been on the rise. The upsurge of tourism is centered in the San Juan area with an uptick in personal watercraft and boaters arriving from other islands and the U.S. (García-Sais, 2008). The major evidence of damage to the coral is from scarring. Researchers documented major propeller scar impacts in La Parguera reserve. This includes shallows near Magueyes Island, Cayo Collado, and Cayo Caracoles. In these locations 43-74% of the area potentially affected by boat traffic had evidence of damage due to propeller scarring. Another specific case of damage is in Cordillera where recreational boaters congregate and have left extensive anchor damage. Also present is propeller wash on the seabed facing the beach from departing boats. A final effect from tourism in Puerto Rico has to do with construction of docks and marinas. These construction projects damage mangroves and sea grasses while introducing sediments and pollutant runoff into the offshore coral reef ecosystems. Since these mangroves and sea grasses are critical to the offshore ecosystem, the construction docks and marinas are of particular concern for coral degradation.

According to the Managing Marine Corridors research team from Worcester Polytechnic Institute (**Doucett**, 2006); recreational overuse and overfishing are two of the biggest causes of marine corridor degradation, such as coral reef damage. Specifically, anchoring in locations such as coral reefs is one of the major problems. This project group recommended to the DRNA that a larger number of mooring buoys be placed in key areas for boats to tie up to instead of forcing the boaters to drop their anchors. These buoys would greatly reduce the damage done to coral reefs from dropped anchors. It is known that a number of mooring buoys were added but they still remain at an unacceptable level.

2.4 Land-based Pollution Sources

In regard to land-based sources of pollution, the IQP project Managing Marine Corridors (Doucet, Giebenhain, Gurbanov, & Slezycki, 2006) discussed the importance of carefully planning any construction done on the coastline as this can cause runoff when it rains. This runoff contributes to the pollution and sediments that are causing the bleaching of the coral reefs in Puerto Rico. This IQP project team also suggested that "environmentally sensitive land use planning be mandated by the government and imposed on developers to plan new construction and to utilize and expand the waste water treatment system as the demand increases" (p. 68).

2.5 Overfishing

Overfishing is one problem leading to the destruction of a coral reef ecosystem. The Caribbean Coral Reef Institute (2010) claims that Puerto Rican reef fish are under pressure by more than one group of fishermen. Fish are being taken by commercial fishers, recreational anglers and spear fishermen as well as by collectors seeking them for fish tanks. The obvious reason for harm to the ecosystem is the decrease in the fish population. This decrease in population may shift the feeding ecology of the coral reef ecosystems. The DRNA has created some new regulations to help reverse the decline in fish populations. These regulations now require recreational fishing licenses, prohibit recreational spear fishing with scuba gear, have established size and catch limits, and created species-specific permits for sensitive species. The fishermen will be doing themselves a favor to follow the new regulations. If they do not, they will soon no longer have any species to harvest.

Fishermen harm the reefs in other ways as well. One way in which the coral reefs in Puerto Rico are being harmed is by fishermen abandoning their traps. Scharer (2004) reports that 24% of fishermen admitted they abandon their traps if they lose them. In reality this number is higher because not all fishermen will admit if they do this. These abandoned traps can crash into the reefs during storms and break the reefs. The fishing boats also contribute to pollution of the water by leaking oil and gasoline into the ocean.

Globally, some governments are creating new regulations to reduce destruction of coral reefs. One example is the Hawaii Protection Campaign that was launched in 2006 and is still in use today (Crownover, 2011). Hawaii is home to some of the most beautiful, unique coral reef ecosystems in the world. These coral reef ecosystems were being destroyed at a devastating rate by causes such as pollution, development, overfishing and alien species. This campaign, led by President Bush and Hawaii's government, restricted gill net fishing in state waters, promoted public awareness of the dangers of overfishing, and encouraged responsible fishing practices. "Scientists have said these restrictions will have a positive impact on the health of Hawaii's reefs" (para. 21).

2.6 Public Awareness

According to the Maintaining Marine Ecosystems Project (Cafferty, Carmichael & Vayda, 2009), approximately two- thirds of all people less than 25 years of age had never seen a DRNA publication concerning coral reefs. From multiple surveys, the researchers discovered that the younger population was a lot less aware of coral reef regulations and was obeying them less than the older generations. This project team recommended that the DRNA give presentations at the local school systems annually in order to educate the younger population about the regulations and importance of coral reefs. The Maintaining Marine Ecosystems Project team also recommended that the DRNA educate the public by means of public service announcements, internet sites, and social media networks such as Facebook. This would ensure that the younger population would be privy to education on the topic as well.

The DRNA has already begun some studies regarding a lack of public awareness about the reefs and has attempted to increase the public's knowledge about actions that harm the coral reefs. The University of Puerto Rico began the "Coral Reef Ecosystem Studies: Integrating Science and Management in the Caribbean" six years ago with a funding level of five billion dollars sponsored by NOAA (Appeldoorn, 2009). This program has three main objectives: to study the processes responsible for decline in coral reefs; to study the feasibility of alternate management strategies; and to offer practical management advice and tools. This program has already created management tools such as the Decision Support System, which is a Marine Protected Area (MPA) trophic model for assessing MPA ecological effectiveness. Other management tools developed by this program include a fisheries assessment model and a water-flow model. All of these management tools have acted as a base to further support the development of improved coral reef management. The "Coral Reef Ecosystem Study" also created a GIS model that estimates sediment deposition and identifies any problem areas.

2.7 DRNA Coral Reef Monitoring Reports

Since 2004, the DRNA has begun to compile comprehensive coral reef monitoring reports (Garcia-Sais, 2008). These reports are from 2004, 2005, 2006, 2007 and 2008, which allows the DRNA to compare data they collect year by year. The data are collected from 15 reefs sites within seven Puerto Rican Natural Reserves (Isla Desecheo, Isla de Mona, Rincon, Mayaguez, Guanica, Isla Caja de Muertos and Ponce). Information that is included for each year in these reports is percent reef substrate cover, percent cover vs. substrate categories, percent cover for coral species, taxonomic composition and abundance of fish species, species abundance vs. richness, and other fish species counts. Altogether, this data was gathered in order to gain a better understanding of the recent coral reef bleaching and diseases around Puerto Rico. Specific emphasis was placed on the primary reef building coral species known as the Boulder Star Coral (*Monrastrea annularis*).

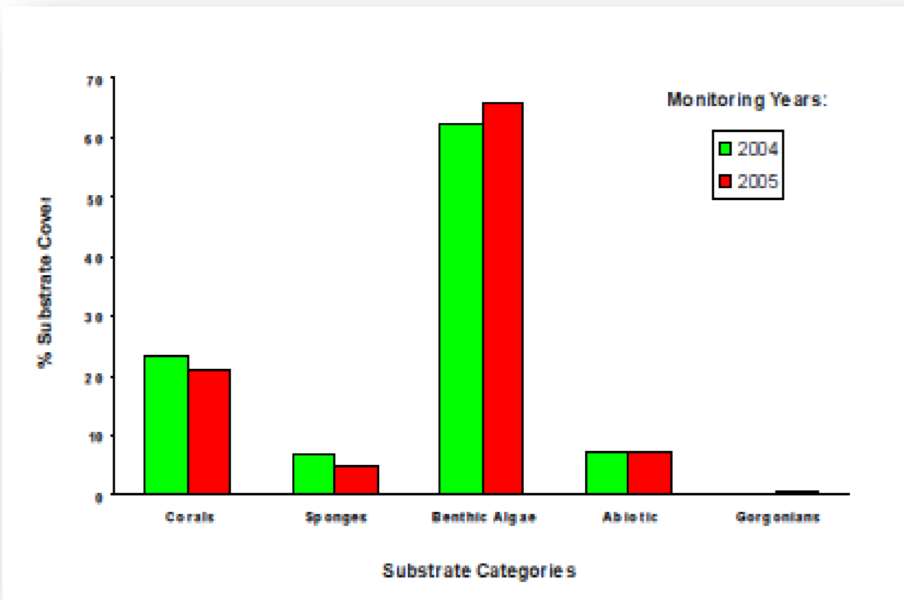
2.7.1 2004 Report

The 2004 Report does not contain many conclusions or concrete results as it is more of a baseline for future results (Garcia-Sais, 2004). The results only show data from Isla Desecheo, Rincon and Mayaguez, which means only 3 of the current 7 monitoring sites, were utilized. The report contains data for various fish and coral species counts including the crucial coral species, the Boulder Star Coral. Also, the report has many pictures to show the physical condition of the reef. Shown below is a picture of a fairly healthy section of the reef:

Tres Palmas Reef (García-Sais, 2004, p. 30)

2.7.2 2005 Report

The 2005 Report increased the studied areas to Isla Desecheo, Rincon, Mayaguez, Guanica, Ponce and Isla Caja de Muertos (Garcia-Sais, 2005). These results were added to the prior baseline knowledge gained by the 2004 Report, and accounted for similar data categories. Comparisons were then made between the 2004 and 2005 Reports using tables and graphs like the one shown below.



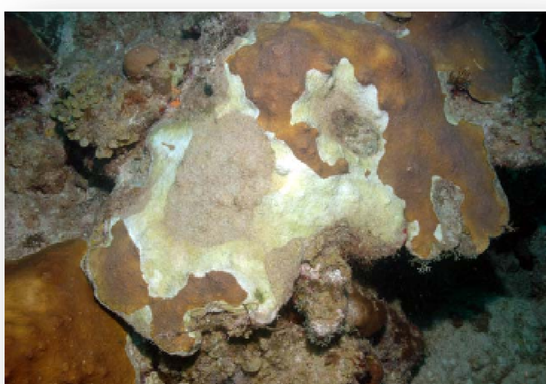
29)

This report was able to offer some conclusions regarding amounts of coral death in 2005. It makes the claim that although the reefs on the west side of Puerto Rico were not structurally damaged nor did they lose any significant percent of substrate cover, the reefs on the southern side of the island did exhibit reductions in live coral cover. In all of the cases of percent substrate reduction, the decline was mostly due to the death of Boulder Star Coral (*M.*

annularis). However, most other species experienced a proportionally similar decline, which suggests that the issue at hand is an ecosystem-wide phenomenon, not just species-specific.

2.7.3 2006 Report

Because of the bleaching event in the winter of 2005, the 2006 Report shows some alarming results (Garcia-Sais, 2006). The report analyzes reefs from the reserves of Isla Desecheo, Rincon, Mayagüez Bay, Guanica, Ponce and Isla Caja de Muerto. Categories of data very similar to the prior reports, such as species counts and percent cover, were collected for this report. These reefs were negatively affected by elevated sea surface temperatures (SST). NOAA has shown that there was a fair amount of thermal stress put on shallow reef communities in Puerto Rico and the US Virgin Islands. Also, the fish population in 7 out of 12 reef stations significantly declined. However, the DRNA is unsure if there is any correlation with the species decline and the bleaching event. The report also shows pictures of many damaged reefs, such as the Tourmaline Reef, which is depicted below.



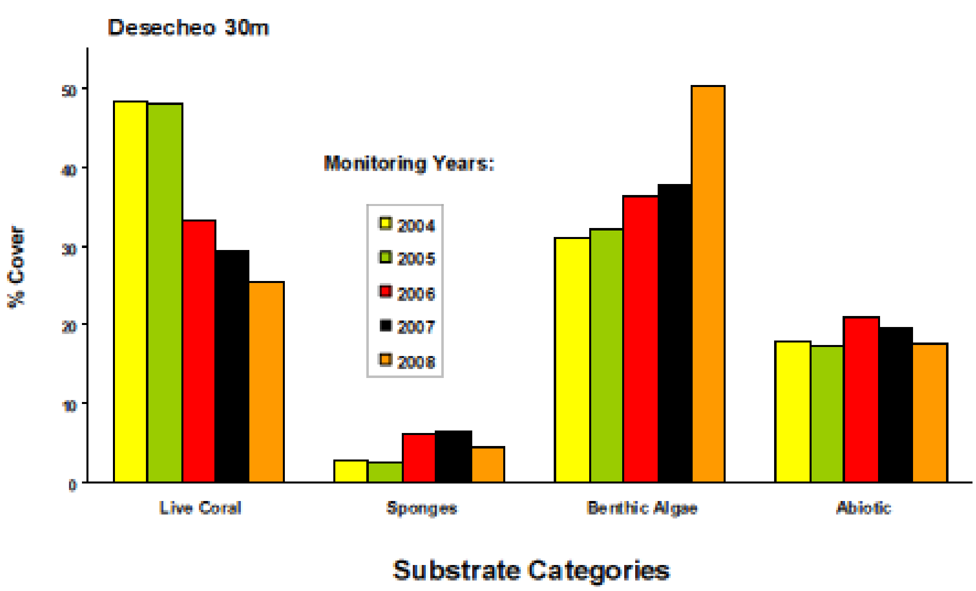
2.7.4 2007 Report

The 2007 report again analyzes coral reef communities from the Natural Reserves of Isla Desecheo, Rincon, Guanica, Ponce, Caja de Muerto and Mayaguez Bay (Garcia-Sais, 2007).

Again, percent coral substrate cover and species counts were collected as data for the report. The data show that although there was a decline in most species counts and coral substrate cover, the change was much less significant than in the prior year. This slight reduction in numbers was considered to be a lingering effect of the 2005 coral bleaching event.

2.7.5 2008 Report

One of the latest reports that the DRNA and Professor Jorge R. Garcia-Sais (2008) compiled was completed in 2008 and documents their research on the coral reefs within Isla Desecheo, Isla de Mona, Rincon, Guanica, Ponce, Caja de Muerto and Mayaguez Bay. This report is able to show a solid time series analysis of the coral reef conditions in Puerto Rico, as the same data were collected that had been compiled in all the previous reports. This resulted in sophisticated analysis tools such as time trend graphs, which can be seen in Figure 4.



This report is very useful, as it has compiled all of the prior research data into one report that makes it easy to observe trends and patterns. The use of visual aids such as shown in Figure

7 is also extremely helpful and such graphs are used to present most of the data collected at each reef.

2.7.6 2011 Report

The most recent report that the DRNA and Professor Jorge R. Garcia-Sais (2011) compiled was completed in 2011 and documents their research on the coral reefs within Isla Desecheo, Rincon, Guanica, Ponce, Caja de Muerto, Vega Baja, Vieques and Mayaguez Bay. This report is able to show a solid time series analysis of the coral reef conditions in Puerto Rico, as the same data was collected that had been compiled in all the previous reports. This report resulted in sophisticated analysis tools such as time trend graphs, which are helpful to observe trends and patterns. Additionally, this data is the utmost valuable because it is the most recent, updated report with data from 2004, 2005, 2006, 2007, 2008, and 2011. The only differences from the prior 2008 report is the start of research on Vega Baja and Vieques, but there was no continuation of research on the Isla de Mona.

2.8 World Wide Conservation

Worldwide, coral reef ecosystems are having similar problems to Puerto Rico. Two of the locations are the Florida Reef Tract found off the coast of Florida, and the Great Barrier Reef in Australia. Florida is looking to increase education and public awareness of the problems occurring in the coral reefs. To do this they are showing up at community events and conducting multimedia public service announcements (Florida LAS report). They also want to reduce the amount of stressors that weaken the reefs; therefore the reefs can be more resilient to climate change. To do this they will strengthen regulations, institute long term water quality monitoring, improve shoreline maintenance and restoration practices, and hold local municipalities to higher environmental standards. Another action they want to take in Florida is to install Marine Protected Areas (MPAs) in order to help fish populations. They are also trying to inform elected officials of the importance of the coral reefs to human welfare in order to receive more funding to carry out their conservation program.

In Australia the World Wildlife Fund (WWF) is also carrying out conservation practices of their own (WWF report). They want to establish effective action to reduce land-based sources such as sediments, nutrients, and pesticides. They also want to end poor fishing practices, such as overfishing, and limit spear fishing. For additional help, they are looking to install Marine Protected Areas. They want to make sure these MPAs are enforced strongly because if not, poachers can destroy them easily. Also in Australia, there is a non-profit volunteer organization called Reef Check which educates boaters, divers, fishermen, and the public about the coral reefs and their problems. This organization also collects data on the Great Barrier Reef to educate people about the reefs, and to possibly help protect them.

2.9 Coral Cultivation

Since 1994, a man named Ken Nedimyer has been running a live aquaculture farm of the coast of the Florida Keys (Nedimyer, 2009). This farm creates the conditions needed for sections of coral to flourish. In 2000, using pieces of coral that grew from his own farm, Nedimyer began finding ways to reattach staghorn coral that had been broken off its main structure. These efforts led to the first official coral nursery and restoration project.

In an effort to create a simple and effective coral nursery and restoration technique that could be used anywhere, Ken created the Coral Restoration Foundation, also known as the CRF (Nedimyer, 2009). The success of this foundation is astonishing. Its first farm started in 1996 with 5 corals, and by March of 2009 it had over 4,000 corals. Many of these sections of coral have already been integrated back into the coral reef ecosystems of the Florida Keys. However, Ken Nedimyer is not the only one attempting this innovative attempt to combat coral degradation. There are agencies such as Applied Marine Technologies (AMT) that are growing coral in the Caribbean (Onion, 2000). There have also been attempts to cultivate coral around the island of Puerto Rico, but never to the degree that the CRF and AMT are undertaking.

2.10 Background Summary

Through our research we have found different natural and human influences on the coral reefs. However, research has not yet identified the full magnitude of these influences. In this project we will use various methods to determine the magnitude of these problems on the coral reef ecosystems in Puerto Rico and also identify possible solutions. The use of prior DRNA Reports and GIS mapping (see Appendices D and E) will also be crucial to a successful project.

3.0 Methodology

The goal of our project was to identify the non-environmental and climate-related stressors on Puerto Rico's coral reefs. In order to achieve this goal we developed a comprehensive set of Geographic Informational System (GIS) maps using existing layers from the DRNA database. We identified trends in coral reef degradation from these GIS maps in order to determine possible solutions to the problems present in damaged reefs. We also accomplished our objectives by means of interviews with experts from University of Puerto Rico and the DRNA staff, as well as from archival research on previous coral reef reports and their stressors.

3.1 Causes of Puerto Rican Coral Reef Degradation

As a key part of our research we used archival research to help identify the locations of coral reef decline in Puerto Rico. Our group conducted archival research to determine what other researchers have found to be the potential causes of Puerto Rico's coral reef degradation. After completing this research, we found relevant GIS layers from the DRNA GIS database such as non-fishing zones and sewage treatment plants and compiled the layers into one interactive GIS map. Each layer was then looked at one by one, reef by reef, to try and identify stressors. In addition to archival research, a significant portion of our information came from interviewing coral reef and marine ecology experts from the University of Puerto Rico and staff at our sponsoring agency, the DRNA. Altogether these methods allowed us to help the DRNA see common patterns in the reefs' ecosystems, potential causal factors for the decline in Puerto Rico's coral reef health and identify possible recommendations to combat the decline.

3.1.1 Interviews with Experts and the DRNA

To gain a better understanding of the issues facing Puerto Rico's reefs, to identify stressors, and to hypothesize possible solutions to the problems of coral reefs in Puerto Rico, we interviewed bio geochemist Jorge Corredor. As a researcher at the University of Puerto Rico, Mayaguez, Mr. Corredor is part of a pool of researchers most knowledgeable on the potential causes of Puerto Rican coral reef degradation. Also, they are thoroughly versed in how Puerto Rico is currently handling these problems. The interview protocol we used for this interview is located in Appendix C. This information provided us with data that was necessary to locate relevant GIS map layers, locate relevant reports, and help make recommendations to the DRNA on how to prevent the coral reef degradation.

Additional interviews were conducted on knowledgeable DRNA staff members. As our sponsoring agency, this government department is fully dedicated to piecing together information about the coral reefs so that they can be maintained in the healthiest condition possible. The interviews with the DRNA staff were informal and were generally used for logistical and technical problems. Damaris Delgado, our project liaison, was interviewed and helped us locate the relevant DRNA reports on their website. Astrid Rodriguez was interviewed to help guide us with the use of GIS software and to gain access to the GIS database. Raimundo Espinoza, a consultant for the DRNA working in the Bureau of Coasts, Reserves, and Refuges office, was also interviewed for his expertise on the relevant laws and regulations of Puerto Rico. Mr. Espinoza gave us a book containing Puerto Rico's relevant laws and regulations, and this information is summarized in section 2.8. We used these laws and regulations to help identify what safeguards are already in place to protect the coral reefs.

3.1.2 Archival Research on Coral Reef Conditions

In order to discover trends in the conditions of the coral reefs, we used DRNA reports found on their website along with reports from the Coral Reef Monitoring Program and the National Oceanic and Atmospheric Administration (NOAA). The data in these reports gave us an accurate picture of the reefs' conditions. Such information provided us with a precise set of indicators for measuring the conditions around each coral reef in Puerto Rico and revealed patterns behind the conditions that are causing reef degradation. These reports included graphs and tables that we have included in Appendix G and allowed us to make comparisons among all the reefs' conditions.

3.1.3 Identifying Land Based Sources of Pollution

In addition to identifying marine causes of coral degradation, we identified land-based sources of pollution that are negatively affecting coral reef ecosystems. After interviewing Ernesto Diaz from the Coastal Zone department at the DRNA, we had a better idea of what GIS map layers regarding coastal zone research to incorporate into our GIS maps to further our understanding of the conditions on coral reefs. This interview also provided insight into other DRNA GIS layers that were helpful in achieving our research goal. This information was coupled with previous research described in sections 3.1.1 and 3.1.2 in order to identify what land-based sources were potentially causing pollution that was harmful to the health of the coral reef ecosystems.

3.2 Identifying Additional Data Needs

The DRNA has nine coral reef monitoring sites where they collect data including Mayagüez Bay, Isla Desecheo, Tres Palmas Reef, La Paraguera, Baha de Jobos, Ponce Bay, Cordillera de Fajardo, Culebra, and Vieques. At these monitoring sites, data had been collected by contractors hired by the DRNA. They collected data and analyzed them to show percent reef substrate cover, percent cover versus substrate categories, coral species versus percent cover, taxonomic composition and abundance of fishes within belt-transects, abundance versus year versus richness, size-frequency distribution of fishes and taxonomic composition and abundance of megabenthic invertebrates. In addition to the DRNA reports, we used reports from the Coral Reef Monitoring Program and NOAA. Once we compiled the existing map layers from the GIS databases as discussed in 3.1, we were able to identify stressor trends and helped us make recommendations about what new data needs to be collected at the coral reef monitoring sites in the future.

3.3 Identifying Existing Puerto Rican Reef Safeguards

This section describes how we determined the existing Puerto Rican safeguards for coral reefs. These safeguards can be defined as ways Puerto Rico protects and preserves its coral reefs. Interviews were conducted with the DRNA staff because they have the most knowledge regarding current Puerto Rican coral reef safeguards. Following the interviews we completed archival research on the laws and regulations the DRNA and the Puerto Rican government has put in place regarding coral reef protection (including Law 147, which protects the coral reefs, and Law 278, Puerto Rico's Fisheries Act). These laws were further explained in the book Guia Practica de Leyes, Reglamentos y Ordenes Administrativas relacionados con los corales y abmientes asociados written by the DRNA (Departamento de Recursos Naturales y Ambientales, 2003).

3.3.1 Determining Effectiveness of Safeguards

Once the Puerto Rican safeguards for coral reefs had been completely identified, we determined whether or not these safeguards were being followed and enforced. Residents and tourists must obey all safeguards to insure coral reef health, so we observed tourist agencies and fishermen in Puerto Rico to see if all rules were being followed. We also talked to another project team from WPI doing research for the Municipio de San Juan on whether or not people observed sewage and pollution control regulations. In order to protect people's identities, we have not mentioned any names of people or companies in our report. All of our observations were used only to help create a general idea of whether safeguards are being followed or not. Since there was not an adequate amount of time to conduct the proper number of observations of this type, we were not able to provide a valid analysis of how well these laws and regulations are being followed and enforced.

3.4 Compiling Resources

Our group compiled a list of resources that we used throughout our research. We created a comprehensive annotated list that details where information can be found and what particular information is available in each bibliographic source. This list was requested by our liaison in order to help people easily access information about the coral reefs seeing as a lot of people contact the DRNA asking for such information. The list includes important experts whom we interviewed or were in contact with and various websites where information on coral reefs is available. We arranged the list into different categories depending on what information the source provides, such as bleaching, disease, solutions, and species counts.

3.5 Conclusion

Identifying the human-induced and climate-related stressors on coral reefs in the area around Puerto Rico has been a long and complex process. We started with general interviews that helped guide us into subjects for our archival research. By observing the reefs first-hand, we gained a general idea of the conditions of the coral reefs in Puerto Rico. Additionally, we used the GIS database to compile existing map layers into more comprehensive GIS maps to enhance our ability to analyze trends in coral health and identify possible sources of stress on the reefs. From the GIS map layers and by analyzing DRNA sponsored reports on coral reefs, we have been able to propose solutions to keep the reefs healthy and suggest what additional data should be collected regularly at monitoring stations by the DRNA contractors.

4.0 Results and Analysis

The goal of our project was to identify the trends caused by human and climate-related stressors on Puerto Rico's coral reefs by developing a comprehensive set of Geographic Informational System (GIS) maps. These compiled GIS map layers, individually created by the DRNA, permitted us to determine possible ways to protect the damaged reefs by identifying patterns of coral degradation. A few layers gathered, for instance, included the locations of DRNA monitored reefs, sewage facilities, fishing areas, industrial buildings, and degree of bleaching and disease at each site. By combining numerous prior GIS maps into one, unified GIS map, trends could be determined in an efficient and organized manner. Furthermore, by comparing graphs on past reports, we noticed a significant correlation between live coral coverage and benthic algae presence. As one of these two factors increased the other decreased in response. Previous graphs from archival research on the DRNA monitoring reports have also indicated a potential relationship between the live coral coverage and fish species and abundance.

4.1 Coral Reef Trends

Although every one of Puerto Rico's coral reefs has seen some form of degradation in the past decade, there have been some reefs that have been specifically more damaged. The DRNA's 2008 Coral Reef Monitoring Report and the Caribbean Coral Reef Institutes 2010 Report provided the data we were able to analyze (see Appendix G for a more complete data set). The Marine Reserves that were analyzed in the 2008 report were Isla Desecheo, Isla de Mona, Rincon, Guanica, Ponce, Caja de Muerto and Mayaguez Bay. For this section we discussed the trends found in the coral reefs that lead to recommendations found in section 5.1.

4.1.1 Pollution

A problem at some of the reefs in Puerto Rico is pollution, especially in the waters off the coast of Culebra. Non-point source pollution from the island is a major problem. The island does not have enough sewage treatment plants, which has resulted in most of the island utilizing septic tanks. However, many of the septic tanks are poorly constructed and leak. Several of the tanks are also constructed below the coastal water table, which means any leak will eventually lead to the ocean. In addition to the septic tank problem, Culebra has numerous illegal discharges from raw sewage into the storm drains that dump into the ocean. Due to the septic tank problems and illegal discharges, there are several fecal coliform violations and enterococci violations surrounding the Island. Figure 9 shows May to November of 2008 levels of enterococci. Figure 8 shows the locations of each site (Ensenada Honda at Barriada Clark (CLA), Ensenada Honda at Municipal Pier (MPI), Lobina Channel (LOB), Bahía Sardinas (BSA), Punta Melones (PME), Punta Tamarindo Chico (PTC), Arrecife El Banderote (AEB), Punta Rompe Anzuelo (PRA), Cayo Luiz Peña-north (CLP), and Playa Carlos Rosario-south (PCR)). During the outgoing tide, the runoff and pollution from Ensenada Honda (CLA and MPI) flows through Lobina Channel (LOB) and eventually goes northwest through the other monitoring sites in figure 8 and also into CLPNR.

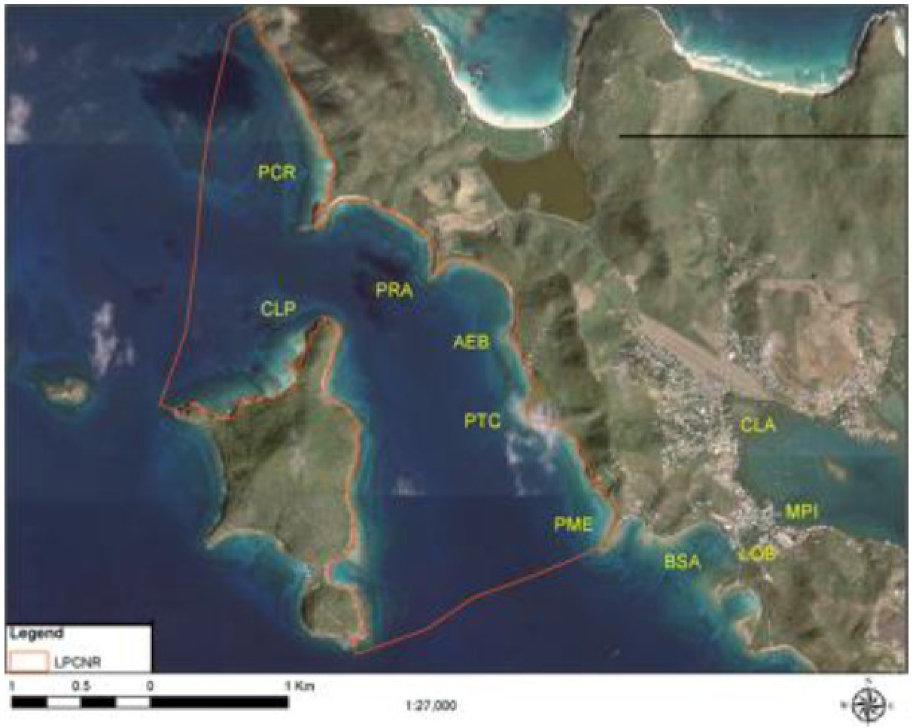


Figure 8: Map of Culebra Water Quality Monitoring Sites (Hernández-Delgado, 2010, p. 255)

Sample	May	Jun	Jun	Jun	Jul	Aug	Sep	Oct	Nov	Mean	Frq
CLA	15	119.5	190	19	1123	76	133	300	10	221	67%
MPI	NS	NS	25	134	125	5	157	100	20	80	57%
LOB	80	65	240	245	2095	1570	70	1150	45	590	100%
BSA	84	77	10	1	57	76	8126	30	0	948	56%
PME	0	0.5	10	1	2	3	239	0	0	26	11%
PTC	NS	NS	NS	NS	2	9	20	0	0	6	0%
AEB	NS	NS	NS	NS	0	6	833	10	0	88	20%
PRA	130	10	28	5	6	13	290	60	1	61	33%
CLP	NS	NS	54	0	0	3	77	0	2	19	29%
PCR	0	0.5	47	0.5	0.5	6	607	0	0	66	22%

NS= Site not sampled for that time period. Red color= violation to EQB class SB water quality classification enterococci standard (35 cfu/100 mL).

Figure 9: Microbiological water quality violations for enterococci across sites in 2008 (Hernández-Delgado, 2010, p. 280)

As shown in figure 9, Culebra has problems with enterococci, which is an indicator of sewage waste in the water. There seems to be a particular trend that areas closest to the main population of Culebra have more enterococci in the water than the others. Even though there are no reefs there, the tides carry these bacteria over to the reefs and the MPAs discussed earlier. We also observed that the enterococci levels are much higher during the summer. In some cases, the levels are not relatively close to the Environmental Quality Board's water quality standard of 35 cfu/100 ml. In July 2008, Lobina Channel (LOB) was 60 times above the acceptable level and in September, Bahía Sardinas (BSA) was 230 times over the limit. This September data may be skewed because of Hurricane Kyle in September 2008, causing more runoff and more bacteria to enter the ocean. This should still be a concern because regardless of Hurricane Kyle, such a large amount of bacteria should not runoff into the ocean. These bacteria are not healthy for the reefs and when there are mass quantities of the bacteria, they can cause coral mortality.

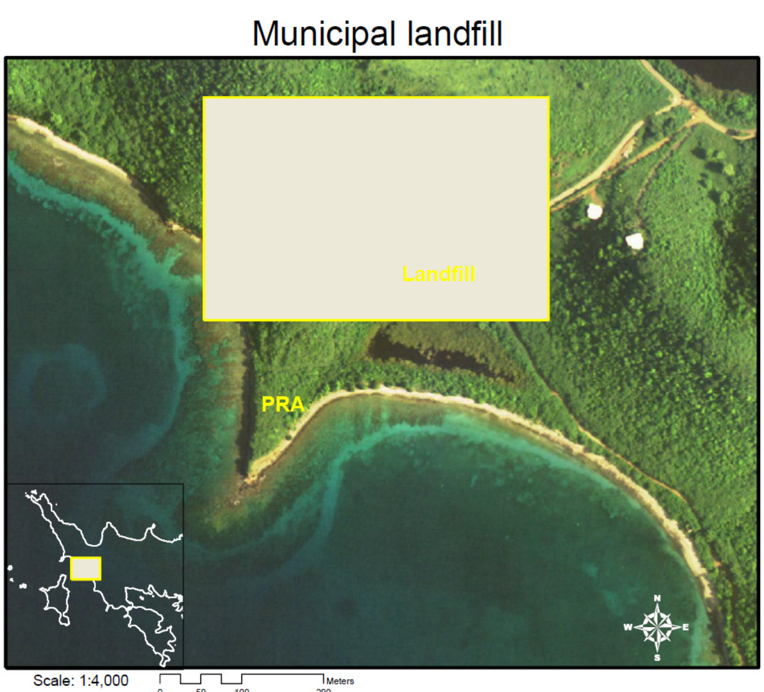


Figure 10: Culebra Island Municipal Landfill (Hernández-Delgado, 2010, 262)

Another problem Culebra is dealing with is the municipal landfill right in the middle of the MPA (Figure 10). During rain storms, sediment-laden runoff caused by the rainstorm may be pouring into the water and onto the reefs. There have yet to be tests to determine whether or not this is happening, but there is generally severe runoff on the island. This problem should definitely be looked into by the DRNA. Also, when there are strong easterly winds, garbage such as plastic bags from the landfill is blowing into the water and getting stuck on the reefs and suffocatingthem. This can be seen below in figure 11.

Figure 11: Trash Bag Stuck On Elkhorn Coral (Hernández-Delgado, 2010, p. 211)

These pollution concerns in Culebra are further shown through the GIS analysis. Virtually every major pollution risk analyzed is located within 6 km of the monitoring sites. Being such a small island leads to this occurrence; however, it also means the infrastructure is not there to decrease the potential for pollution leakages and problems to occur. This includes the landfill and treatment plants mentioned along with gas stations, hotels, marinas, airports, and high boat traffic. From visiting Culebra, we saw first-hand how many tours go to the area. This problem may also be prevalent in other areas as well.

The monitoring site at Guanica sits at the mouth of a bay. There is a river present (Loco River) that dumps into the bay which runs through an agricultural valley for most of its length as can be seen in figure 12.

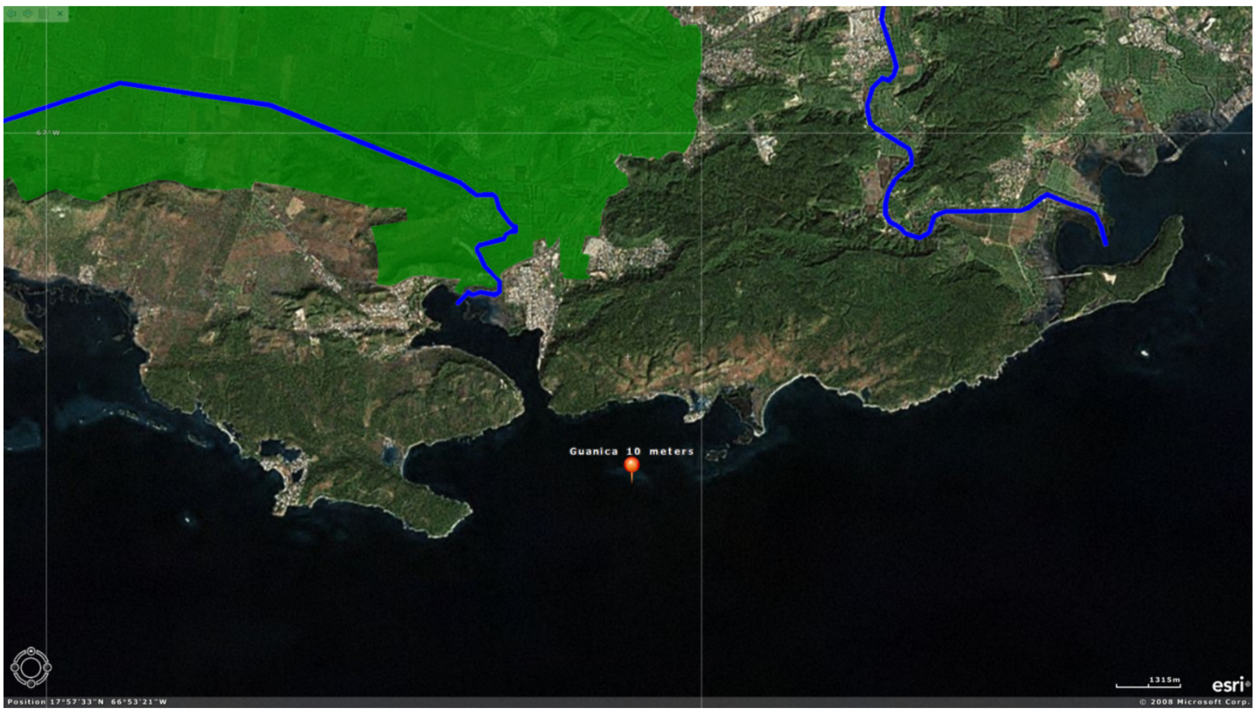


Figure 12: Loco River in Guanica Running Through an Agricultural Valley

This situation increases the likelihood harmful chemicals could be present in the water leading to increases in algae or disease. Besides that, Guanica exhibits the same general pollution markers as the other reefs including beaches, gas stations, hotels, landfills, treatment plants, and superfund sites. This monitoring site is very close to the coast, however, which would increase the pollutions ability to have an impact before dilution. As seen in appendix D and F, other monitoring sites have general pollution markers as well. Appendix D is an excel sheet created from studying the GIS layers, which identifies how close these general pollution markers are to the monitoring sites. Appendix G is a further in depth examination of each monitoring site. From these appendices it is recommended increased monitoring be done to incorporate water quality testing. Once this water testing is done, it can be determined if these pollution markers are in the water, and potentially polluting the reefs.

4.1.2 Benthic Algae Growth vs. Coral Death

As seen in the numerous graphs in Appendix F, this is a pattern that shows how the amount of coral coverage goes down the percent benthic algae coverage rises. This trend became extremely apparent due to the 2005 bleaching event that devastated most of Puerto Rico's reefs. The 2011-2012 Coral Reef Monitoring Report shows that this trend occurred at Tourmaline Reef, Puerto Botes and Canoas, Cayo Coral, West Reef, Derrumbadero and Isla de Mona. The levels of algae and coral cover have stayed constant since 2008, which gives the impression that the condition of these reefs has remained stable for now. This can clearly be seen in Derrumbadero's graph from the 2011-2012 Report, shown in Figure 13.

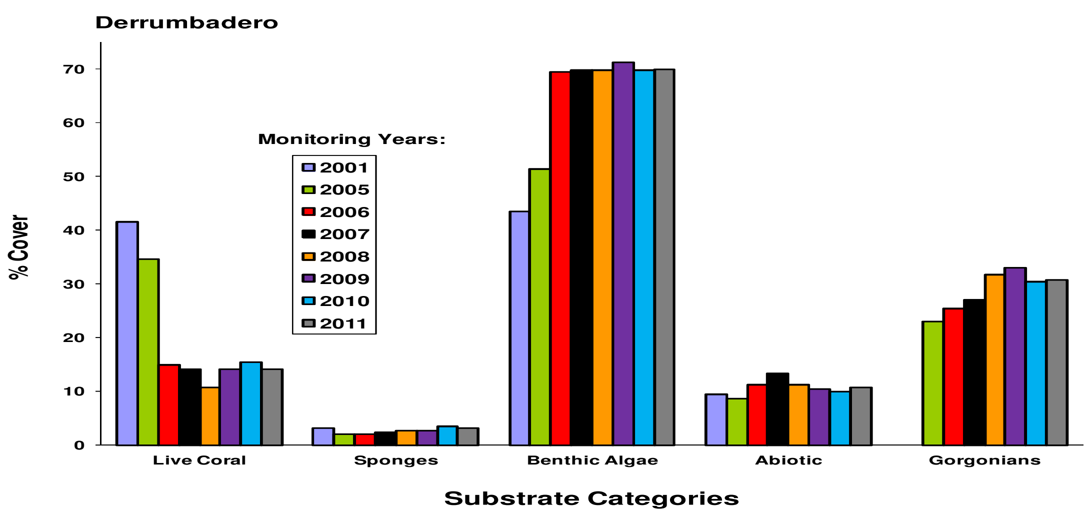


Figure 13: % Cover vs. Substrate Categories Derrumbadero (García-Sais, 2011, p. 151)

The most affected species of coral was the Boulder Star Coral (*M. annularis*), which is the primary reef building species for many of the Puerto Rican reefs. The primary species of benthic algae that has been growing on the reefs is *Lobophora variegata*. The levels of both of these species should be closely monitored, as they account for a large percentage of the ecosystem. It is also extremely important that more data is collected around the reefs to find any causes for this algae bloom. Levels of chemicals that would spark algae growth, such as nitrates and phosphates should be closely monitored. It would also be effective to look into the affect benthic algae has on the coral organism. This would confirm that the algae growth in directly influencing the coral degradation.

4.1.3 Monitoring Depths vs. Coral Cover

Another pattern that we came across in our research was the effect the depth of the reef had on the amount of coral coverage that was lost. In most cases if the reef was in shallower water it suffered far worse coral degradation. On the contrary, reefs in deeper waters appeared to be healthier and less affected by coral degradation. This can clearly be seen by the three different monitoring depths at the Tourmaline Reef. There were drastic changes in the percent coral coverage at the 10m depth (left), slight changes happened at the 20m depth (middle) and finally at the 30m depth (right) there were actually improvements to the live coral coverage.

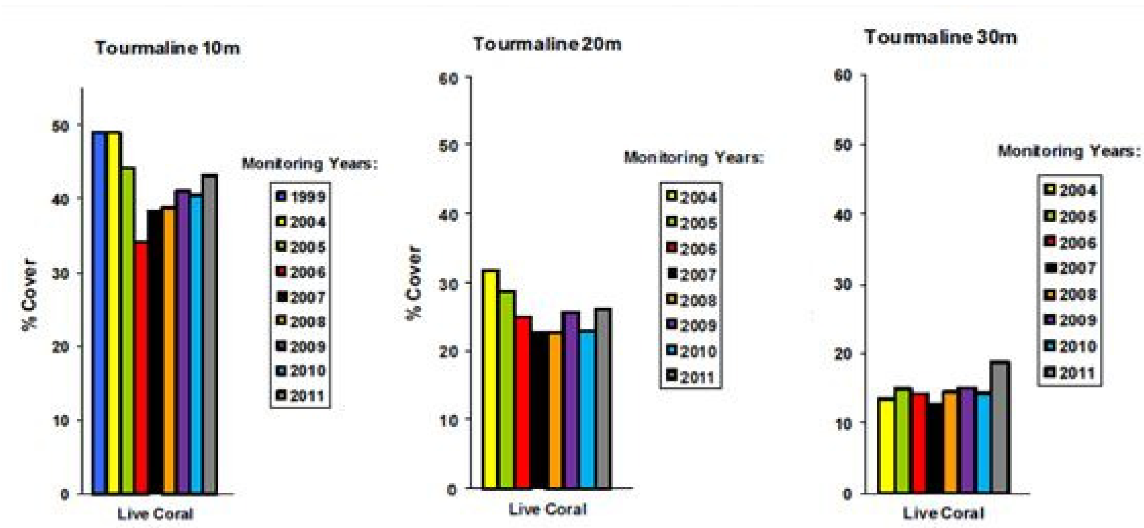


Figure 14: % Cover vs. Live Coral Tourmaline (García-Sais, 2011, p. 93, p. 105, p. 82)

It appears that the deeper waters have served as a buffer for many of the potential hazards to the reefs. These hazards include temperature change, sediment

4.1.4 Fish Species Decline

Leading up to 2008 there was a steady decline in the species richness and abundance at most monitoring sites around Puerto Rico. This is evidence to the delicate ecosystem that was drastically affected by the 2005 bleaching event. However, after a decade of data collection there has been a deeper trend forming at some reefs between these two data sets.

Overall the species richness has been in a slight decline, which indicates there is a drop in the species diversity at most reefs. This drop in the number of species present at each reef has led to a decrease in competition for available resources at each coral reef. Therefore, accompanying this drop in species richness is an increase in the species abundance. This means that there is a higher concentration of individual fish present within the reefs. Our analysis suggests that this drop in competition has led to an increase in the species abundance. This trend can be seen in the following graphs from the Puerto Botes Reef at 15m.

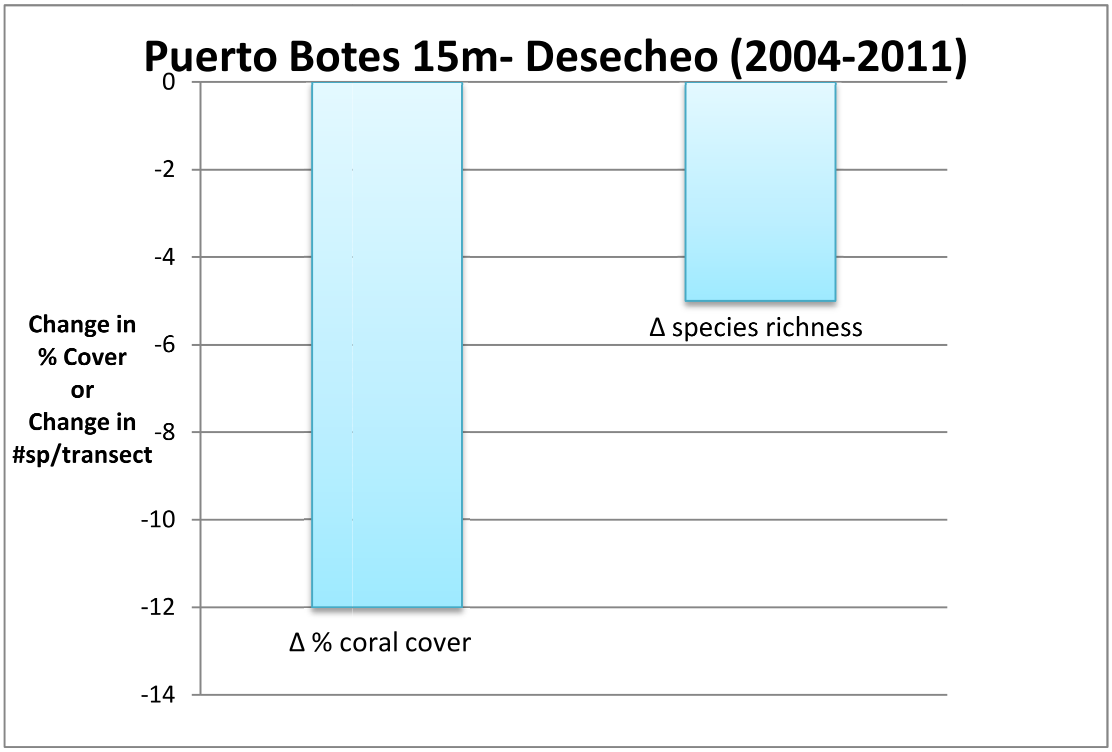


Figure 15: Change in Species Richness, Puerto Botes 15m

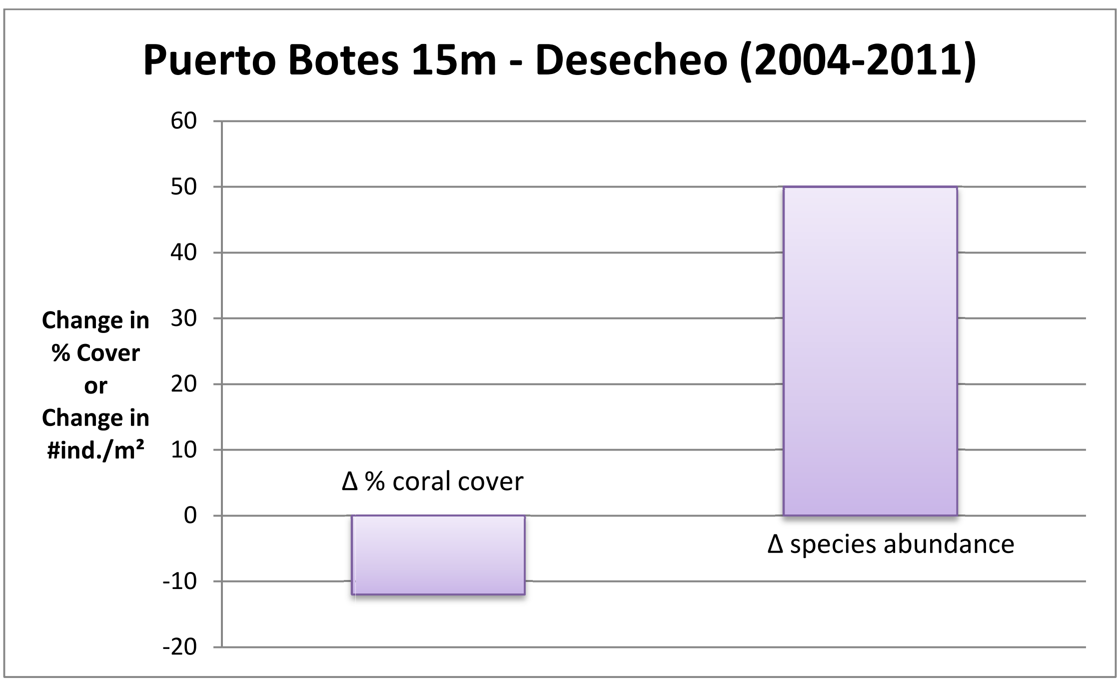


Figure 16: Change in species abundance, Puerto Botes 15m

4.2 Safeguards

In order to determine how to better protect the coral reefs, we looked at how Puerto Rico is regulating the coral reefs and what their future strategy is. Our sponsoring agency, the DRNA, has a Local Action Strategy in place for the years 2010 to 2015. This document contains the Puerto Rican government's plan for managing the reefs for this five year period. The DRNA also provided a document containing the laws, rules, and regulations of the island. This included Law 147 and Regulation 260, which were relevant to protecting and conserving the coral reefs. These are the only regulations that protect the reefs. For Puerto Rico's extensive coral reef ecosystems there should additional legislation to protect the reefs. Perhaps a specific set of rules and regulations for each reef would be a better way to regulate what happens around each reef.

4.2.1 Local Action Strategy

The Local Access Strategy (LAS) creates goals and objectives for Culebra, the Northeast Reserves, Cabo Rohao, and Guanica. The four general areas the LAS looks to address are sediment cover from the coast, impacts to water quality, outreach in education, and maintaining the coral reef ecosystem. For the time being we are only going to focus on Culebra, the Northeast Reserves and Guanica. On the positive side, the Local Access Strategy addresses some major threats to these three reef areas.

Specific to Culebra, there are five areas of concern for coral reef conservation. The LAS recognizes that erosion and sediment transport, poor water quality, lack of enforcement on land use regulations, negative impacts of tourism and recreation, and absence of enforcement are the main threats to Culebra's coral reef ecosystems. Our research has supported these claims. The LAS has taken these issues into account and created five separate goals to alleviate these problems. If these goals are successfully carried out then all potential hazards will be addressed and hopefully, as a result, the reef will rebound.

For the Northeast Reserves (Fajardo area) there were nine areas of concern which are impacts of recreational activities, impacts of tourism, need of community participation, extension of priority area, need for outreach and education, need for train of recreational service providers, water quality control, erosion and sediment transport, and absence of management and enforcement. Once again, the LAS set up goals to alleviate these issues and if they are carried out the coral reefs will be affected in a positive manner.

In regards to Guanica, there are six areas of concern which include exceeding carrying capacity in the area, need of Best Management Practices (BMPs) in agricultural activities to prevent runoff, inefficient use of the water treatment systems, training of enforcement personnel, absence of management enforcement, and extension of the priority area to the East. According to the LAS as well as our own research, the coral reef ecosystems will hopefully rebound if these issues are faced.

These Local Action Strategies are well thought out and thorough for Culebra, Fajardo, and Guanica. However, it fails to create a comprehensive strategy for several other reefs around Puerto Rico. Our research shows that many other reefs are at a fragile state and are in need of intervention.

4.2.2 Laws, Rules & Regulations

For the protection of their coral reefs, Puerto Rico has two main laws. The first is Law 147, which is meant to protect, conserve and manage the coral reefs. Another law relevant to the condition of the reefs is Regulation 260, which controls the extraction, possession, transport and sale of coral specimens in Puerto Rico.

There are also two other laws that deal with fishing restrictions and regulations around the island of Puerto Rico. Law 278 states that any aquatic or semi-aquatic organism found in a non-private area is considered to be open to be captured by the public. This unfortunately does not do too much to prevent overfishing in areas with coral unless they are deemed private by the government, such as in areas like Natural Reserves. Tightening regulations on fishing in order to prevent damage from lines, anchors, and reduction in species populations would most likely positively affect the fish populations around Puerto Rico's coral reefs. The fish populations are important for keeping the reef ecosystem in proper balance. Another regulation is Law 210, which regulates what can be deposited in the water around coral reefs in order to prevent pollution from reaching the corals. It specifically prohibits the deposit of any oil, acids or anything else that will contaminate the marine life. However, from our observation at San Jose Bay it does not appear that anybody follows these regulations. In fact, the people of Puerto Rico may not even know about these rules and regulations, making them impossible to follow.

4.3 Effectiveness of Laws and Regulations

To further understand the status of protection of the reefs in Puerto Rico, we decided to do some firsthand observations to see if laws and regulations on the Island were being followed and enforced. As a group we went on a snorkeling trip on a catamaran in the Fajardo area. We also went on a trip to the bioluminescent bay in Fajardo as well. Additionally, one group member went on a fishing trip in Laguna San José.

4.3.1 Snorkeling

On March 17, we went to Fajardo to go on a Catamaran snorkeling trip. Prior to snorkeling on the reefs, the captain briefly warned us not to touch the reefs. We were informed not to touch the reef to protect us from getting hurt, but did nothing to suggest it might be harmful to the reef. Also, the captain did not mention why the reefs were in such poor shape nor did he try to educate us about the reef in any manner. After his quick speech, we entered the water and people immediately disobeyed the tour guide's orders by touching and standing on the reefs. It was even more evident that people were touching the reef when we went back onto the boat and noticed that people had cuts on their backs. From this experience, we concluded that despite the brief warnings, people did not hesitate to break the rules and touch the reefs. This may be because the captain did not warn them that this kills the reef, therefore, should have been previously stated by the tour guide. All reef tour guides should properly address the current condition of the reefs to snorkelers, as well as stress the negative effects touching the reefs has on its health.

4.3.2 Laguna San José.

On April 16, one group member went on a fishing trip in Laguna San José. The captain did not mention any laws or regulations that he should have been aware of. The captain did, however, say that the DRNA had done a study of the water and found high levels of heavy metals. Therefore, he said he tells all his customers not to take the fish home to eat. When the group member asked him about the coral reefs, the captain seemed unaware that the reefs in Puerto Rico were in such a decline. He said public knowledge is very low on the status of the environment. On the way back to the marina, the group member witnessed someone trying to spear fish, which is illegal in that area. Also on the trip, the group member observed a large amount of debris in the water, such as plastic cups and aluminum cans, which the captain mentioned is a regular occurrence. It was clear from this trip that people have not been following regulations nor are they even aware of them, and there is a large pollution problem. It is important to address that there is limitation in this data since these were only two specific instances and may or may not represent a wider pattern. Although this is small and limited observed data, it still proves that there is a definite problem that needs to be addressed through better education and enforcement. Also, stricter regulations may need to be added in the tourist sector, for example.

5.0 Conclusions and Recommendations

After analyzing the GIS maps and reading data reports written by the DRNA, we identified non-environmental related stressors and their impacts for each monitoring report. We have developed many conclusions and recommendations for the DRNA to help protect, preserve, and improve the health of the coral reefs.

Lack of public awareness is one of the major problems regarding the degradation of the coral reefs. Without the public knowing specific reef regulations, many of the rules are being ignored and broken. This leads to people anchoring boats on the reefs, standing on the reefs, removing pieces of coral as souvenirs, and other such events without even realizing the harm caused. We recommend that public awareness is increased drastically by means such as posters, fliers, informational pamphlets, and coral reef regulation programs.

After observing graphs and results from the 2011-2012 Coral Reef Monitoring Reports and GIS maps, there is an obvious pattern on how depths of the reefs are affected differently. Deep reefs are surviving more successfully than reefs at shallower depths. Top reefs are more susceptible to damage from temperature changes and pollution, hence why the live coral percent for shallow reefs have been decreasing more drastically than deeper reefs.

The runoff/pollution that is dramatically affecting reefs, especially at shallow depths, is an impending issue in itself. Pollution from buildings, garbage, and sewage plants are being dumped into the ocean at an alarming rate. In order for reefs to rebound, pollution levels need to be lowered significantly and monitored constantly. Runoff from storm drains and erosion are also causing the same problem. The best way to help the reefs is to control this runoff by any means possible and conducting more research to determine a successful solution in preventing this runoff. Culebra has seen the most negative impacts from pollution and runoff, which is shown previously in Figure 9. If the levels of pollution and runoff are not reduced immensely in the near future, it is very likely that all of the coral off of this island will die completely with no chance of rebounding.

At the 5m portion of the Tres Palmas Reef system there is a case of White Pox disease, also called patchy necrosis. The white patchy spots from coral death suggest that there is a presence of the coliform bacteria, *Serratia marcenscens,* in the water. These bacteria are commonly found in the intestines of humans and other animals, suggesting a correlation to human sewage pollution. This disease has harshly affected the fringing Elkhorn Coral Reef (Acropora palmata). Despite this infection reaching almost every colony of coral, the reef system appears to be resisting the infection. The resistance is due to new growth within the reef, indicating the conditions besides the White Pox disease are favorable for coral growth.

While some coral reefs are, in fact, beginning to rebound, some have shown no such progress. West Reef, Puerto Canoas, and Puerto Botas Isla Desecho have not displayed any signs of rebounding. Furthermore, it is unknown if Mona is rebounding because the DRNA stopped monitoring this site completely and was not mentioned in the 2011 Coral Reef Monitoring Report. It is vital to continue monitoring Mona in order to insure the health of the reef in the future as well as to collect data consistently for precise results.

In addition to the data currently taken from each monitoring site, it is necessary to expand upon that data. Testing of pH, heavy metals, salinity, and temperature are vital components for the health of coral reefs and are not monitored at the current coral reef monitoring sites. Likewise, specific species of algae and bacteria, as well as levels of nitrates and phosphates need to be collected to determine the growth of algae blooms. This additional data will help the DRNA to understand trends and patterns of the declining and thriving coral reefs.

5.1 Recommendations

Based on these conclusions we formulated a set of recommendations in order to help further protect Puerto Rico's coral reef ecosystems from continued degradation. These recommendations should be helpful for the DRNA to keep the reefs from further decline and improve their health for the future.

We recommend that the DRNA collect water samples at monitoring sites in order to complete chemical analyses. Specifically, levels of chemicals, bacteria and specific species of algae need to be collected at their monitoring sites. These chemicals include nitrates and phosphorus coming from agricultural and industrial waste that can increase algae blooms, which are associated with coral population decline. The DRNA needs to research the interaction between algae and coral reefs to determine the severity of the algae growth at the reefs in order to determine acceptable levels of chemical runoff that can be monitored and regulated from land based sources. To be included in testing should also be pH, heavy metals, salinity, and temperature.

We recommend that Marine Protected Area's be created or expanded around the island of Puerto Rico. This recommendation will help stifle overfishing. When the large apex predators or other fish species are removed from the ecosystem the balance can be disturbed, which negatively affects coral reef health.

We recommend that the DRNA work to increase regulations and regulation enforcement. This includes, specifically, regulation enforcement on pollutant runoff that is negatively affecting coral reef ecosystem health. There will be no end to the pollution problems around the island if regulations are not expanded or if regulation enforcement does not increase.

We recommend that the DRNA install more buoys at the reefs around Puerto Rico whether it is a monitored reef or not. This recommendation is in place to decrease the amount of mechanical damage to corals by reducing anchors being dropped on top of the coral and propellers impacting the coral in shallow areas. Specifically, marina areas are in great need of these buoys, like in Fajardo and Rincon, which is where they tends to be heavy boating traffic.

We recommend that an effective public awareness program be put in place to facilitate knowledge of coral degradation and preventative measures within the public. This recommendation is in place because in Puerto Rico there is either a lack of knowledge or a lack of interest in stopping the degradation of coral reefs. This includes being aware of MPA's and other regulations put in place to protect the marine ecosystems around the island. With an educational campaign, land-based sources such as pollution and ocean-based sources such as overfishing can be reduced to help reverse the current negative trends. This could include mandatory training programs and tests attached to receiving permits or boating licenses and for renewals so that new regulations or conditions can be taught.

We recommend that the DRNA use coral cultivation in a greater capacity. This recommendation is to combat the negative effects from Puerto Rico's coral degradation by facilitating their regeneration with new healthy coral. This cultivation will center on reef building species such as the boulder star coral, which allow the reefs to increase in size and remain healthy.

As a group we believe that these recommendations will further the DRNA's goal of preventing environmental and non-environmental coral reef degradation by promoting an increase in overall reef ecosystem health.

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Appendix A: Sponsor Description

The Departamento de Recursos Naturales y Ambientales (DRNA), or in English, the Department of Natural and Environmental Resources (DNER), is a publicly run government agency in Puerto Rico that is managed financially by the Commonwealth and through licensing and permits. The mission of the DRNA is "Protect, conserve and manage natural resources and environmental development in a balanced way to ensure future generations [sic] enjoyment and stimulate a better quality of life" (DRNA, 2012). The DRNA was created on June 20, 1972 under the name of the Department of Natural Resources (DNR) by Law 23 of the Commonwealth of Puerto Rico. This department contains various subdivisions including Mineral Resources, Forestry, Environmental Planning and Management, Scientific Research and Natural Resources.

The DRNA(2012) is internally organized into various branches (see Figure A1). Within the organization there is one central DRNA Office. Underneath this one central office there are 68 working units throughout the island. These offices seek to integrate components of management, education, and research in order to achieve the mission of the organization as a whole. Each branch of the DRNA is responsible for implementing its own policy in order to protect and conserve Puerto Rico's natural resources. The specific branch that we worked with is the Bureau of Coasts, Reserves, and Refuges**.** This Bureau is split into the Division of Coastal Zones, Division of Marine and Estuarine Sanctuaries, and Division of Nature Reserves and Wildlife Refuges. For example, the Division of Coastal Zones strives to lead public and private development of the coastal zone, promote active management of the coast, and promote environmental education, scientific research and citizen participation in management of coastal resources. This division receives funding through the DRNA and federal grants from the NOAA. One of the bureau's major projects is the Coral Reef Conservation and Management Program. This program is split into Conservation and Management and Monitoring of Coral Reefs. This program is part of the larger Coral Reef Initiative, which was enacted by President Clinton under Executive Order 13809 (DRNA, 2012).

There are no organizations that compete directly with the Bureau of Coasts, Reserves and Refuges; however, there are several non-profit organizations that supplement the work of the Bureau. These non-profit organizations share the same goals as the Bureau of Coasts, Reserves, and Refuges and aim to protect the coral reefs. Two examples are CORALations and The Conservation Trust of Puerto Rico (Coral Reef Alliance, 2012). Often times, these organizations complete the research and monitoring on coral reefs so they are really an ally of the DRNA.

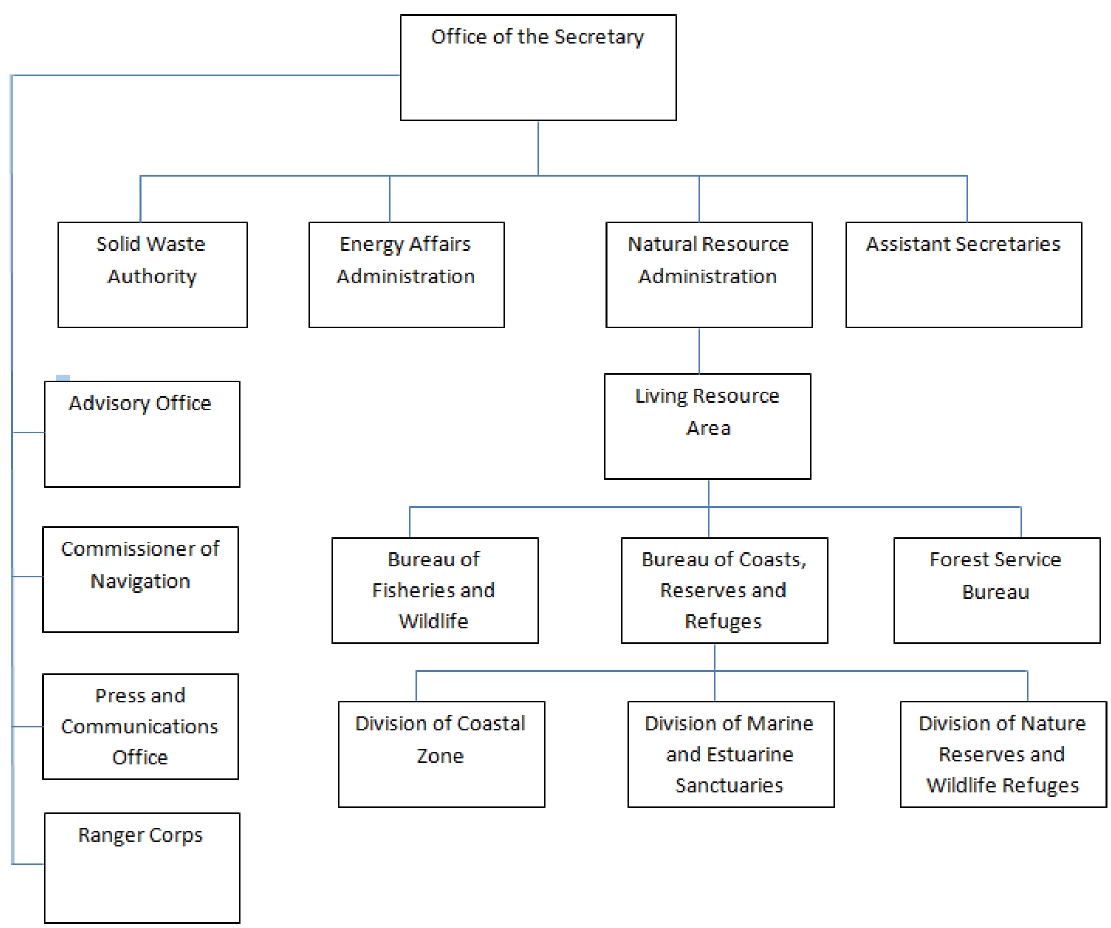

Figure A-17: Departamento de Recursos Naturales y Ambientales Organizational Chart (Departamento de Recursos Naturales y Ambientales, 2012)

Appendix B: GIS

The Geographic Information System (GIS) software incorporates data, hardware and software for displaying all geographically referenced information in an organized manner (Esri, 2011). GIS allows for the viewing and interpretation of data visually to help reveal relationships, patterns and trends. GIS data are typically portrayed in the form of maps, globes, charts, and reports. Data displayed this way help answer questions and solve problems making the data easy to observe. GIS technology can be integrated into any enterprise information system framework and benefits organizations of all sizes and in almost every industry.

Better decision making, improved communication, better record keeping, managing geographical information, cost savings and increased efficiency are many of the benefits a GIS provides (Esri, 2011). Making correct decisions about locations is critical to the success of an organization, and GIS is the preferred technology when these types of decisions need to be made. A few examples include real estate site selection, route/corridor selection, evacuation planning, conservation, and natural resource extraction. GIS-based maps and visualizations are a type of language that improves communication between different teams, disciplines, professions, organizations, and the public. Maintaining authoritative records about the status and change of geography is a responsibility of many organizations. GIS provides a strong structure for handling these types of records with full transaction support and reporting tools. Operational expenses are decreased from 10 to 30 percent through reduced fuel use and staff time, enhanced customer service, and more efficient scheduling. Additionally, GIS is becoming essential to understanding what is happening, and will happen futuristically, in geographic space. Managing data geographically is a new approach to management by transforming the way organizations operate.

GIS is used for mapping in a way that enables people to identify places that are in question and to see any patterns that may exist in those areas (Esri, 2011). Quantities, densities, and change can all be mapped using GIS. For example, change may be mapped in an area to anticipate future conditions, decide on a course of action, or to evaluate the results of an action. By mapping where and how things move over a period of time, it is possible to gain insight into how they behave. With relevance to this project, GIS layers displayed coral reef monitoring sites with migrated data and stressors associated with the monitoring sites. Some of these stressors and data may include location of reefs, dates monitored, depth, temperature, water quality, fish species, coral condition, and so on.

GIS, like most computer programs, is not without its own faults. While using the ArcGIS Explorer software we experienced many setbacks and delays. With the addition of more layers to the base map, the program became bogged down and slow while closing randomly. This issue was compounded by the fact that the individual layers would become unresponsive slowing down analysis and compilation. While in full function ArcGIS is a great tool for data analysis; however, you must be aware of the programs faults and have patience while manipulating various layers.

Appendix C: Interview Summaries and Transcripts

Interview Summary- Kristina Dewitt

Attending: Sean Galligan, Lindsey Grasis, Jason Hopkins, Thomas Svirksy
Location: Weymouth High School
Time: 2:30 PM
Date: Wednesday February 8, 2012

Q1: Where did you study Coral Reefs?

Kristina initially studied SCUBA diving and data collection on Lady Elliot Island which is at the heart of the Great Barrier Reef. Then after diving for a few weeks off of Whitsundays she began studying coral reef ecosystems at the University of Cairns Australia

Q2: What exactly did you study about the coral reefs?

Kristina specifically did courses related to the discovery of the marine environment located around the Great Barrier Reef. Also a lot of her research and discovery was based on the mutualistic relationships associated with the coral reefs' zooxanthellae.

Q3: What research methods did you use when studying the reefs?

Kristina used various research methods in her time in Australia. The most common research method was case studies of different aspects of the coral reefs. The majority of Kristina's case studies were on the species analysis and relationships of sea cucumbers.

Q4: How have you seen bleaching and disease affect coral reefs in Australia and worldwide?

The first real influx of bleaching in Australia was in 1998, which was 2 years after Kristina's time at the Great Barrier Reefs. Kristina also went diving in the Bahamas and Bermuda where she said bleaching hadn't quite harmed the reefs yet. However, she said at all dive locations they were concerned with human impact. For example, they limited the number of dives within a day to control presence in the ecosystem. Another example for how careful they were about diving in these reefs is how Kristin said they were more careful about how you interacted with the coral reef marine environment than when she took a tour of the African safari.

Q5: In Australia, did you come across any solutions to bleaching and disease that were trying to be used?

Run-off was really their only concern regarding damaging the reefs at this point for Australia. They had already seen it affect the box jellyfish and were worried it could continue to harm the rest of the marine environment.

Q6: Are there any reliable sources of information or colleagues you found to be helpful in your research? If so, could you please list them?

Kristina gave us the contact information of relevant professionals from the University of New South Wales.

Interview Transcript-Lauren Mathews

Location: Gateway Floor 4 Common Area
Time: 2:30
Attendance: Lindsey Grasis, Sean Galligan, Jason Hopkins, Lauren Mathews, Tom Svirsky

Sean: Good afternoon, I'm Sean this is Lindsey, Jason and Tom. Our project is based around the coral reefs around Puerto Rico and the bleaching and disease happening down there. So we are conducting this interview to gain a little more understanding and see what you know about it. Just for starters what projects or research have you participated in Puerto Rico. I know you went down as an advisor,
Lauren: Right, so in a minute I'm going to ask you for a little more background on your project. So I went down, it must be 7 or 8 years ago now with a group of students and we had 1 project that was sort of in the area of marine ecology that was interested in coral reef ecology, and the focus that you have probably read that as part of the many projects you need to read for background. That project was focused primarily on impacts on local fishing, the local fishing industry of regulating how people can use coral reefs. So it sounds like your project is a little bit different then that which is great. That project was I think the students found it very rewarding and very challenging, so I don't know if you will face the same affects. Who is your sponsor down there?
Sean: The DRNA totally is our sponsor but it's Damaris Dominguez I believe.
Tom: We had one and then like two weeks ago she switched and we still haven't heard back from our new one yet.
Lauren: It's ok that happens.
Jason: It was Aileen Velazco.
Tom: Aileen Valezco was the original one.
Lauren: I don't know, so you have totally different sponsor then the last coral reef project, which I think is a good thing.
Sean: That's kind of encouraging, so you said like you did kind of participate in a project that had coral reefs involved in it. So are you kind of familiar with the bleaching and disease that has been happening in Puerto Rico or worldwide even.
Lauren: I am familiar to some extent, you know as much as I am a marine ecologist, so I am familiar with coral bleaching in general. I'm not familiar with what is specifically known about those reefs I don't know if they have more insight into what is going on down there specifically with respect to their reefs so you may have to tell me a little bit about what you have learned.
Sean: (to tom) And you wanna talk about some background that we have kinda done.
Tom: So Sean was in charge of what was a coral reef, Jason did what causes the bleaching.
Jason: We looked at bleaching and disease. We looked how tourism affects it and damages it. We looked at some of the climate related stuff that Sean did. Then we thought about the runoff from the construction along the coast. Is that pretty much what we have covered as far as research?

Tom: Yeah, I just found a site the other day that every 4 years looks at all the reefs basically worldwide and it looks like the major cause of this is increase in water temperature. So I think our next step is going to be what is causing the increase in water temperature, whether it is just climate change but I think there is other factors as well.
Sean: So like at this point we have a lot of ideas kind of what could be it. So we are kind of antsy to get down there and look at the data and see what the DRNA has come up with, so we can actually figure out what is causing the bleaching and disease.
Lauren: So my understanding of the state of knowledge is that there is a great deal of, there are multiple hypotheses for what could be causing these problems, and there is no reason to assume that a it is a single cause or that b every reef system has the same set of causes. So I think that what you are talking about now the climate warming is sort of the latest in a set string of hypothesis and I want you to do more investigation. So I think that the climate change relationship in this story is not so much a direct impact of temperature change on the corals themselves. You know the ocean temp has gone up by some fraction of a degree or something which isn't much, but the change in the amount of carbon in the atmosphere effects the amount of carbon that is dissolved in the water and that affects the pH of the water the acidity of the water and I think that is consider to be more directly related to what is going on. So take a look at what people are saying about acidity and pH and dissolved ions and all that stuff. You have to learn a little more chemistry to go along with you biology.
Sean: We got two Chem Engs.
Lauren: Excellent that will be your job.
Sean: So you talk about like pH, what are some like maybe some other factors that you have seen affect marine ecology or marine biology?
Lauren: Well so you are talking about corals right now which are very vulnerable for some specific reasons. They can't move, they can't get away from anything that is noxious to them, and unlike a lot of aquatic organisms they are soft bodied. So, even though corals themselves are hard, those hard skeletons are enclosing a very soft squishy little thing. So, you guys I'm sure will go snorkeling or scuba diving when you are down there. If you make the mistake of touching a coral it will feel soft to you, because of the hard skeleton that is left behind after the bleaching happens is underneath and usually the active polyp is out and it's very soft. So, that means anything in the water tends to get into the body of the organism. They have very little protection against anything. Any changes that happen quickly in the environment or any pollutants or anything that might get into the water, and that's different from fish and things like shrimps and lobsters that have outer coverings that give them more protection. So and that's one reason that things like corals are considered useful for this kind of investigation. Because they are going to be affected first, they are sort of like canaries in a mine shaft, you look at them first for their reactions to environmental changes and then you can infer that other things are going to happen. I think I got distracted from what your question actually was.
Sean: It was still good information.
Tom: That was very helpful.

Sean: Yeah we were just asking kind of like what factors maybe have you seen effect because you have done crayfish, is that correct?
Lauren: Yeah that is what I work on now and they are very you know subjected to very different affects. They are freshwater, which means they probably get a lot more pollution and a lot less of things like this pH change that I mentioned earlier and a lot less of a problem as result of fishing that sort of thing. So, when you are talking about a marine system like a reef, I know people talk about things like pollution. I'm not sure how much direct evidence there is in support of that.
Sean: Yeah it's tough to gather information on that.
Lauren: We know that we are putting a lot of pollutants out into the water but the oceans are really really enormous so the dilution affect is pretty significant in marine ecosystems. So, in terms of chemical pollutants probably not it, but I don't think we know that for sure yet and then there is other things. You know these reefs are fished heavily, and people tend to fish high up in a food chain. They fish the top level of the food chain and that has implications for everything else in the food chain including maybe the corals. So, it could be a complex ecological phenomenon that we don't understand very well.
Tom: The grouper population has just gone way down and that's like one of the bigger species in the reef system so they aren't eating as much of everything else and there is more of those species
Lauren: Exactly. So whatever is right under them gets their population gets bigger and if they are involved somehow in the health of the reef then that has important affects right. Do you guys know what happens biologically when a coral bleaches?
Jason: Was it the algae in it gets kind of like spit out essentially
Lauren: You are going to have to learn to say quickly the word, the word is zooxanthellae.
… Pronunciation conversation…
Lauren: Do you know why those are important?
Jason: They have like a symbiotic relationship with the corals is what we have found.
Lauren: Yeah what do they give the coral?
Sean: Is it the carbon dioxide?
Lauren: This is a quiz for you guys, you think you are at an interview. Their photosynthetic, the zooxanthellae are photosynthetic. So they are able to actually fix sunlight into energy. And part of that energy they give then to the coral the coral itself. So the coral doesn't actually do much in the way of hunting or getting food. They just get the food from their commensal organisms. The zooxanthellae the benefit to them is a little bit more straight forward, they get the shelter of the coral. They don't have to be floating around. If you're a plankton you tend to be eaten but if you're living inside a coral you don't get eaten. So that's the benefit that they get. So when a coral spits out all of its zooxanthellae that means it has no way to get more food. There is some disagreement about whether after that happens a coral can then get more before it dies. I think that may happen, but on the other hand if they can't do it quickly enough they will starve to death. And why the spit them out is definitely not known. Do they die first and then they spit out

their zooxanthellae or is something confusing the corals and they are just expelling them when they shouldn't be. I don't think that's is known or at least I'm not aware of it.

Tom: Definitely something to look into.

Sean: Oh and another thing is what are maybe some research strategies that you think maybe would help us when looking into the coral and analyzing reefs?

Lauren: Background research or data analysis?

Sean: Or even actually observation wise.

Lauren: What does your sponsor want you to do, do you know?

Tom: That's why we have been trying to get a hold of them.

Sean: We have a vague understanding to where we know they have collected a lot of research and data. They said basically the data that you need will be available to you but I think also we are going to need to go and physically observe the reefs, which is going to be fun but at the same time we want to efficiently know how to analyze the reefs

Lauren: I think you're probably largely going to be limited to the data they have. Because one problem is even if they get you out to the reefs frequently you're still only going to be there for 7 weeks and you can't get enough data in 7 weeks. So what you want to find out as soon as you can is what data those are that they have and they probably won't let you see them until you get down there. Probably just not going to send them to you until you get there. But you want to keep an eye out. You want data on water chemistry I think which is assume what they are going to have but until you see I don't think you really know. What I would suggest you do now is continue to make contact with people who know something about this. In fact you probably want to find some real coral biologists or climate change biologists who are interested in this sort of thing. And get in contact with them by email and see what they have to say. You know once you see your data, you will know the questions to formulate for them. But they will be interested in helping you. So, if you find, and you should be looking at biology or ecology departments at other universities and see who there is doing coral reef biology. Feel free don't be afraid to contact them. They work with students. They are happy to talk to you

Tom: After this we are actually going to try and find people down there that we can set up interviews with.

Sean: Do you have any suggestions for universities in the area.

Lauren: Yeah I was trying to think of names and I don't have any names for you off the top of my head. But I would look at university of Hawaii. In the Caribbean I'm not sure where you would look to other then university of Puerto Rico and you might find someone from PR and that would be great because you could then actually meet with them. But otherwise maybe Mexico. The University of Mexico or I don't know what it is, Mexico City something, but they will have probably someone.

Tom: I'm sure one of the Australian

Lauren: Yeah of course they will, Australia, so you might have to branch out of the Caribbean and find who is really doing this.

Tom: Today's technology isn't too hard anymore

Lauren: That's right Florida too actually and there is a reef off the coast of Texas so you might look at some universities in eastern Texas. See if anyone is doing anything there. Reefs in Texas are called the flower gardens.
Tom: Actually I think I saw that when I found that website. I was like flower gardens. It was like flower gardens and Caribbean reefs, what are flower gardens?
Sean: And actually what from your experience in being down there, how does Puerto Rico view the reefs. Are they kind of like a protected entity? Are they really protective of them or is it just kind of there like a tourist attraction?
Lauren: I think, I can't answer that with any expertise. Have you talked to professor Vernon-Gerstenfeld about this?
Sean: Not in detail. She is in California I think right now.
Lauren: If you get a chance to talk to her you could put that question to her. I suspect that depends like anything that depends on who you are talking to. So, if you ask that question to people in San Juan you might get a very different answer then if you ask people out in rural areas. I would say that probably, probably I don't know if you are going to be interacting with local people to find out how they feel.
Sean: We have kind of set up a little bit like fishermen I think we are going to try and survey.
Lauren: I think you will actually, I hope you will be pleasantly surprised by the sort of ability to see into the future that most of the people down there will have. That if they understand that any conservation strategy will benefit them in the long run that they will be supportive of that. So they know that the reefs are in trouble and they know that unhealthy reefs have implications for their own ability to fish and to make a livelihood. I suspect that there is not too much tension down there. But there is always some. Any sort of environmental regulation, any time somebody talks about conservation in anyway. That always involves, I just don't think it's possible to do without some sacrifices by people. And anytime you ask anybody to make a sacrifice. Everybody wants everybody else to make a sacrifice but not them and that's just human nature. So have you researched the concept of tragedy of the commons?
Sean: I have heard about it before I guess.
Lauren: You might want to take a look at it. It's a good thing to put into your introduction and it makes it impressive. So the tragedy of the commons essentially has to do with what we call common pool resources, which is any kind of resource that doesn't belong to anybody but instead belongs to some whole community. Like the ocean is very much a common pool resource. Nobody, no nation owns the open ocean. You own a little bit of your coastline but the open ocean is up for grabs. So the tragedy of the commons says that if nobody owns anything and everybody just gets to take however much they can as fast as they can, then no one is every motivated to not over harvest that resource. So the phrase the tragedy of the commons comes from, I forget the historical the first time this concept was proposed, but it had to do with grazing on common lands, the commons.
S: Do you guys have any other questions?

Interview Transcript-Jorge Corredor

Location: Phone Interview
Date: 3-21-2012
Time: 10:00
Attendance: Lindsey Grasis, Sean Galligan, Jason Hopkins, Jorge Corredor, Tom Svirsky

Jorge: Hello this is Jorge corridor.

Jason: Hi this is Jason, Lindsey, Sean, and Tom from the DRNA group.

Jorge: Good morning to you. Are you with Sean, Lindsey, and Thomas?

Jason: Yes we are all around the phone on speaker.

Jorge: So listen folks, I received your interview protocol. I think it was very productive that you went ahead with that rather then make it being in the cold. So I have an idea of what you want and how do you want this to work out?

Tom: Whatever is easiest for you. We can ask you the questions. We can kind of have a pre question conversation. I don't know if you prepared any answers.

Jorge: Well I don't have any written answers but I did look over the questions and have verbal answers for you so let me just go ahead and address your questions if you feel that's convenient.

Tom: That would be really good thank you.

Jorge: You must know I'm a bio geochemist and as we used to say back in school what we do is we take organisms and we grind them up and throw them in a machine and see what we can figure. So in that sense we are instrumentally dependent and my research has been such. My familiarity with the coral reefs has nothing to do with the chemistry of the coral reefs. With the nutrients of particularly the nitrogen and in light of current indications with pH of the environment. Of course I keep apprised with the biology going on and the ecology of the coral reefs. Which is why I sent you, I don't know if Lindsey received an email I sent today with regards to an article that came out in science magazine and I have it right in front of me right now and the article is called Trophic Downgrading of Planet Earth. What it talks about, it talks about the laws of large apex consumers because of human kind's pervasive influence on nature and the consequences of degradation on systems. So in that sense I wanted to warn you folks that this problem of coral reef degradation. The problem is not all coral bleaching and disease and the significations. There is a lot more to this then these rather simple primary stressors. But the primary stressors no doubt in my mind is the removal of large predators. This has dramatic consequences not only on the coral reef ecosystem but in other very different ecosystems. So one, the giant kelp beds depend on the presence of water. If there is no water you have an explosion of sea urchins. If you have an explosion of sea urchins you don't get any kelp so the whole ecosystem changes. Something similar happens to our reefs in that the removal of large apex predators including sharks, large fishes, large predator fishes, the grouper, even the turtle. But in any case for me the main problem has been the replacement of the hard coral and hard coral algae by microalgae. You might write down one name and that name is lobophora. We find in our deeper reefs here is already covered in lobophora. So what we are experiencing now is a regime change in the environment going from pristine coral reef to an algal bottom rubber community. So in regards to what I know about coral bleaching and disease in Puerto Rico there is not much I can tell you. I don't know if you have access to literature. With regards to bleaching you should have read there is ample there with regards to bleaching. Professor Garcia my colleague Jorge Garcia is one of the foremost authorities in not the cause but rather in the presence or absence in Puerto Rico of bleaching so you might go to his work. With regards to disease of course Dr. Ernesto Weil here is the foremost authority so you might talk to him. Other than that I can say that the 2005-2006 bleaching was indeed dramatic here in the coral reefs. Any questions about anything we have covered?

Tom: Nothing so far. So as we said in our email yesterday, our project is we are looking at the literature that has been produced and we are trying to gather it. I'm sure you are aware of GIS mapping. So we are taking the coral reef monitoring reports that the DRNA has along with some reports from the coral reef institute and NOAA and we are compiling the data that they collected into these GIS layers to try and help us identify these causes and maybe possible solutions to it. But, we are trying like you said to look at species populations such as the large predators and incorporate layers on that.

Jorge: Good. I'm pleased to hear that and let me also say there is another important predator that people don't mention anymore and that is sedimentation. Many reefs are susceptible to sedimentation at least corals are. All of them are like the cockroaches of the ocean…more susceptible to sedimentation from runoff. One of the problems we have had in Puerto Rico is deforestation. Coffee is making a comeback and the problem with the coffee is sun coffee is the one being planted right now and in order to plant sun coffee what they do is they chop down the shade trees because of the inconvenience. When you were planting coffee it was shade coffee and for that there are certain species of trees that are used. As a matter of fact there was an importation of Colombian trees to Puerto Rico because these are the ones used in Colombia for shade coffee. Well right now of course common sense being dollar driven if you have sun coffee you are going to get more coffee and there is now such a variety being planted. Consequentially from these trees you get increased runoff of saturated soils that is red type.

Tom: Okay.

Jorge: If you are interested in this topic the authority on this who is no longer working on the subject but is quoted extensively is Roberto Acevedo. The paper is old but they are on coral is what I know.

Tom: Ya that is something that the DRNA wants us to look at as well is the runoff. We are also going to be looking at possible sewage runoff as well.

Jorge: You can Google up Acevedo Coral Sedimentation and the first one that comes up is called Modification of Coral Reef Zonation by Terrigeneous Sediment Stress…Then most regards to sedimentation spread most factors of unique causes of bleaching and disease there is no doubt that increased temperatures are the causes of these bleaching events. Most particularly, in the presence of anticyclonic areas traversing the northeastern Caribbean in our neck of the woods. The anticyclonic areas cause sitting of the water in the area and consequently make for a deep layer and they are going anticyclonic that is clockwise. They manage to increase the persistent of warm water in our southern coastal reefs. There is a very well-known instance of an anticyclonic area in Jamaica. They call it the Columbia-Jamaica anticyclone and this area can stall for months. In that area in the south of Jamaica has become particularly susceptible to coral bleaching. Any questions so far?

Jason: No this is all very good information.

Jorge: Good you are going to send me a copy of your report I expect.

Tom: Oh definitely.

Jorge: What trends have you seen in the affected coral reefs and marine ecosystems around Puerto Rico? Dismal trends I might say. We are living a real shift in our lives. The reefs here are not what I saw when I first came here 33 years ago. The change as well has been dramatic on the shelf reefs, which is what we have here on the south coast. The shelf reefs have been quite affected by bleaching but the deep reefs have also been affected. The shelf edge reefs, these are the reefs to a depth of 20 meters which you would think would be a little bit more protected. But it turns out the relationship is overt because they are covered in lobophora its dramatic…The deep mesophotic reefs are surviving quite well and these are reefs in depth of 30 to 50 meters and you will have to get a hold of his (Garcia's) reports…The 2011 report is coming out from Dr. Garcia. Have you interviewed Garcia?

Tom: Not yet but I believe we have one set up. Do we? Did we email him?

Lindsey: Ya I don't know if he ever ended up responding.

Jason: I'm not sure if we got a response but we have seen a ton of reports with his name on it.

Jorge: Continuing on with your questionnaire…Industrial runoff is not quite as much and then there is of course the ocean outfall…EPA does not allow ocean outfall in the mainland U.S. This not being the mainland U.S the EPA provides a waiver so they can dump practically raw sewage with primary treatment only into our waters. There is one off of Carolina. There is one off of Aguadilla. There is one off of Ponce. Those are the ones I know about I believe there are three or four more. The data should be a matter of public record but they aren't so good luck hunting that down.

Appendix D: GIS Layer Information

Table 1: GIS Trend Information part 1

	Guanica	Fajardo-La Cordillera	Jobos Bay	Vieques	Mayaguez	R P
Prioridad_Conservacion	2 km	2 km		<1 km	10 km	
Rios	5 km	7 km		<1 km	10 km	
Barreras Costeras	1 km	2 km	0 km	0 km	10 km	
Modelo Impacto Derrame Aceite Costas	1 km	<1 km	<1 km	<1 km	10 km	<
Sitios	1 km	7 km	0 km	<1 km	10 km	
Zonas Idustriales	3 km	6 km		6 km	13 km	3
Urbanizaciones Inuststriales		5 km		5 km	13 km	3
Hoteles y Paradoes	2 km	4 km		1 km	13 km	3
Hoteles	2 km	4 km		2 km	13 km	3
Gasolineras	4 km	4 km	1 km	6 km	10 km	3
Centros Comerciales		6 km			15 km	
Aeropuertos a Puertos		10 km		6 km		
Alcantarillado		4 km	1 km	<1 km		<
Plantas Alcantarillados	4 km	7 km	6 km	7 km	18 km	
Plantas Generatrices			3 km		15 km	
Plazas Municipales	5 km				15 km	3
Plantas Acueductos						
Registros Sanitarios	4 km	6 km				
Puertos Maritimos a Puertos		6 km	5 km		15 km	
Tanques Agua	4 km		2 km		10 km	3
Tanques Soterrados		5 km		6 km	15 km	
Tanques Acueductos	6 km	4 km	2 km	3 km	10 km	3
Vertederos	7 km	14 km	3 km	12 km		
EPA Superfund	2 km	2 km	4 km	6 km	13 km	
EPA storet monitoring locations	2 km	4 km	1 km		13 km	3
EOA national priority list			5 km			
EPA Air monitoring locations	4 km	3 km	4 km			
Firms	1 km	0 km	0 km	0 km	10 km	0
Rasgos Orograficos	3 km			5 km	10 km	<
Rasgos Geograficos	7 km					<

Zonas inundables fema 2007		0 km		0 km	10 km	0
valles agricolas	4 km				10 km	
refugios de vida silvestre				3 km		
playas publicas	2 km	<1 km		1 km	10 km	2
legado forestal	2 km	8 km			10 km	
lagos lagunas						
humedales casi casi	0 km	0 km	0 km	1 km	10 km	<
embalses		9 km				
Corredor Biologico	5 km					
Bosques estatales	2 km	6 km	1 km			
acuiferos general	2 km	3 km	<1 km	<1 km	10 km	<
plantas tratamiento	4 km	7 km	6 km	7 km		
plantas filtracion		9 km				
cuerpos aqua superficial	7 km	3 km	2 km	6 km	10 km	
elementos criticos 2008	2 km	<1 km	<1 km	<1 km	10 km	2
areas para banistas	2 km	<1 km		1 km		2
areas naturales protegidas 2010	0 km	0 km	<1 km	0 km	0 km	0
Areas prioridad conservacion 2008	2 km	<1 km	0 km	<1 km	10 km	
Areas prioridad conservacion karso	2 km					
Aeropuertos a Puertos		9 km				
restaurantes	5 km	5 km		2 km	10 km	
marinas		4 km	1 km		10 km	1
Boyas Marinas 2005	<1 km	0 km		1 km	4 km	
Reservas Naturales	3 km	0 km		<1 km	10 km	0
Areas de Manejo	0 km	0 km	<1 km	0 km	0 km	
Areas Nat Protegidas	0 km	0 km	<1 km	0 km	0 km	0
Critical Wildlife	2 km	0 km	0 km	<1 km	10 km	

Table 2: GIS Trend Information part 2

	Caja de Muertos	Culebra	Ponce	La Parguera	Isla Desecheo	Isla Mo
Prioridad_Conservacion	8 km	0 km	6 km	3 km		
Rios	8 km		8 km			
Barreras Costeras	7 km		6 km	<1 km		
Modelo Impacto Derrame Aceite Costas	<1 km	0 km	6 km	<1 km		<1
Sitios		0 km				
Zonas Idustriales	10 km	4 km	6 km			
Urbanizaciones Inuststriales	9 km	4 km	13 km			
Hoteles y Paradoes	10 km	4 km	7 km	3 km		
Hoteles	10 km	4 km	6 km	3 km		
Gasolineras	7 km	5 km	6 km	5 km		
Centros Comerciales	12 km		9 km			
Aeropuertos a Puertos	11 km	3 km	11 km			
Alcantarillado	10 km	3 km	6 km	3 km		
Plantas Alcantarillados	14 km	6 km	9 km	3 km		
Plantas Generatrices						
Plazas Municipales	15 km	4 km	9 km			
Plantas Acueductos		6 km				
Registros Sanitarios	12 km		8 km			
Puertos Maritimos a Puertos						
Tanques Agua			11 km	3 km		
Tanques Soterrados		4 km	8 km			
Tanques Acueductos	13 km	2 km	10 km	3 km		
Vertederos	15 km	1 km	9 km	7 km		
EPA Superfund	13 km	6 km	9 km			
EPA storet monitoring locations	9 km		7 km	2 km		
EOA national priority list						
EPA Air monitoring locations						
Firms	0 km	0 km	6 km	<1 km		0 k
Rasgos Orograficos		3 km				
Rasgos Geograficos					5 km	10
Zonas inundables fema 2007		0 km		<1 km		
valles agricolas				5 km		
refugios de vida silvestre		1 km		8 km	<1 km	
playas publicas	1 km	1 km	6 km	3 km		

legado forestal				3 km		
lagos lagunas						
humedales casi casi	<1 km	0 km	6 km	1 km		
embalses						
Corredor Biologico						
Bosques estatales				2 km		
acuiferos general	8 km	<1 km	6 km	2 km		<1
plantas tratamiento	14 km	6 km	8 km	4 km		
plantas filtracion		6 km	11 km			
cuerpos aqua superficial		2 km	8 km			
elementos criticos 2008	<1 km	<1 km	8 km	2 km		<1
areas para banistas		1 km				
areas naturales protegidas 2010	0 km	0 km	7 km	0 km	0 km	0 k
Areas prioridad conservacion 2008	<1 km	0 km	7 km	<1 km	<1 km	<1
Areas prioridad conservacion karso	<1 km		8 km			<1
Aeropuertos a Puertos	11 km	3 km	11 km			
restaurantes	12 km		9 km	3 km		
marinas	11 km		6 km	2 km		
Boyas Marinas 2005	<1 km	0 km	7 km	<1 km	<1 km	<1
Reservas Naturales	0 km	0 km	7 km	0 km	0 km	0 k
Areas de Manejo	0 km	0 km	7 km	0 km	0 km	0 k
Areas Nat Protegidas	0 km	0 km	7 km	0 km	0 km	0 k
Critical Wildlife	<1 km	<1 km	7 km	0 km	<1 km	<1

Appendix E: GIS Layers

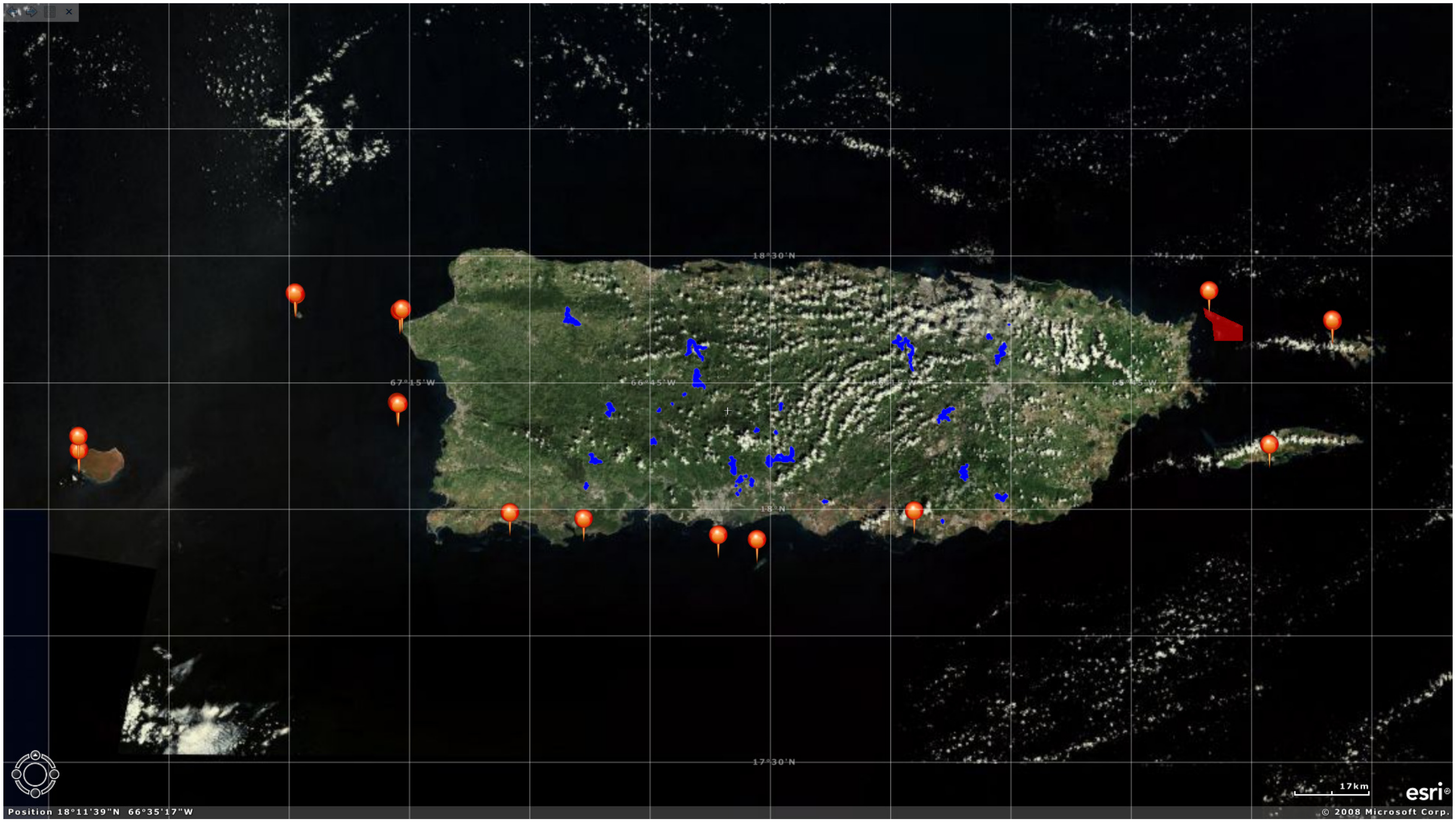

Figure 18 Lakes and Lagoons

Figure 19 Wildlife Refuges

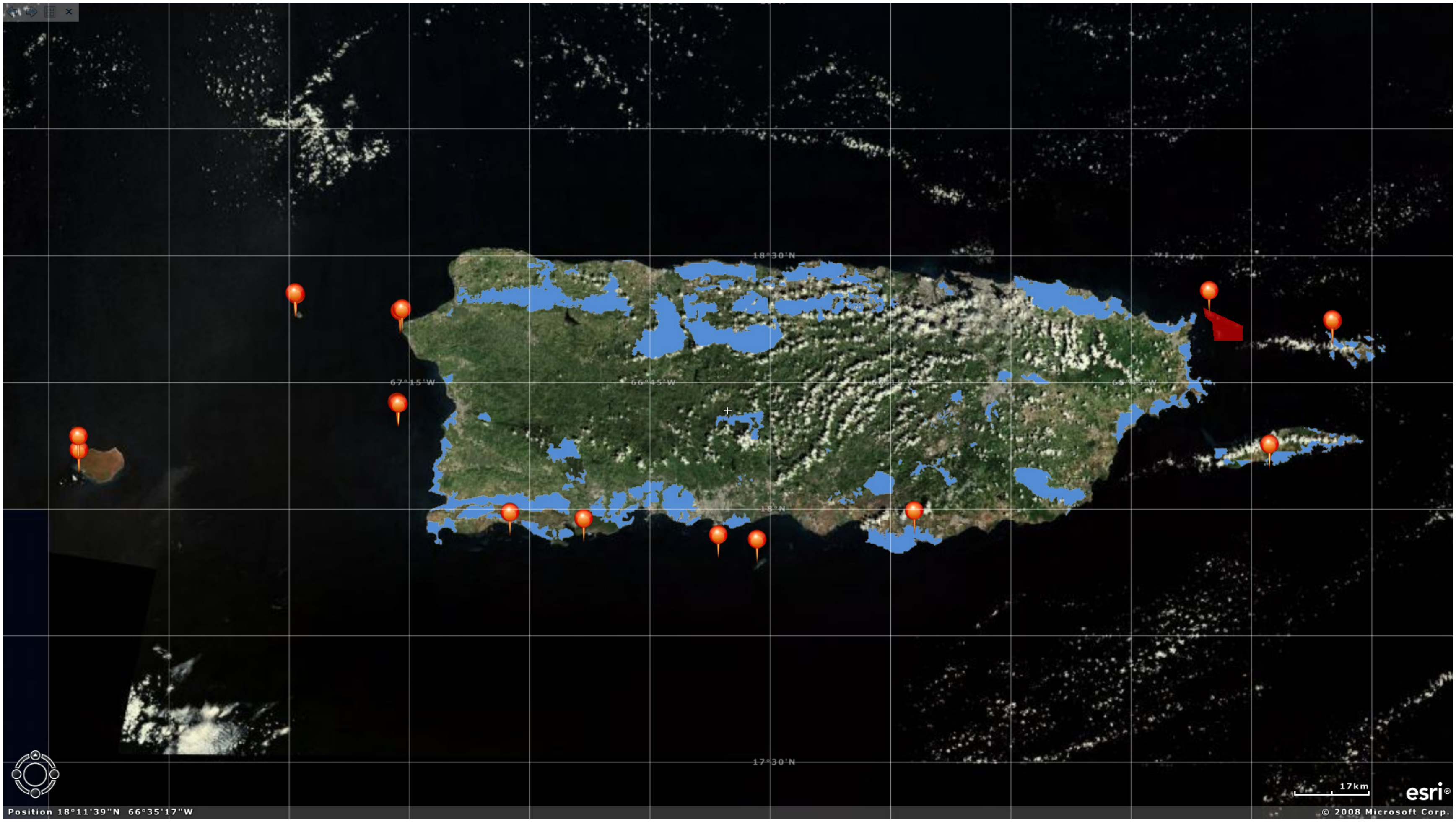

Figure 20 Conservation Priority

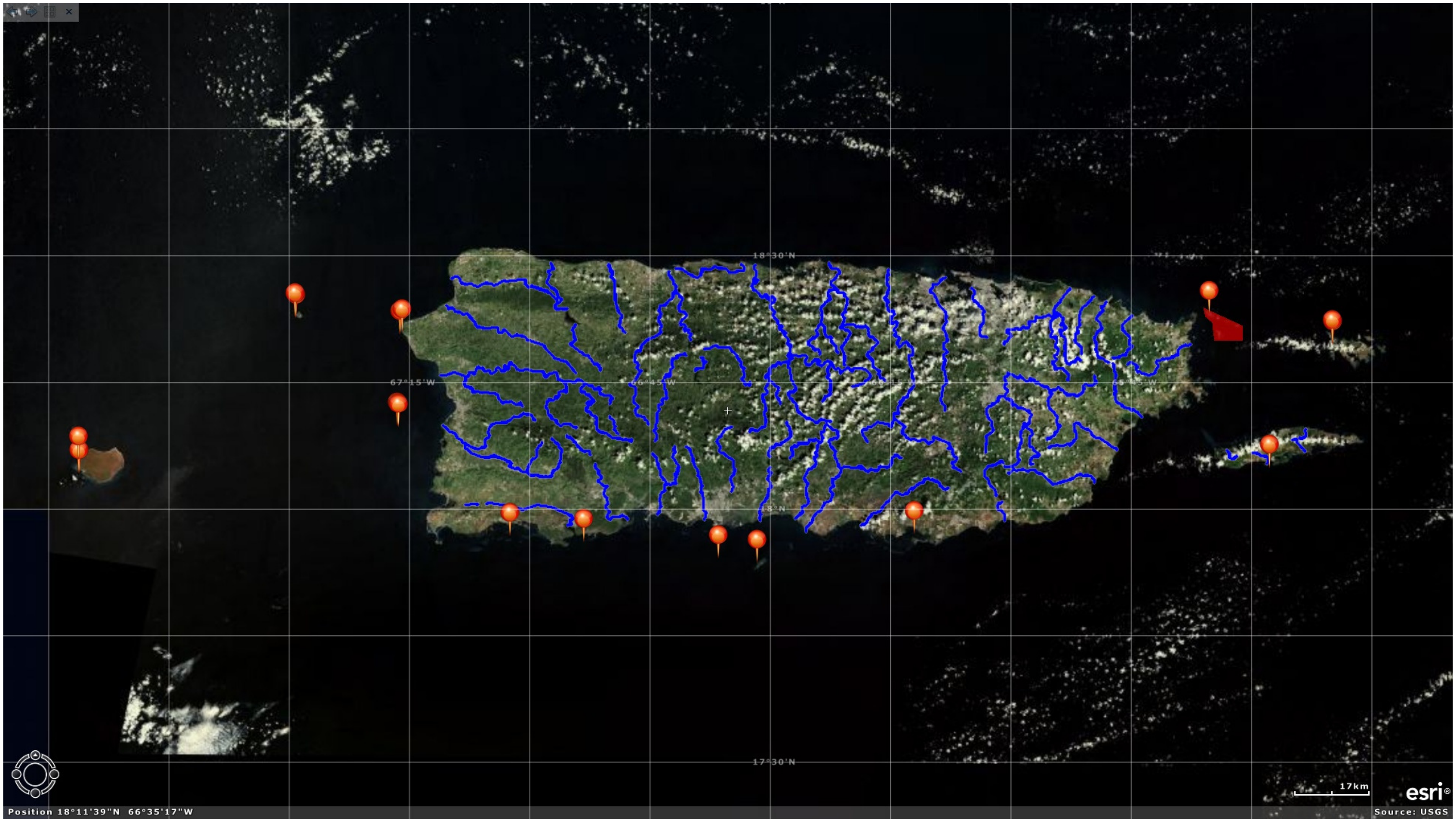

Figure 21 Rivers

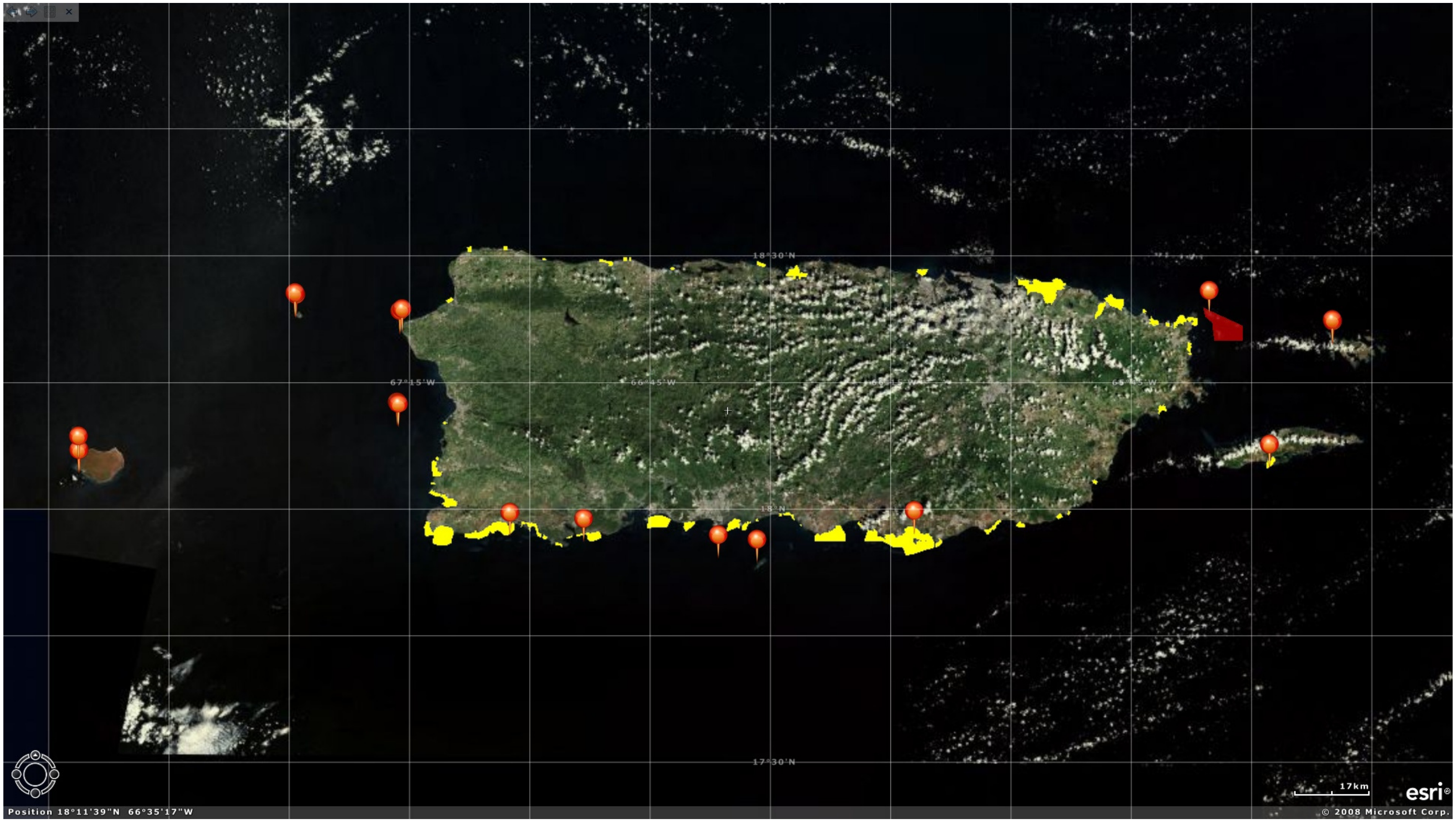

Figure 22 Costal Barriers

Figure 23 Oil Spill Impact Model Costs

Figure 24 Sites

Figure 25 Industrial Zones

Figure 26 Industrial Developments

Figure 27 Hotels

Figure 28 Gas Stations

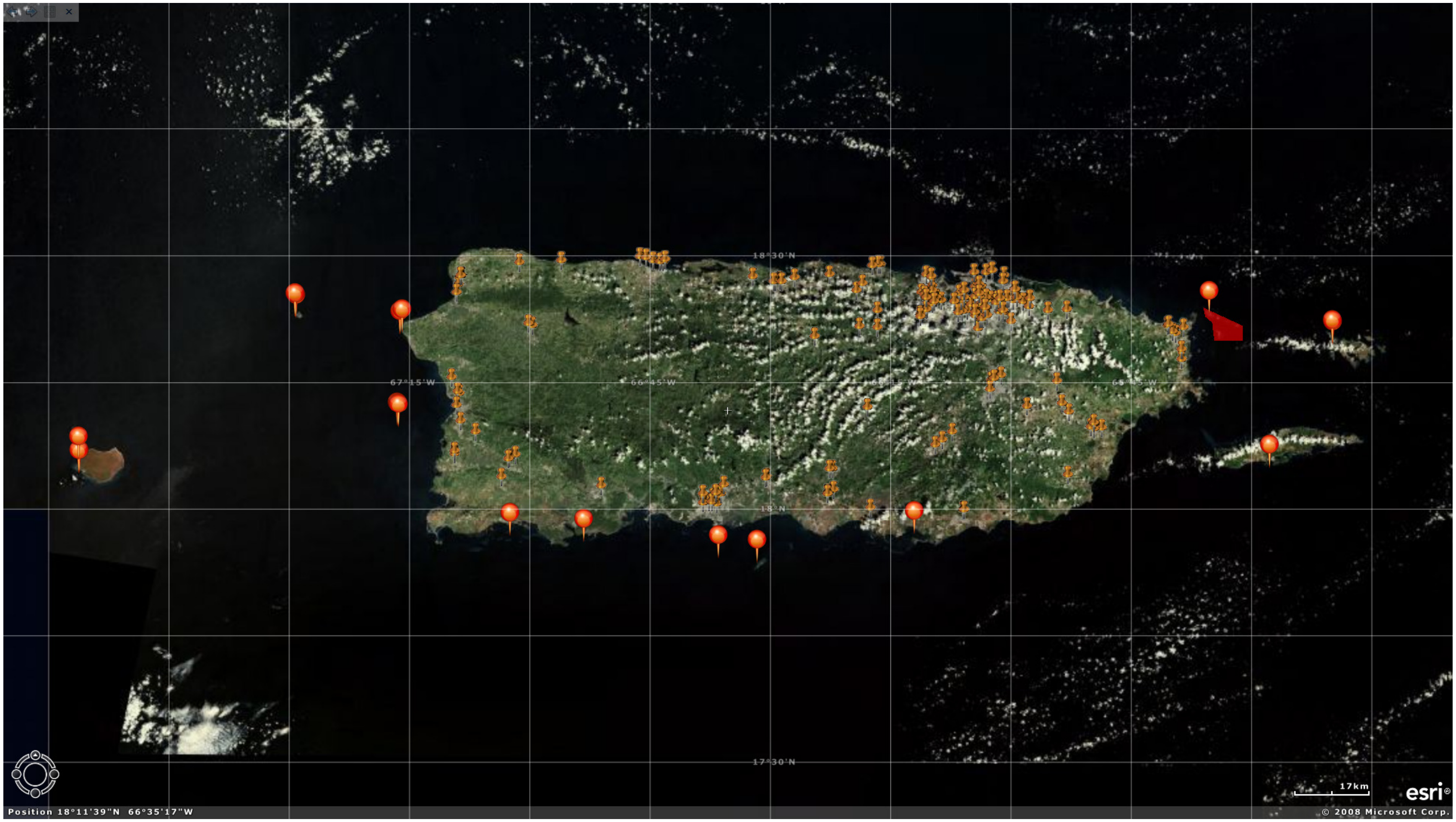

Figure 29 Shopping Malls

Figure 30 Airports

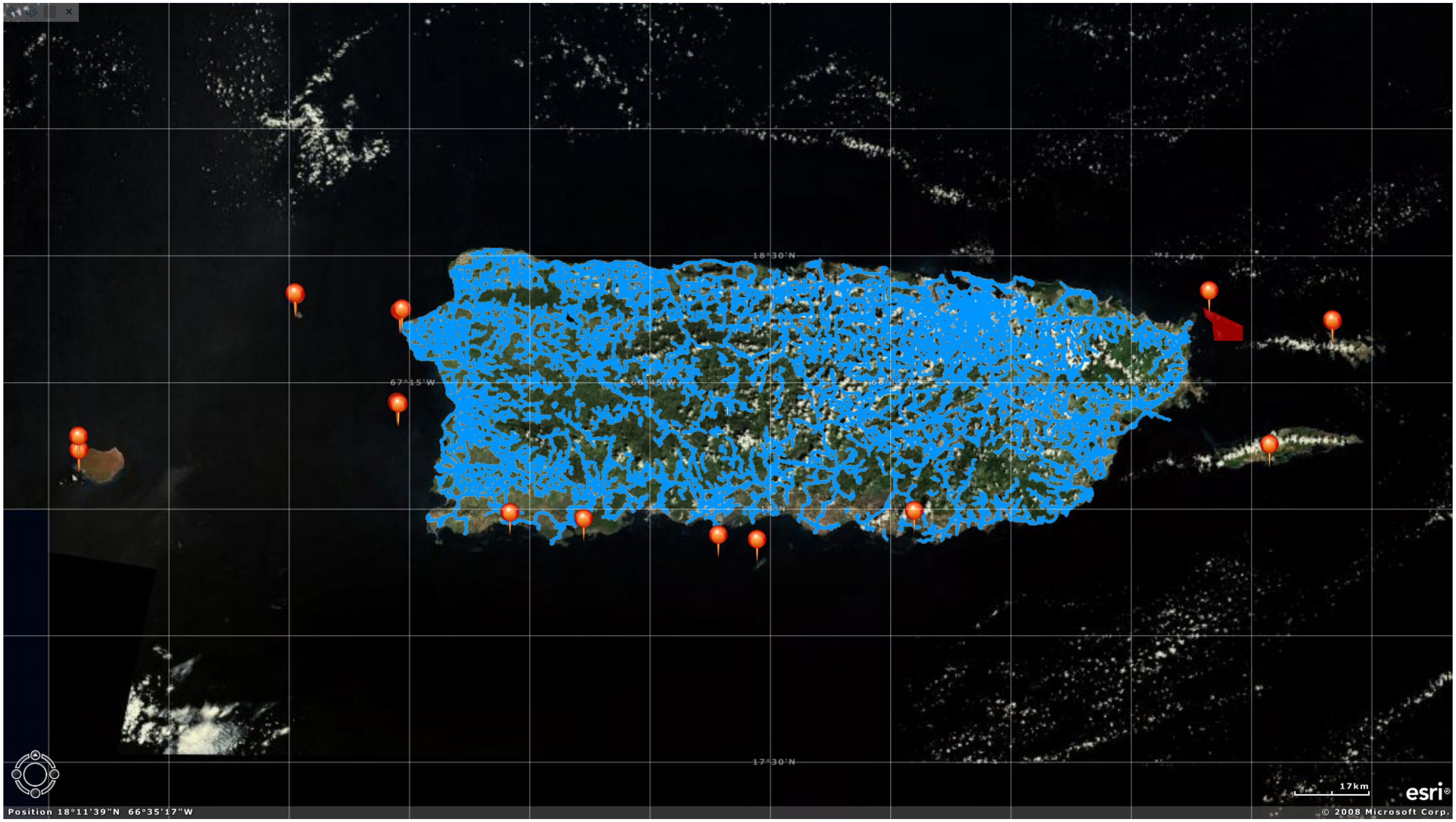

Figure 31 Aqueduct

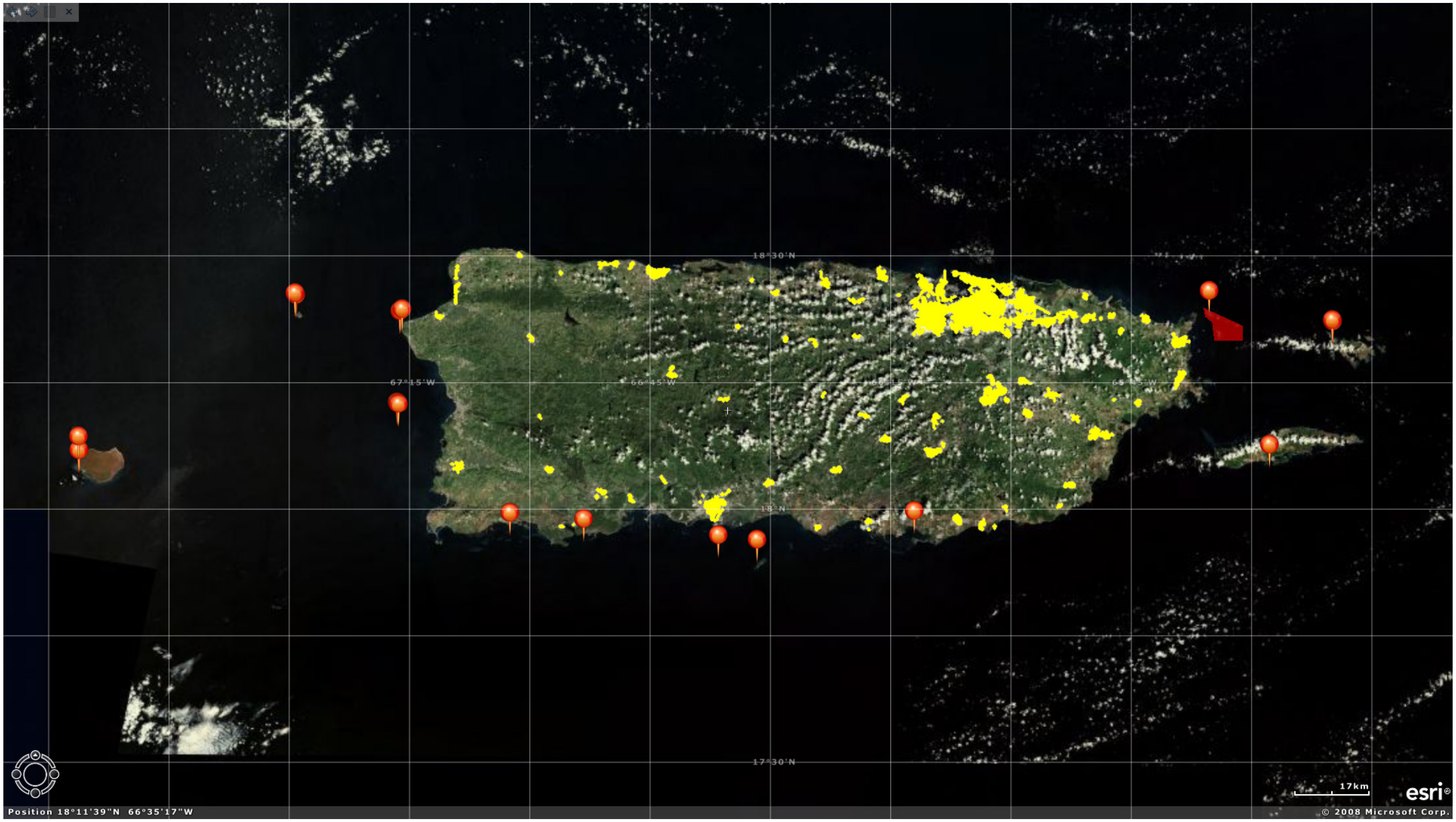

Figure 32 Sewer Layer 1

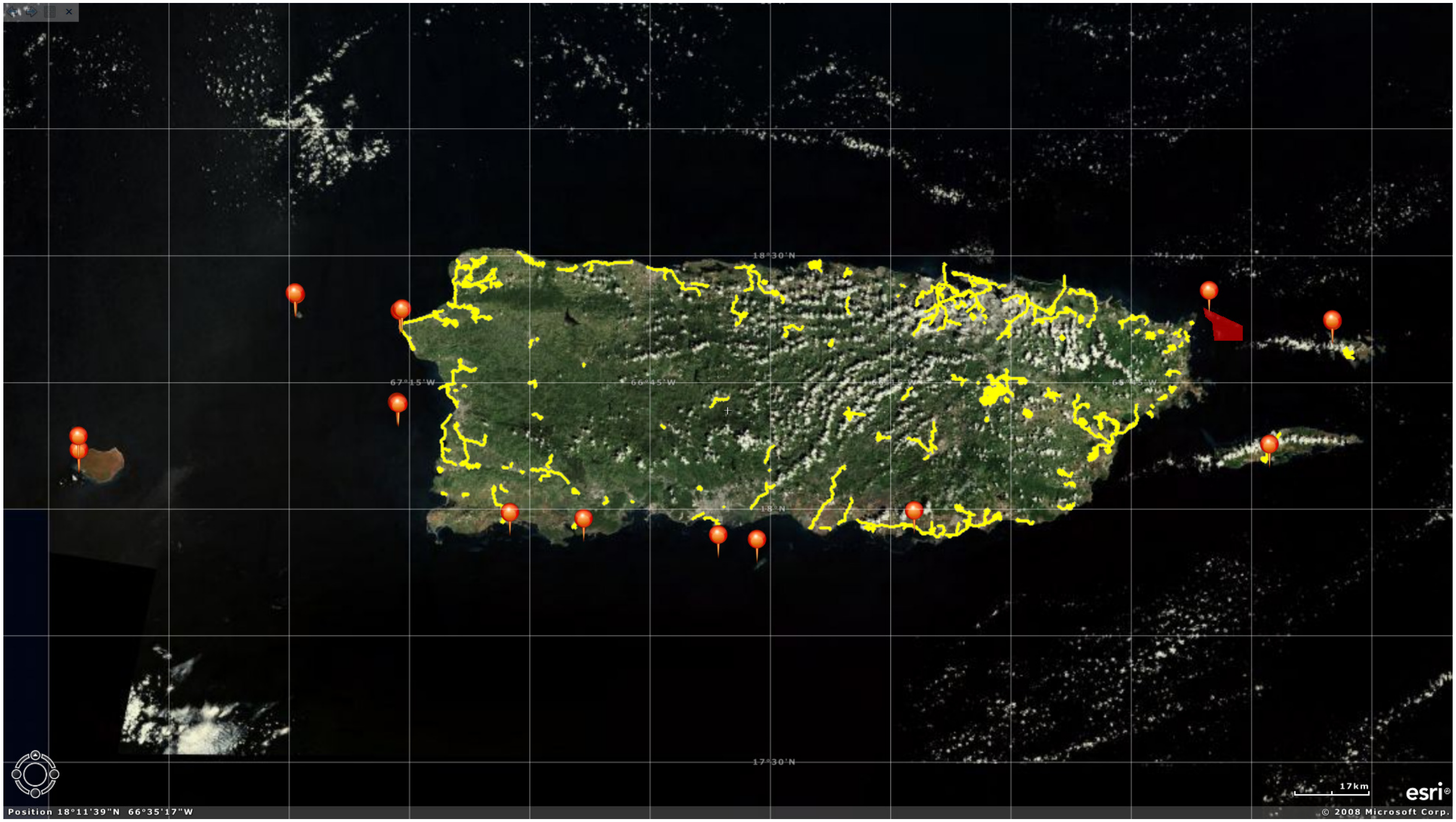

Figure 33 Sewer Layer 2

Figure 34 Sewage Plants

Figure 35 Power Plants

Figure 36 Municipal Places

Figure 37 Water Supply Plant

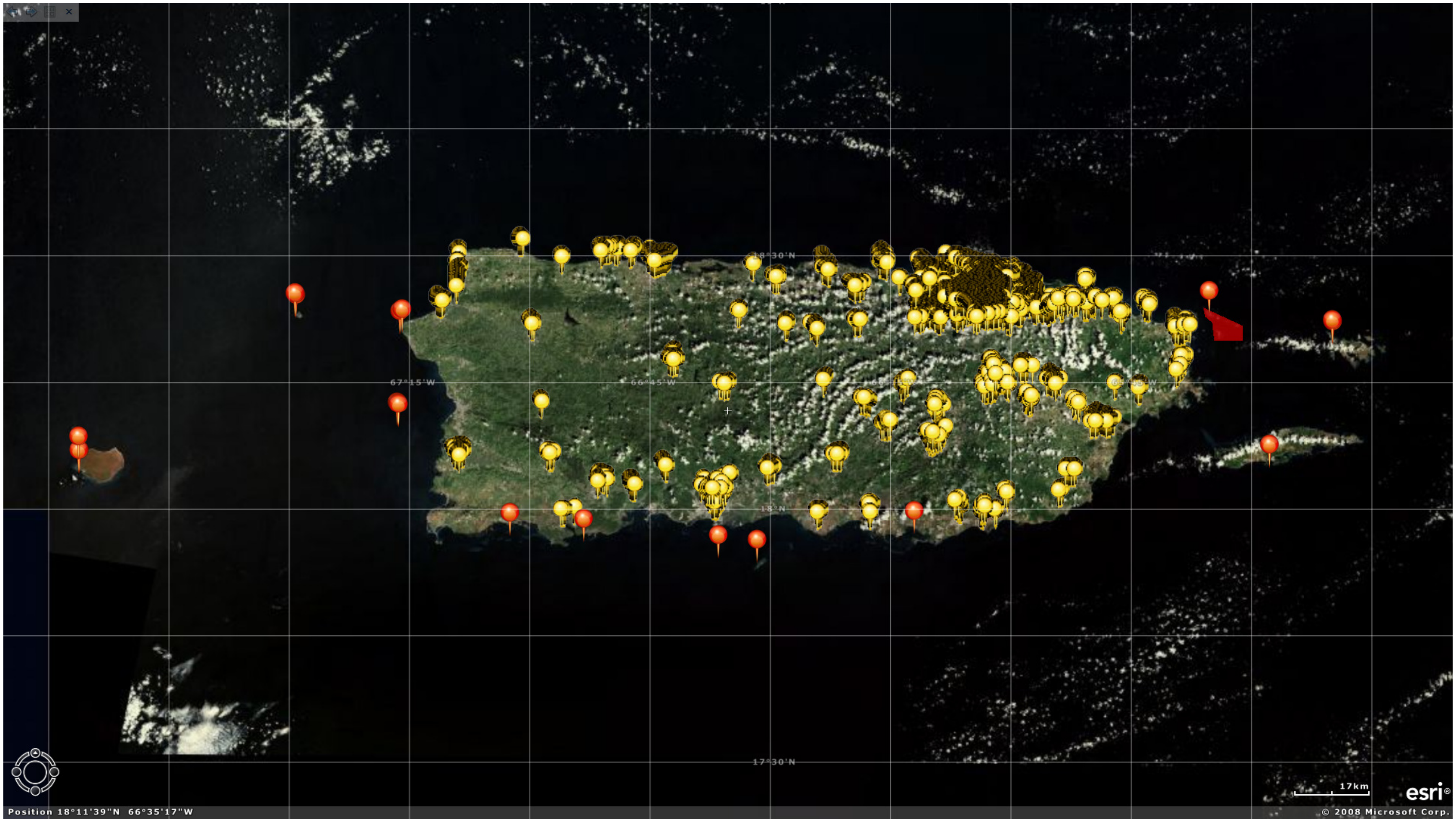

Figure 38 Health Records

Figure 39 Maritime Ports

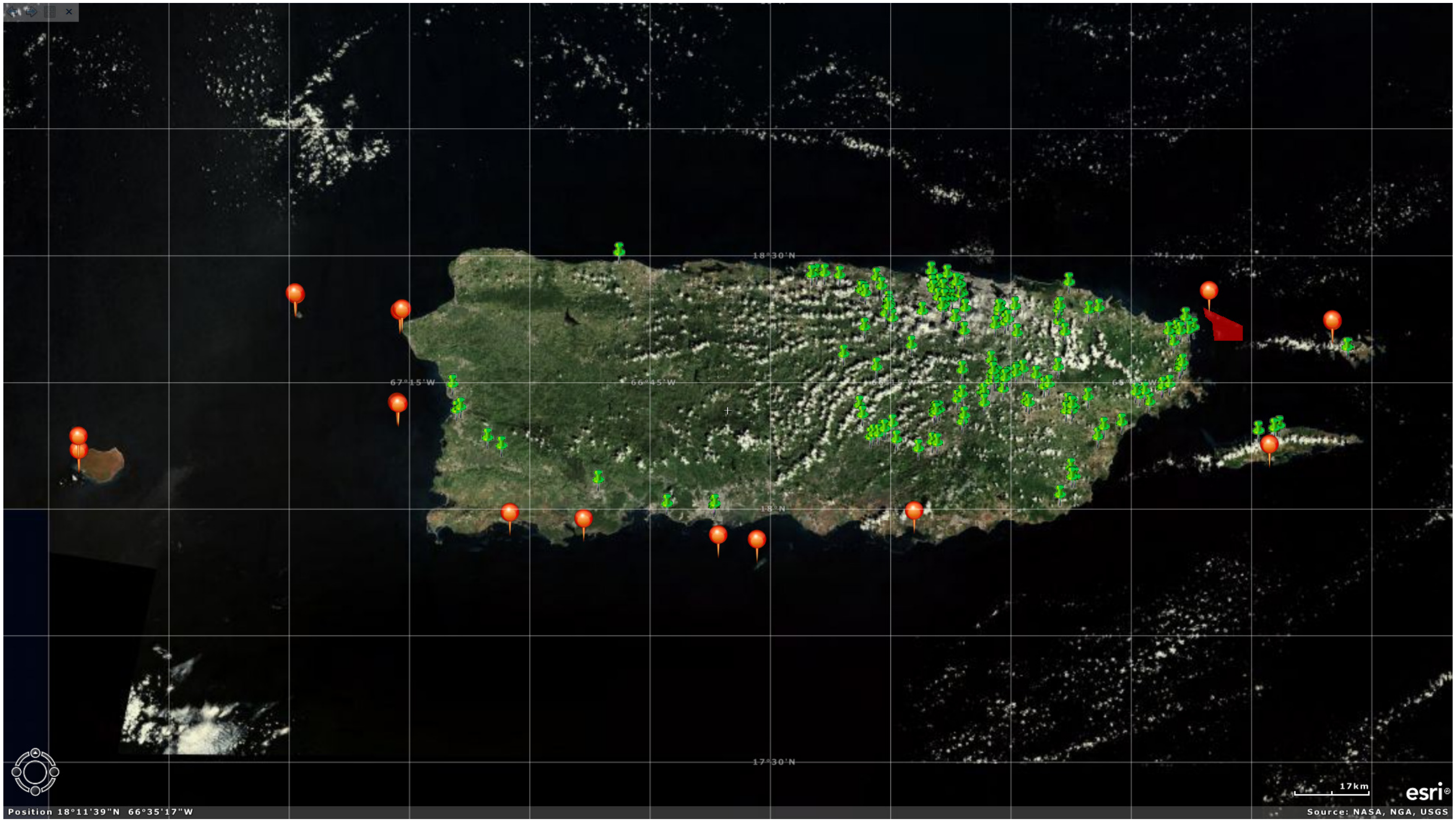

Figure 40 Underground Tanks

Figure 41 Water Tanks

Figure 42 Water Supply Tanks

Figure 43 Landfills

Figure 44 Socioeconomic Points

Figure 45 EPA Superfund

Figure 46 EPA National Priority List

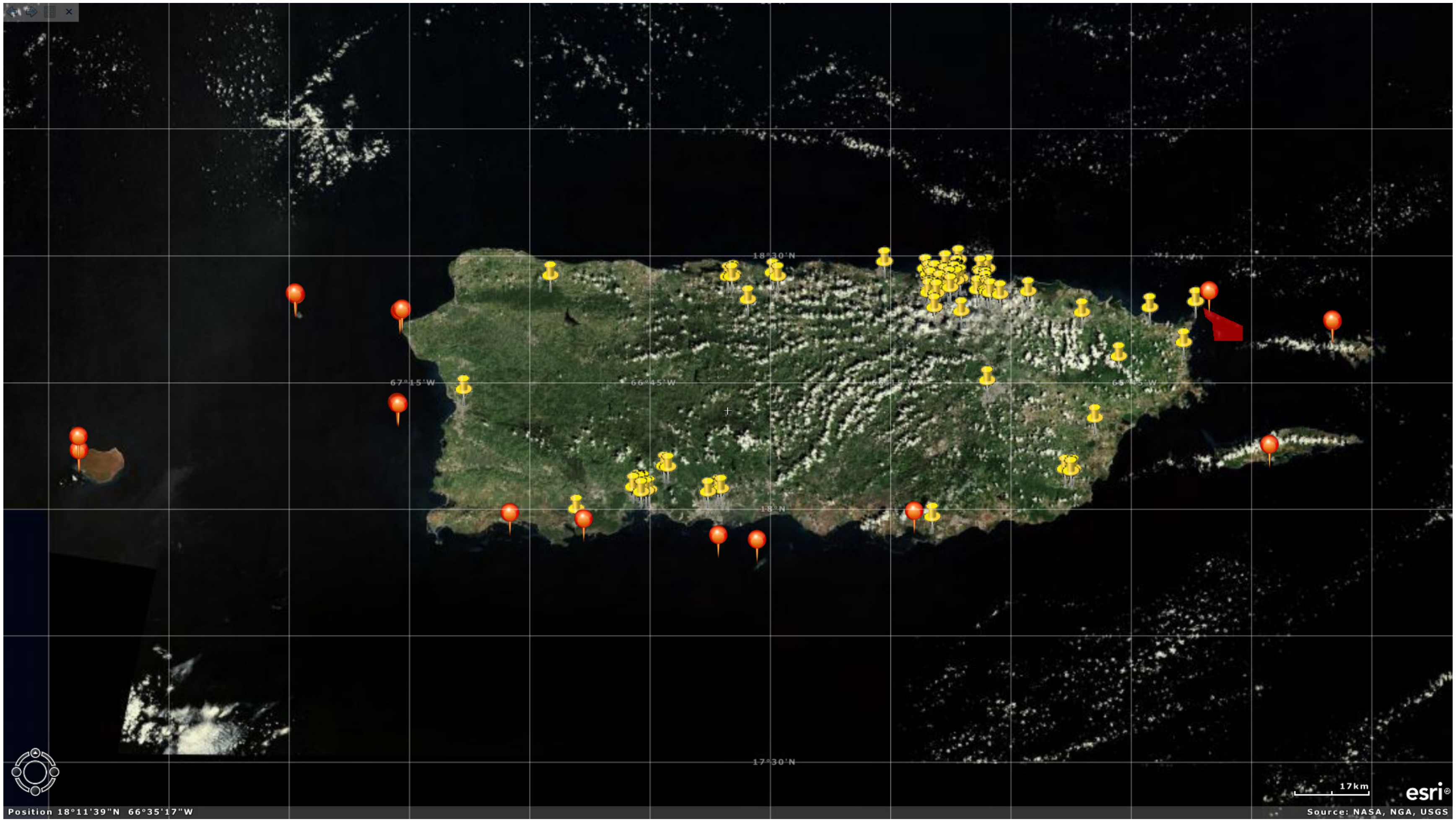

Figure 47 EPA Air Monitoring Locations

Figure 48 Firms

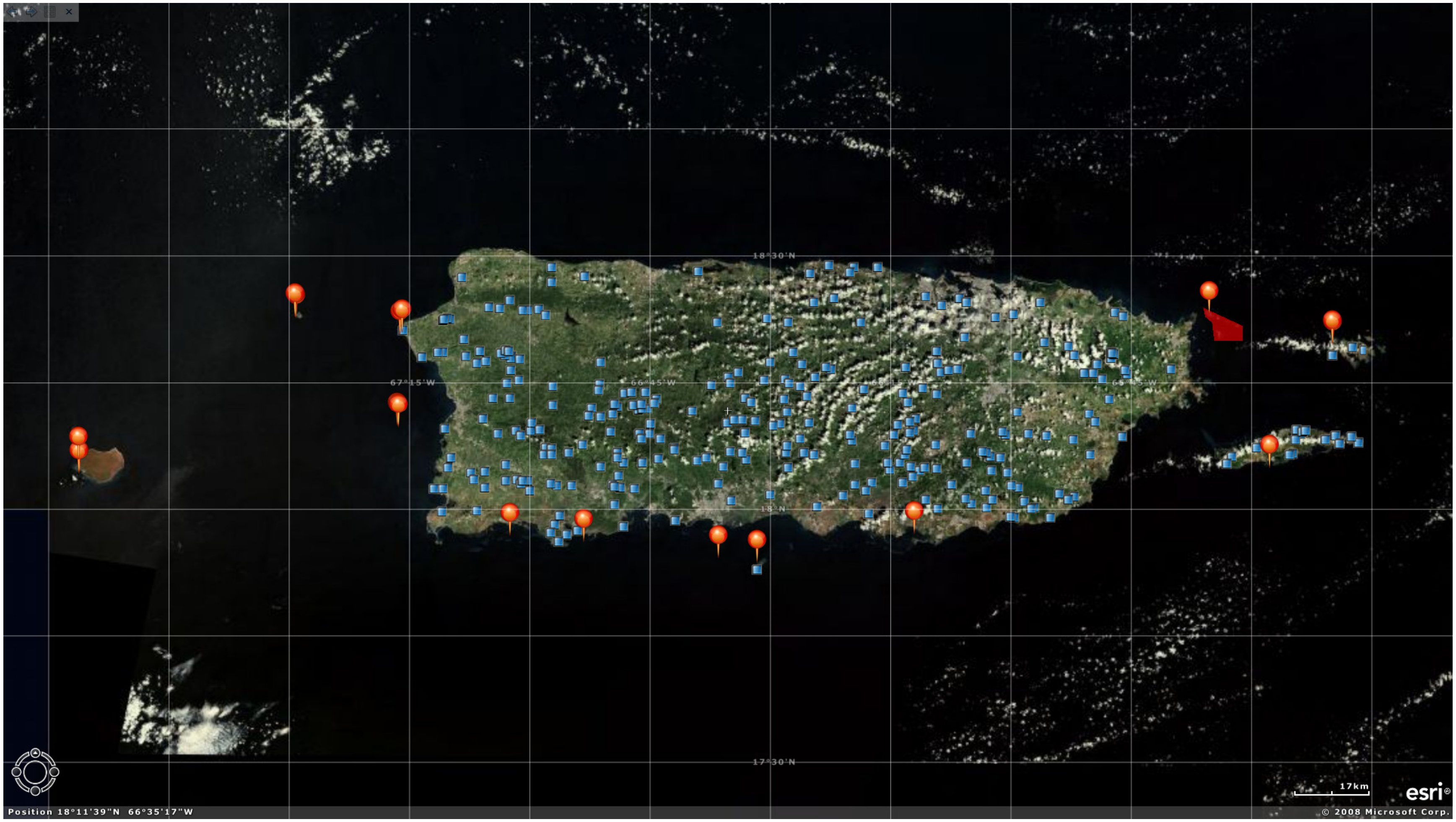

Figure 49 Orographic Features

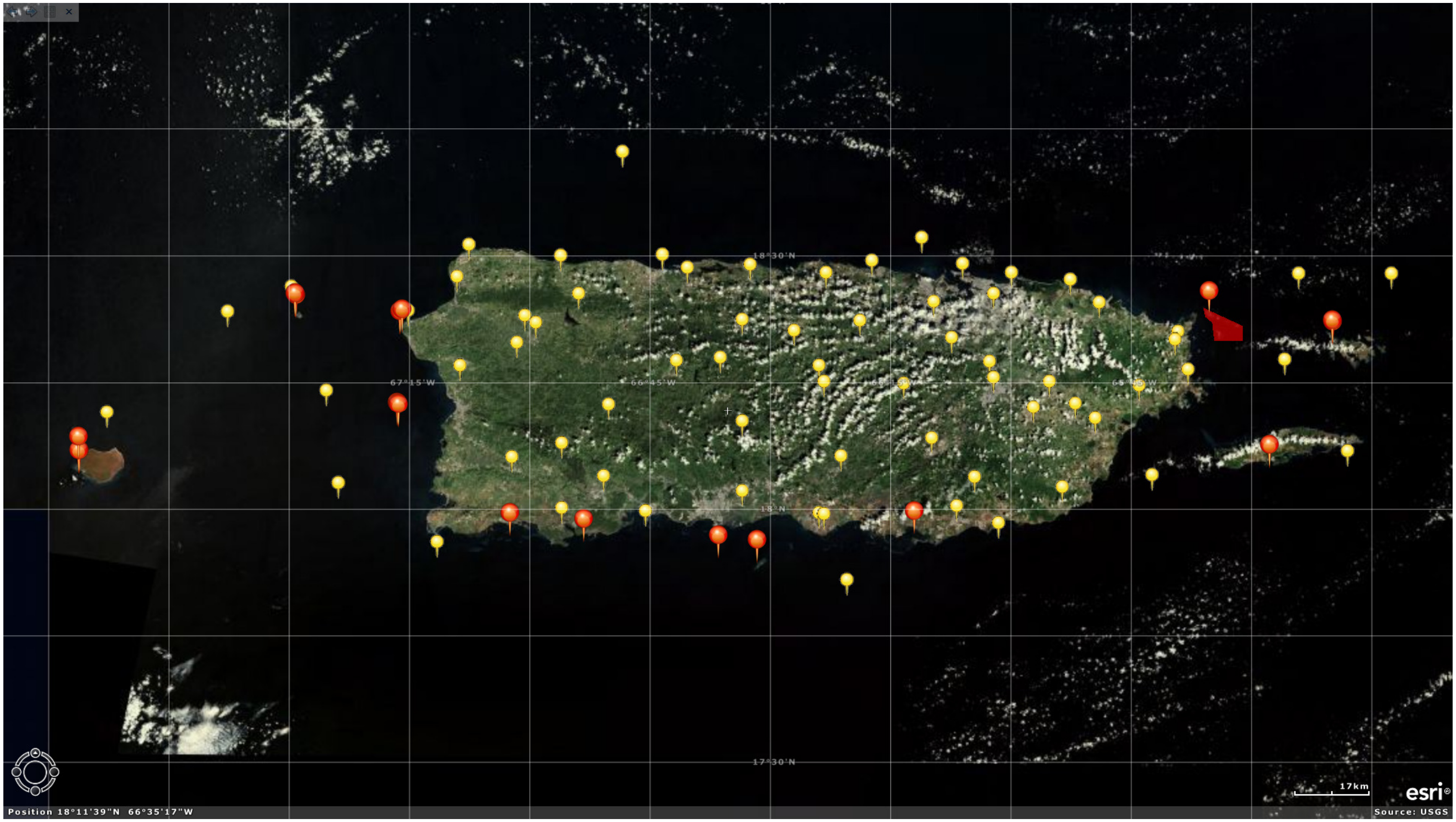

Figure 50 Geographical Features

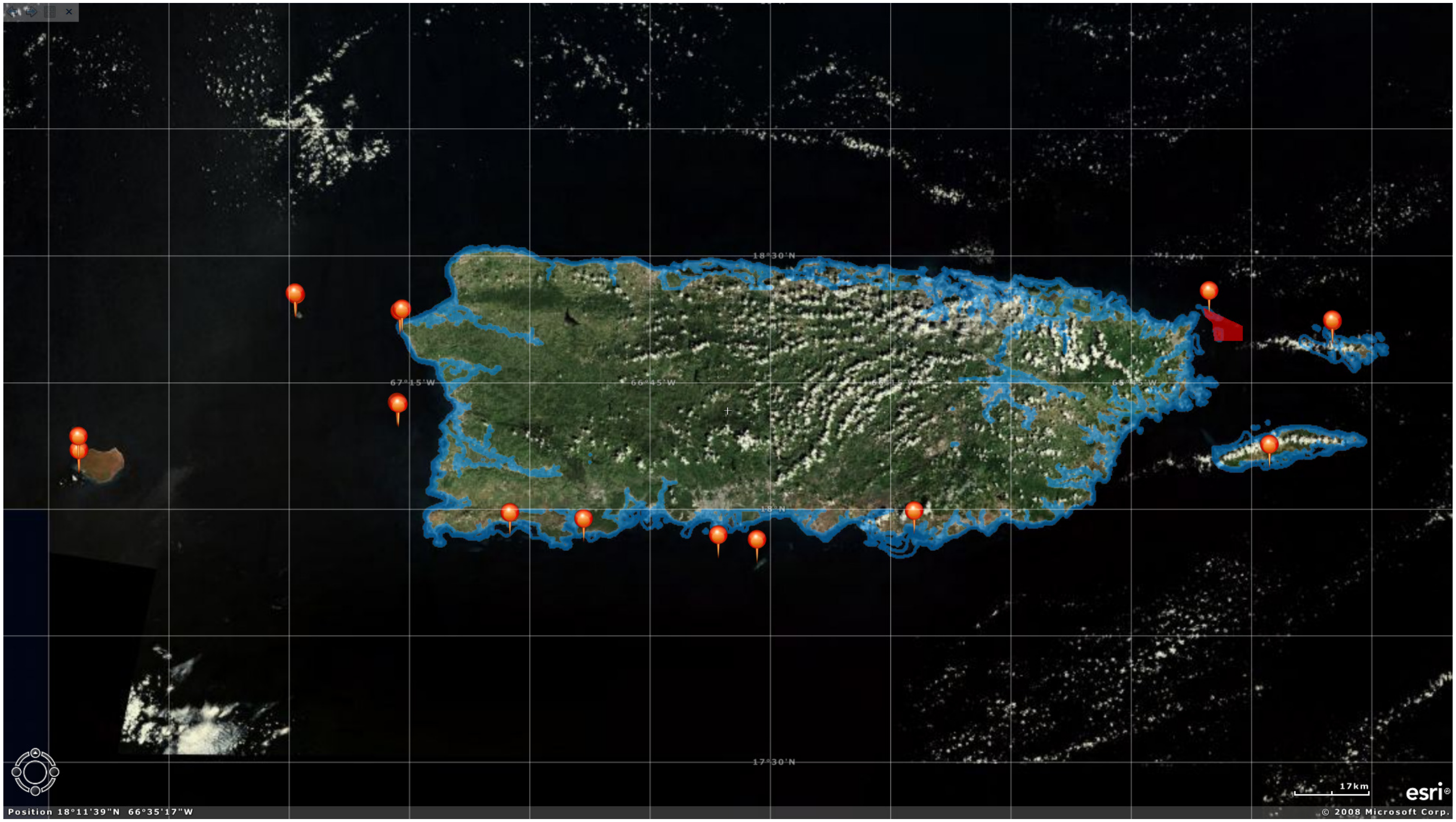

Figure 51 FEMA Flood Zones 2007

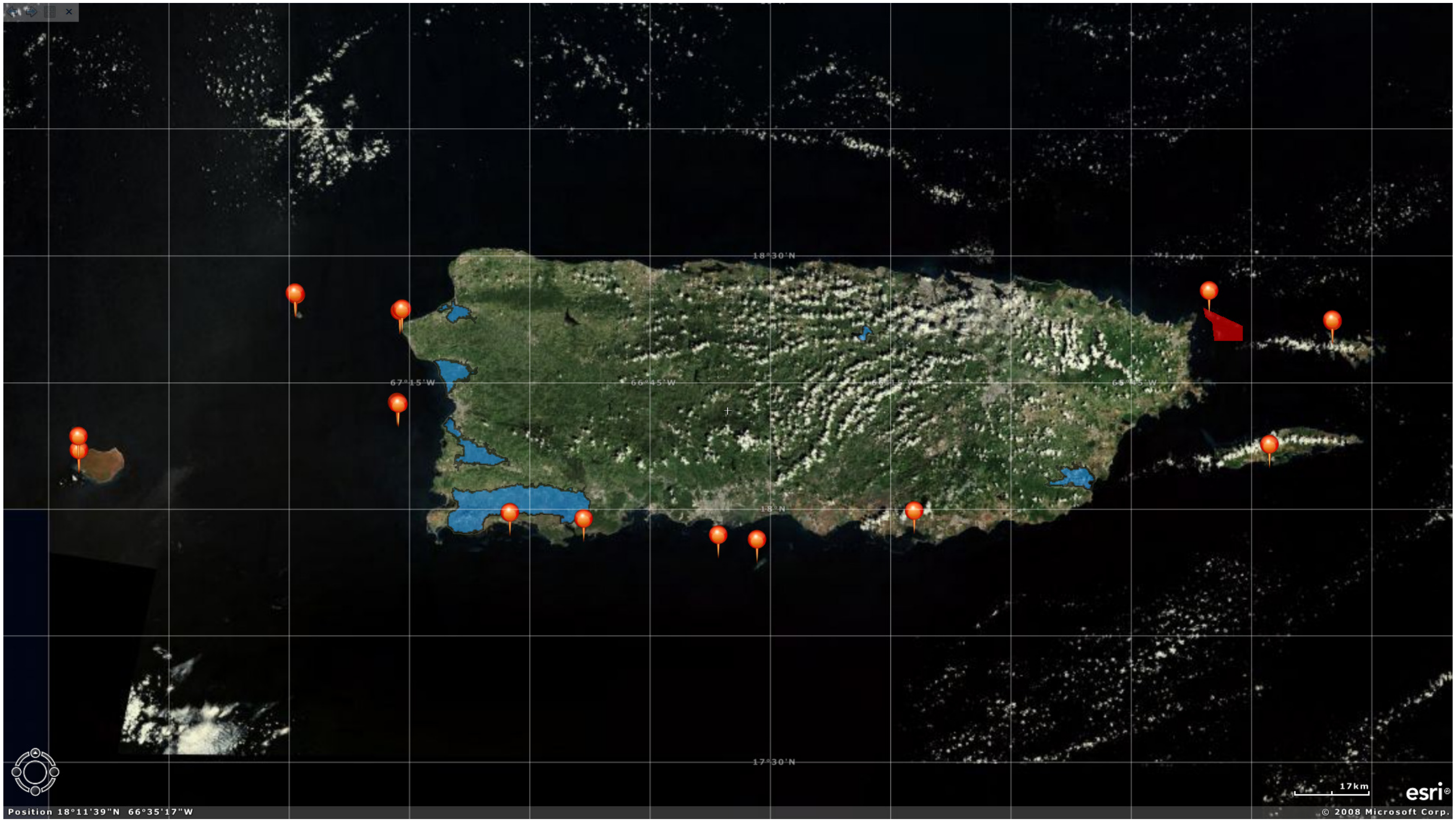

Figure 52 Agricultural Valleys

Figure 53 Public Beaches

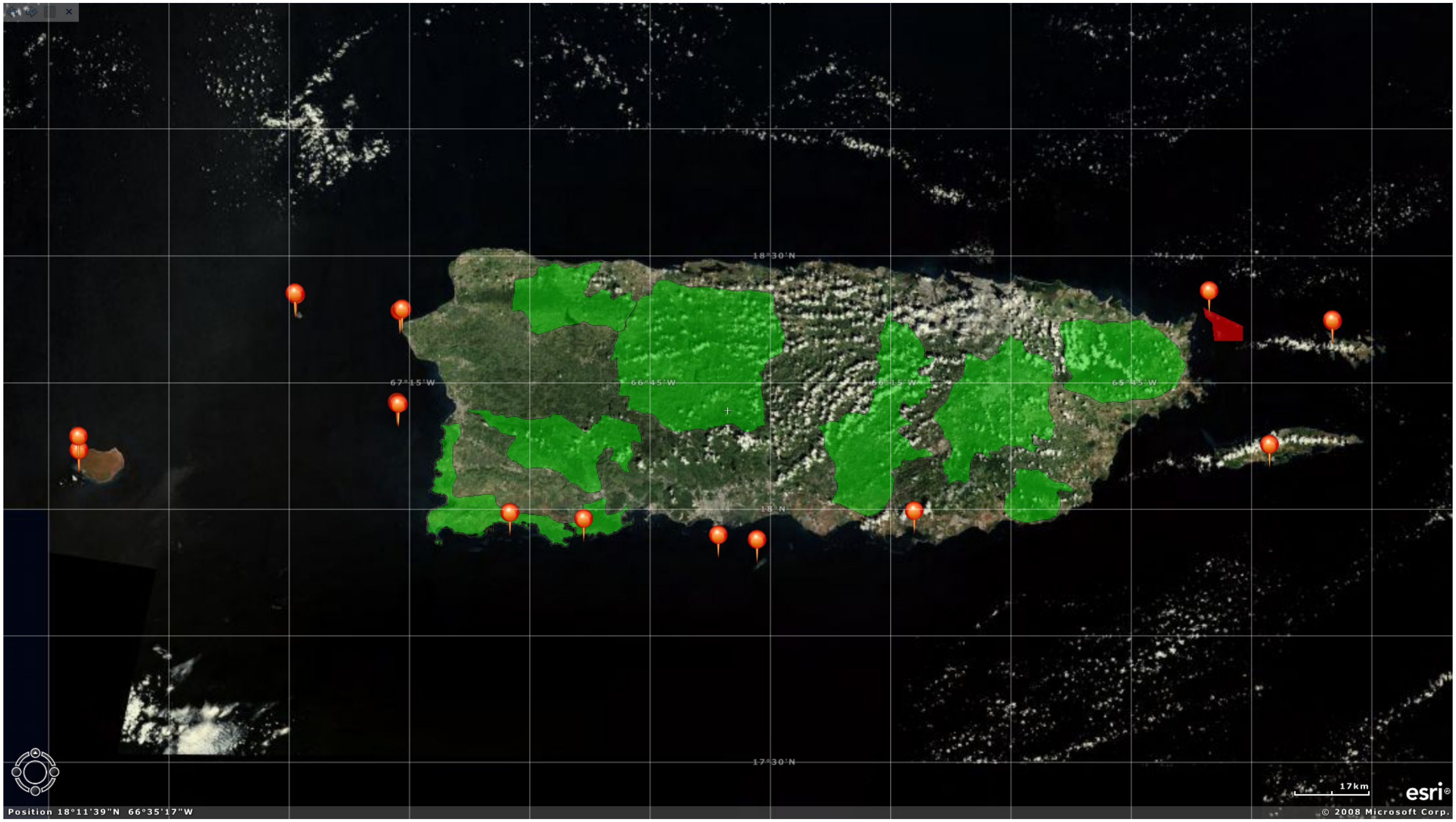

Figure 54 Legacy Forests

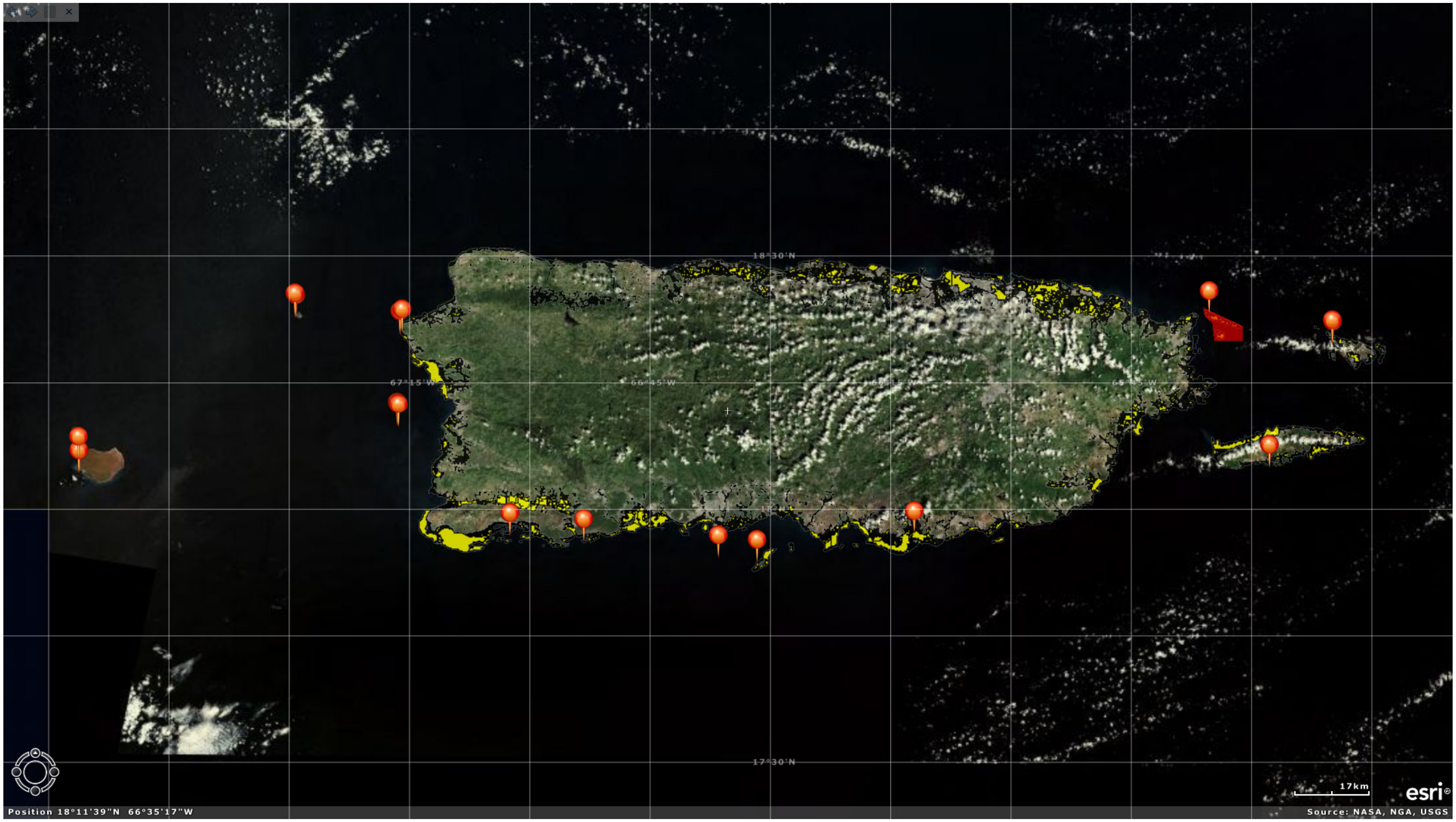

Figure 55 Wetlands

Figure 56 Reservoirs

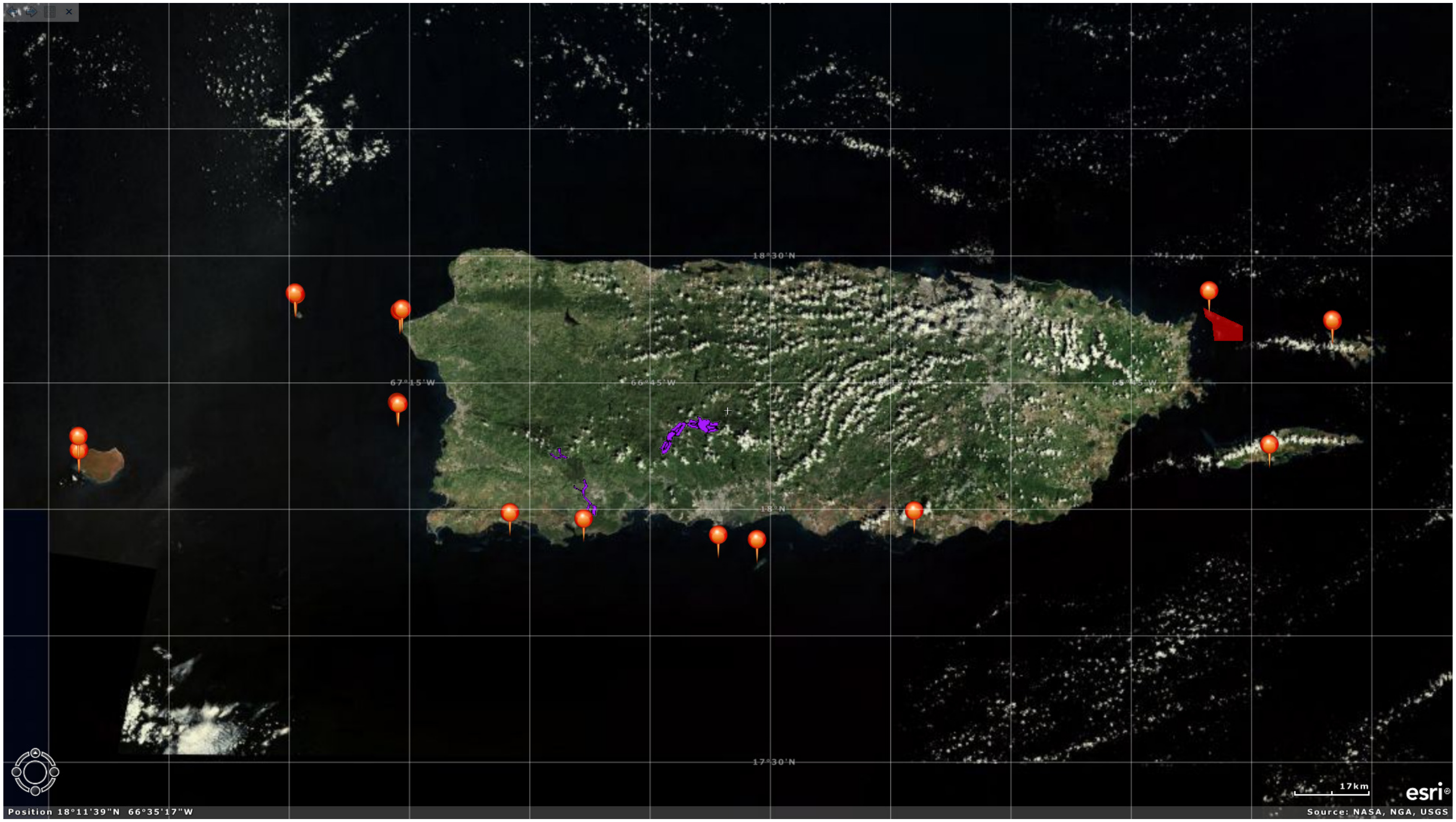

Figure 57 Biological Corridors

Figure 58 El Yunque National Forest Zoning

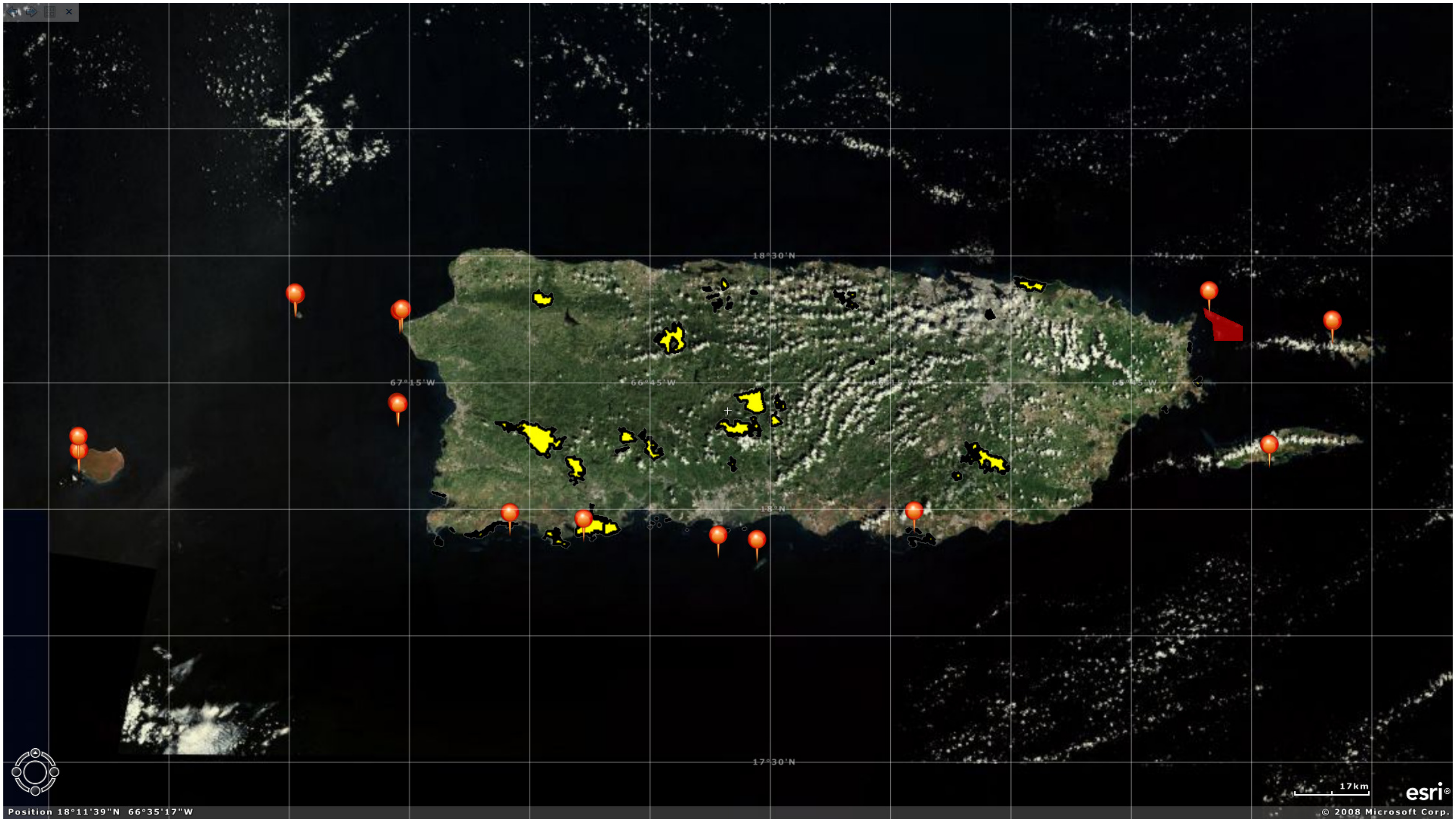

Figure 59 State Forests

Figure 60 Treatment Plants

Figure 61 Filtration Plants

Figure 62 Surface Water Bodies

Figure 63 Critical Elements 2008

Figure 64 Auxiliary Forests

Figure 65 Swimming Areas

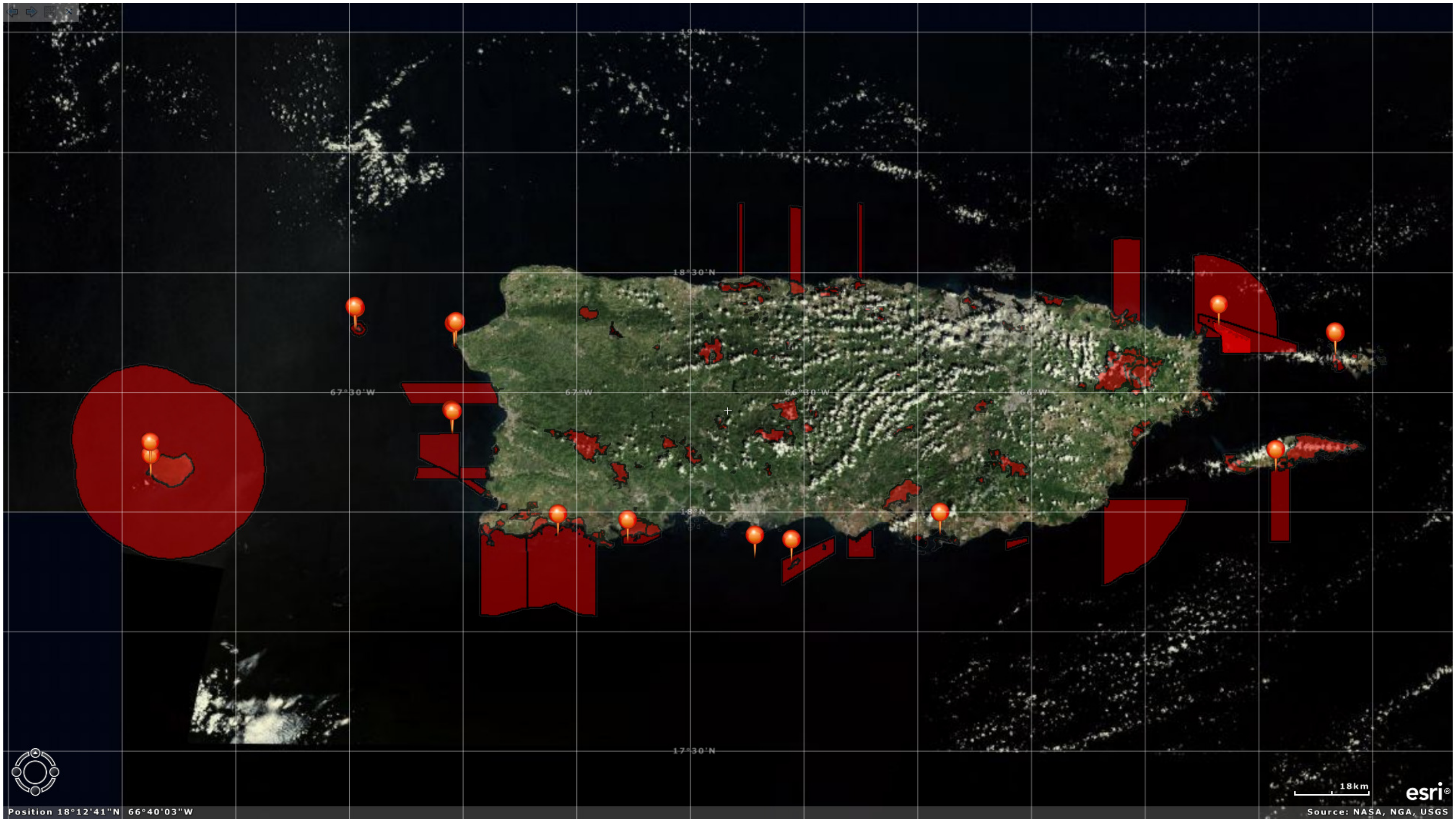

Figure 66 Priority Area of Conservation 2010

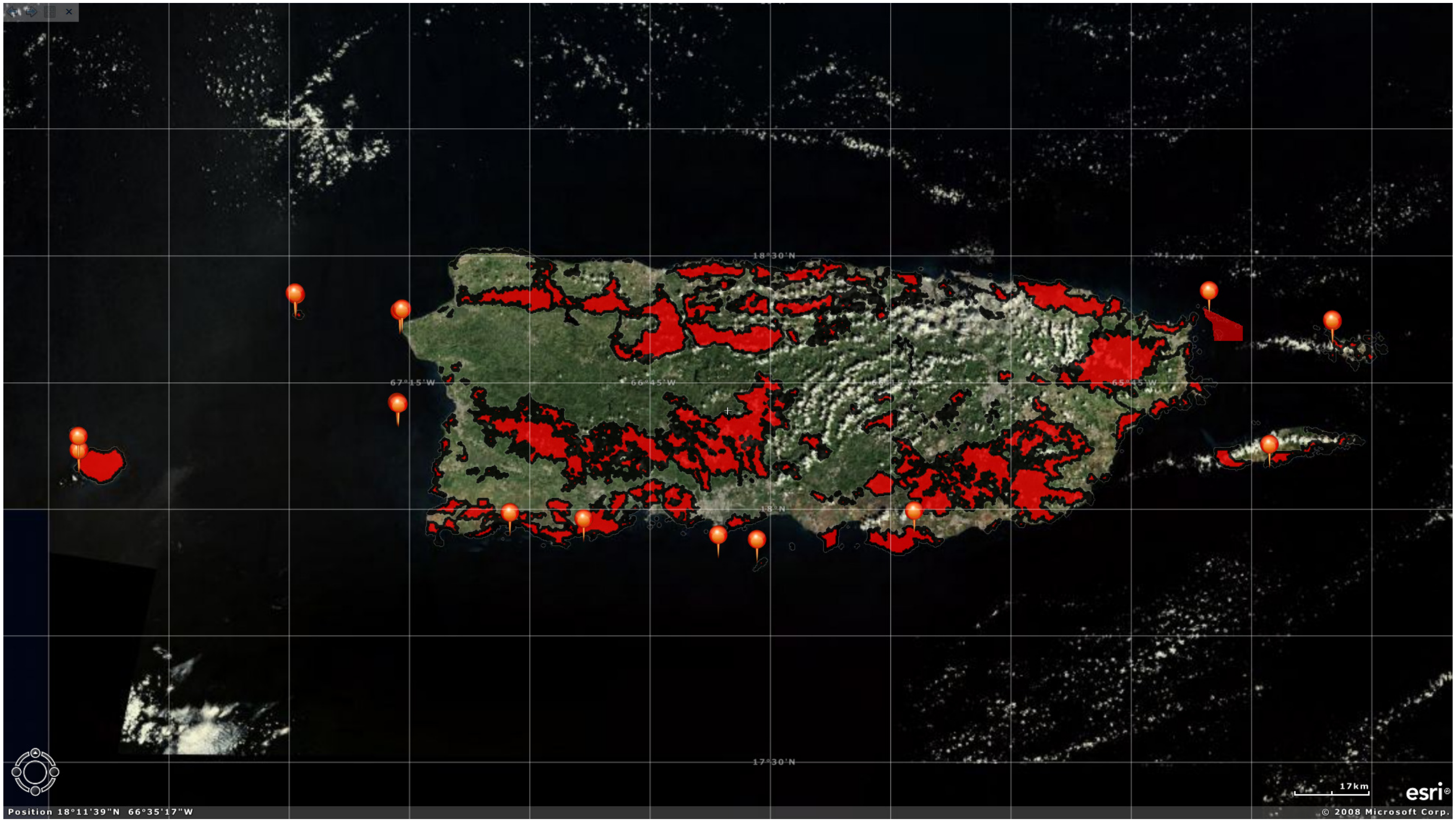

Figure 67 Priority Area of Conservation 2008

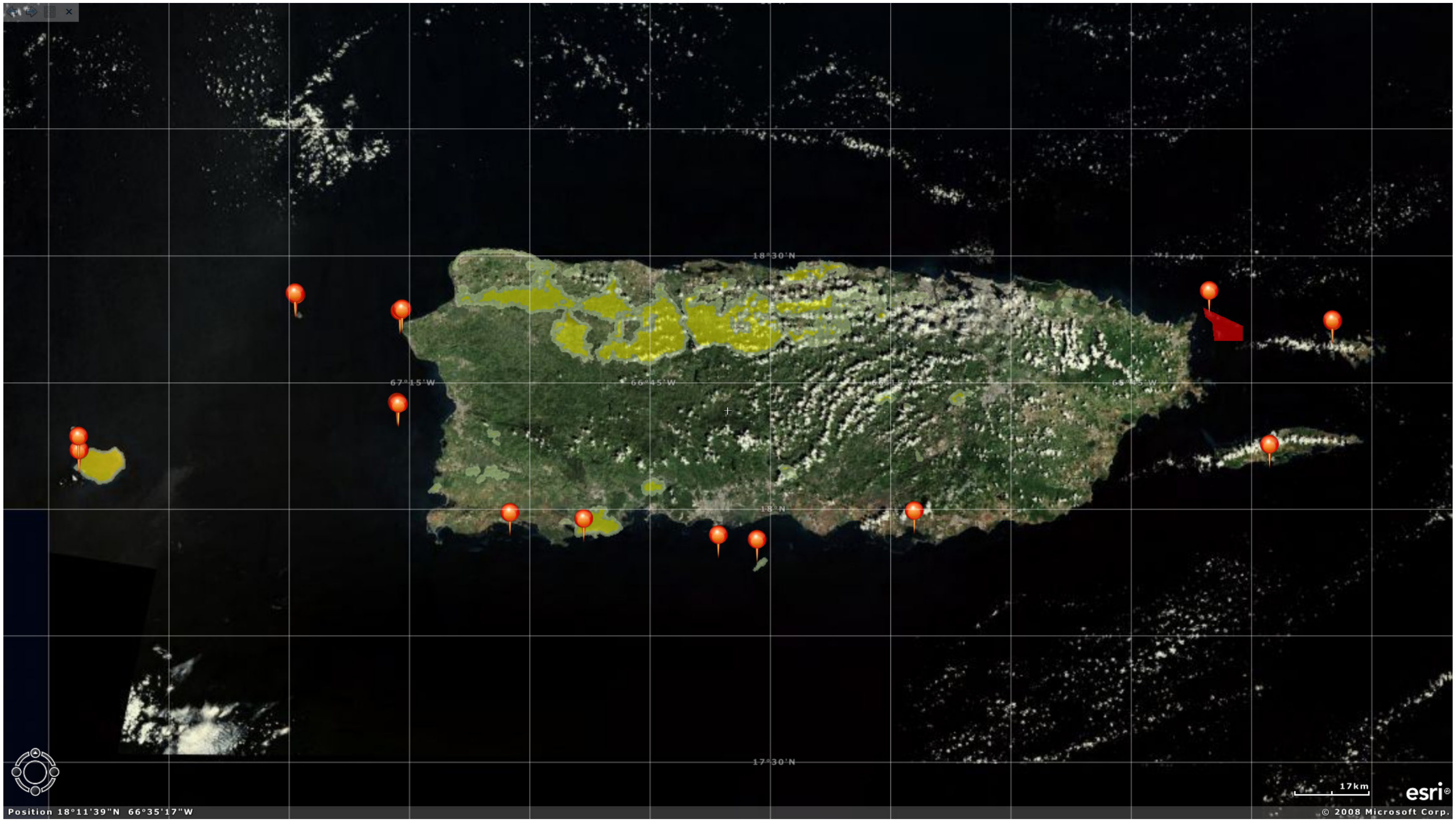

Figure 68 Priority Area of Conservation Karso

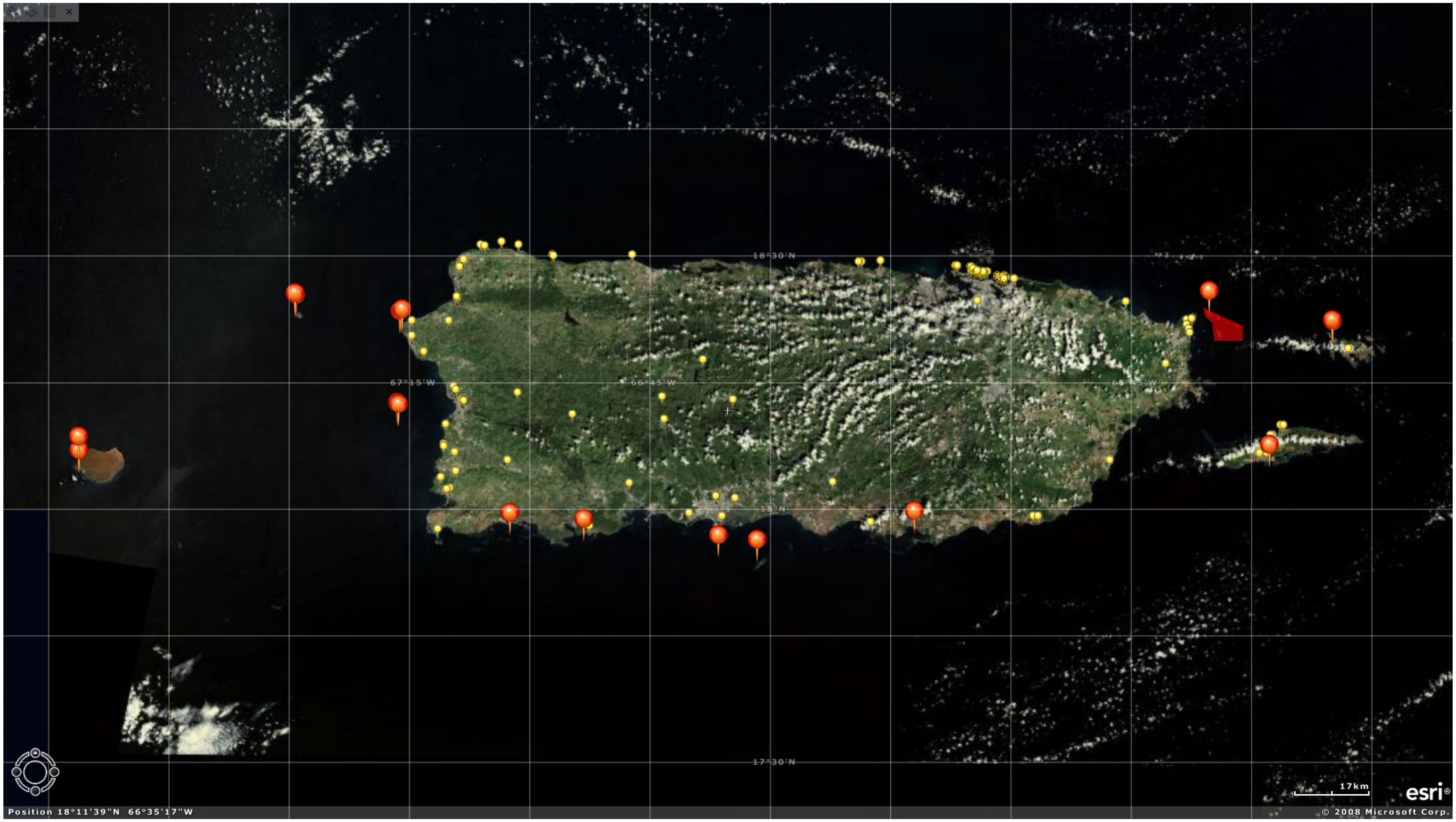

Figure 69 Hotels layer 2

Figure 70 Restaurants

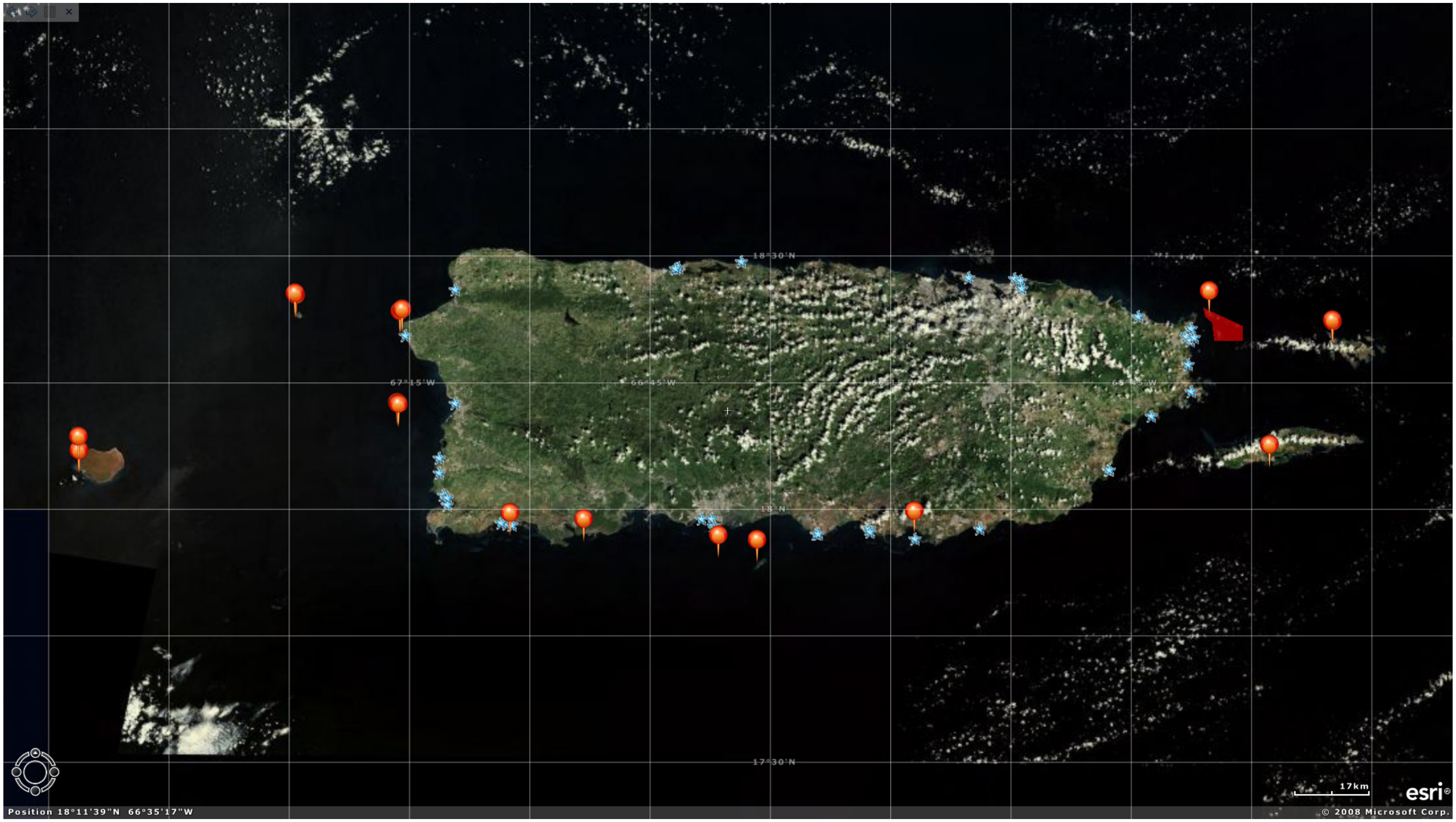

Figure 71 Marinas

Figure 72 2005 Maritime Buoys

Figure 73 Carso

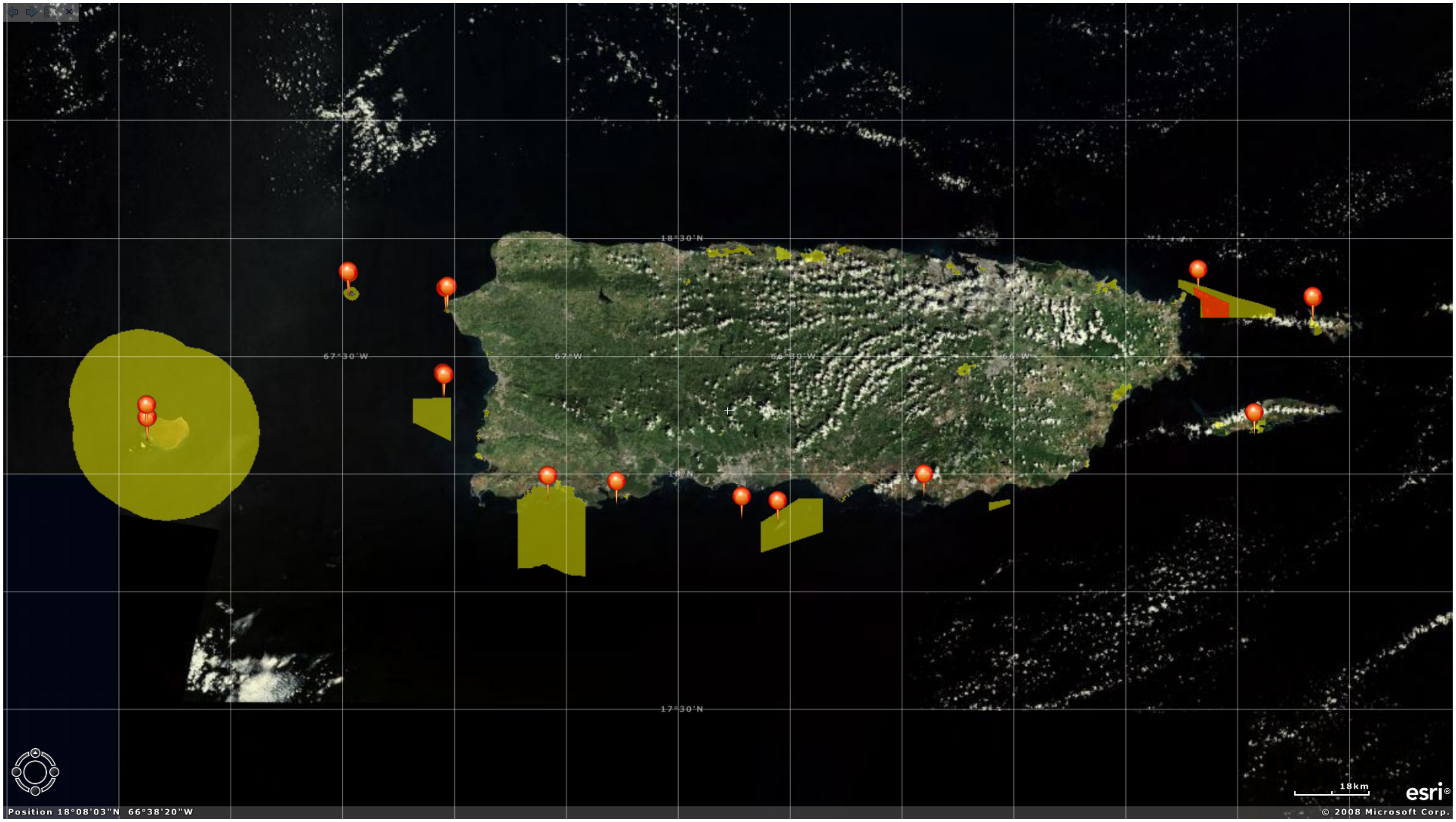

Figure 74 Natural Reserves

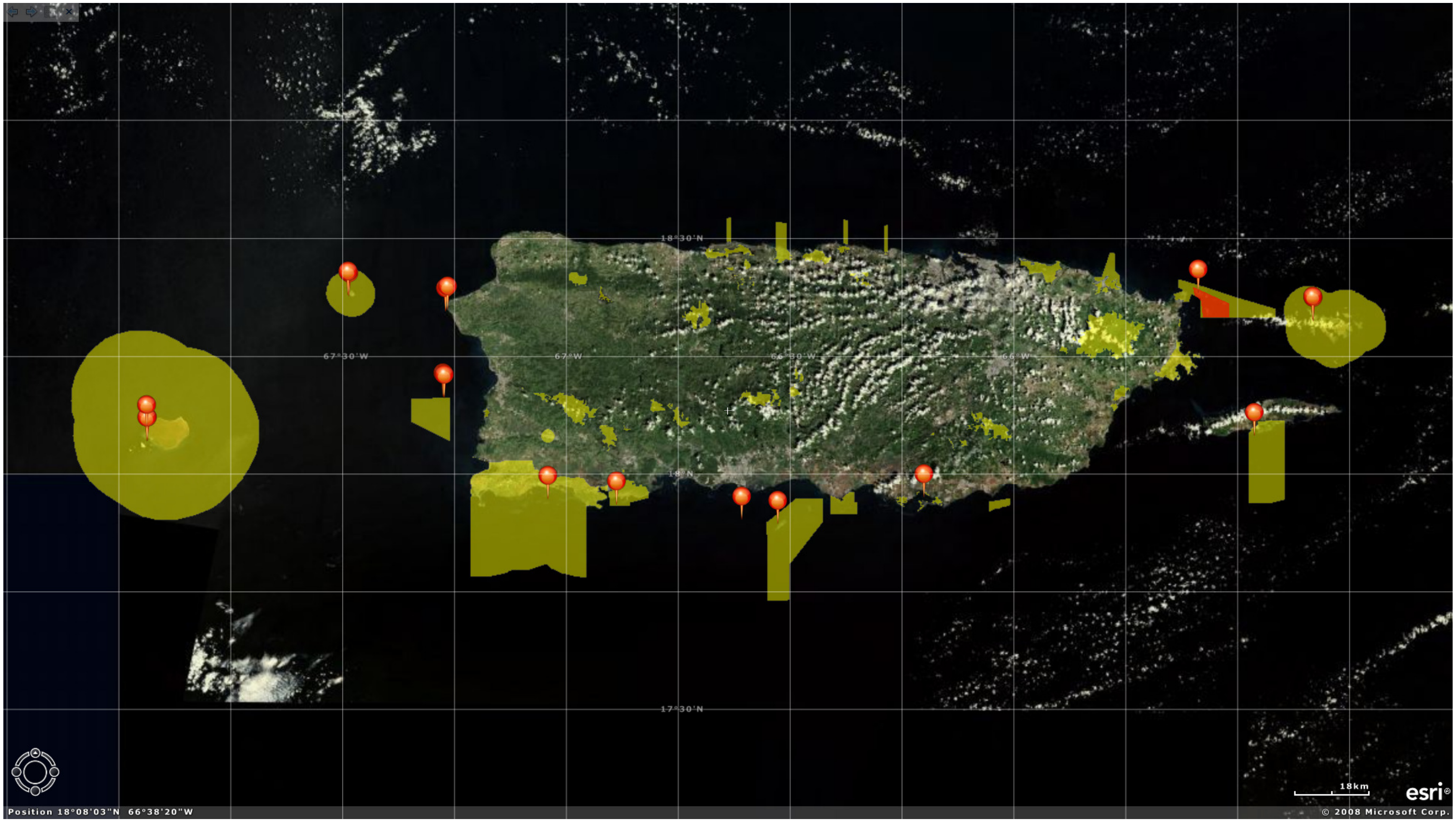

Figure 75 Management Area

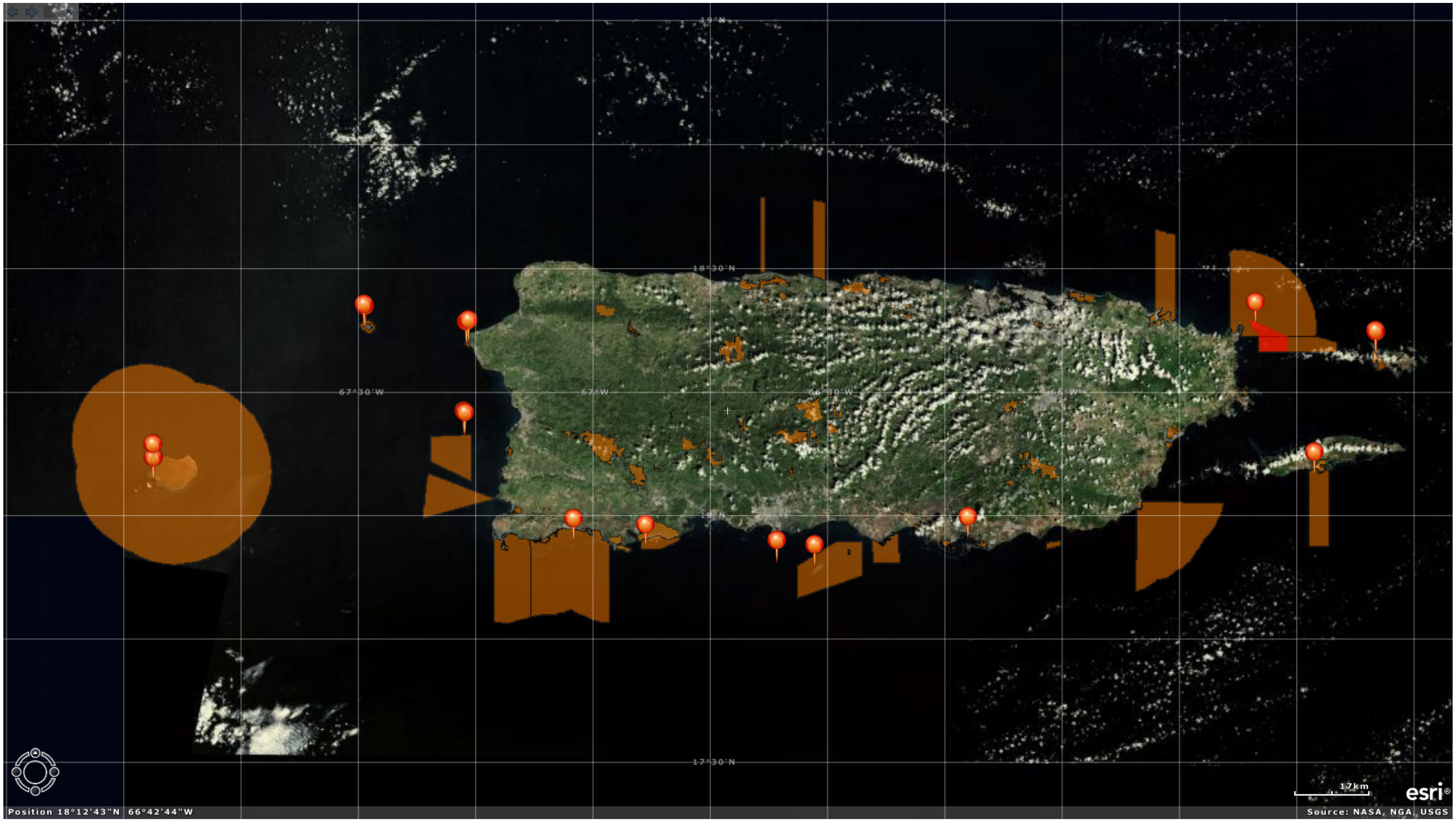

Figure 76 Protected Natural Areas

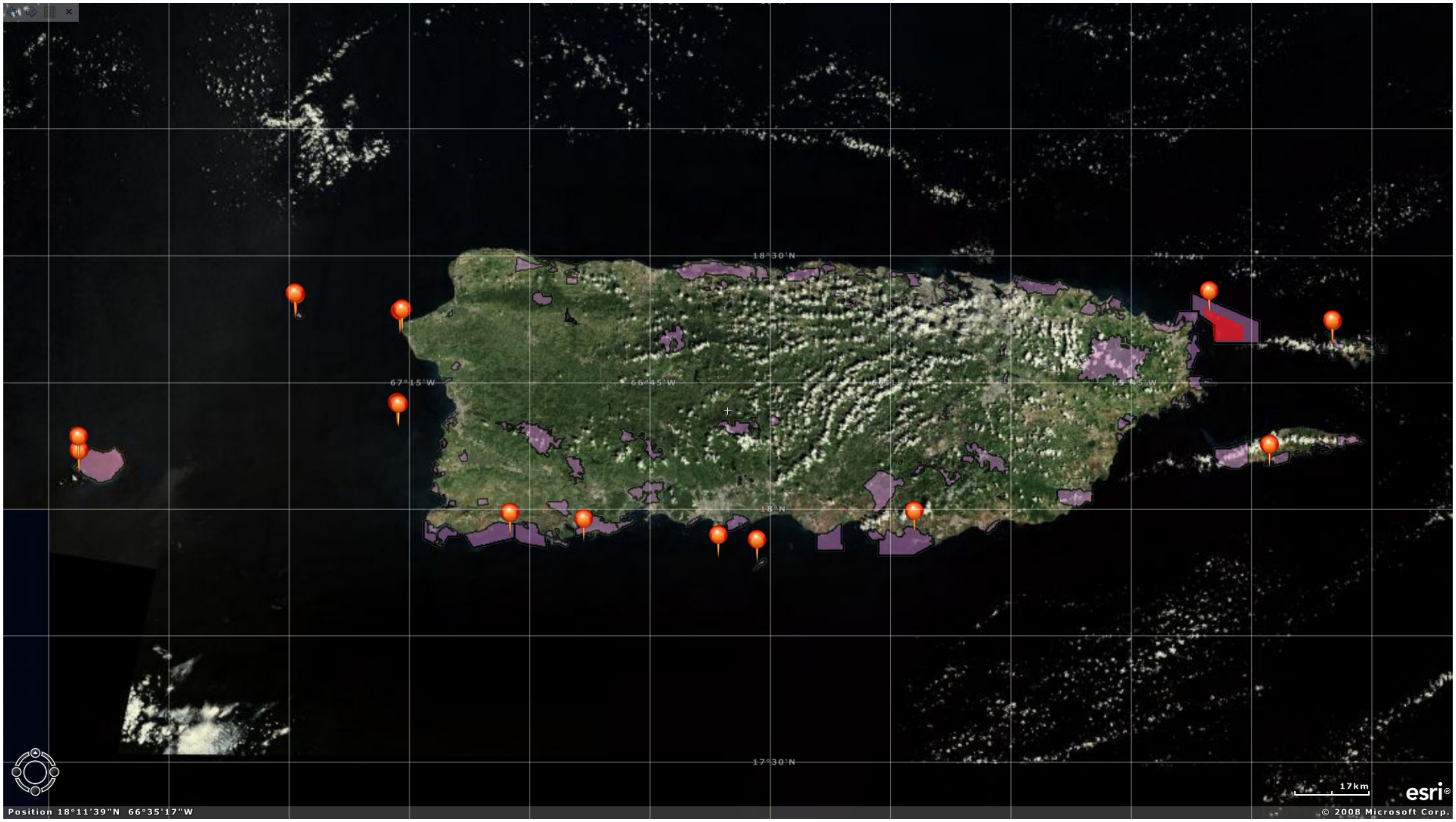

Figure 77 Critical Wildlife

Appendix F: DRNA 2011 Report Data

Locations

Table 3: Monitoring Site Coordinates (García-Sais, 2011, p. 4)

Site	Depth (m)	Latitude (°N)	Longitude (°W)
Isla Desecheo			
Canoas	30	18°22.706	67°29.199
Botes	20	18°22.8949	67°29.3160
Botes	15	18°22.920	67°29.300
Isla de Mona			
Playa Mujeres (T 1-3)	18.9	18°04.302	67°56.215
Playa Mujeres (T 4-5)	16.6	18°04.309	67°56.271
Las Carmelitas	8.5	18°05.923	67°56.300
Playa Sardinera	30.0		
Mayaguez			
Tourmaline	30	18°09.985	67°16.581
Tourmaline	20	18°09.910	67°16.512
Tourmaline	10	18°09.7919	67°16.4160
Rincon			
Tres Palmas	20	18°20.790	67°16.248
Tres Palmas	10	18°20.832	67°16.206
Tres Palmas	3	18°21.023	67°15.959
Ponce			
Derrumbadero	20	17°54.2400	66°36.5159
Guanica			
Coral	10	17°56.1720	66°53.3040
Caja de Muertos			
West Reef	10	17°53.7000	66°31.7040

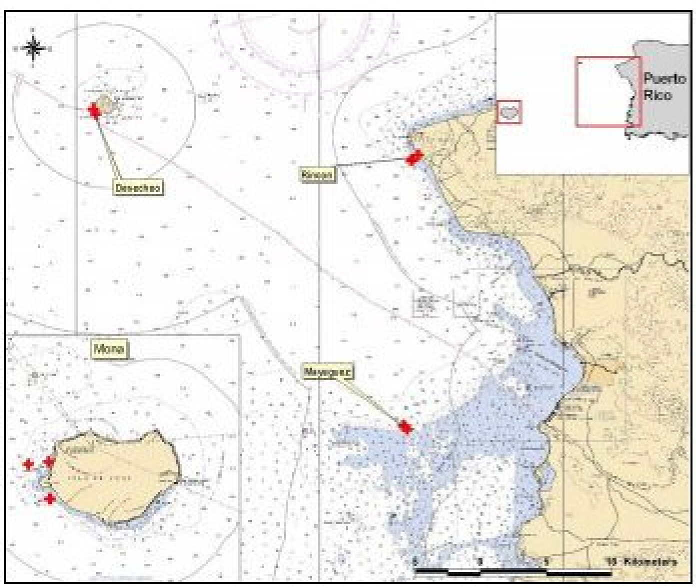

Figure 78: Location of reef sites at Isla Desecheo, Isla de Mona, Mayaguez and Rincon (García-Sais, 2008, p.7)

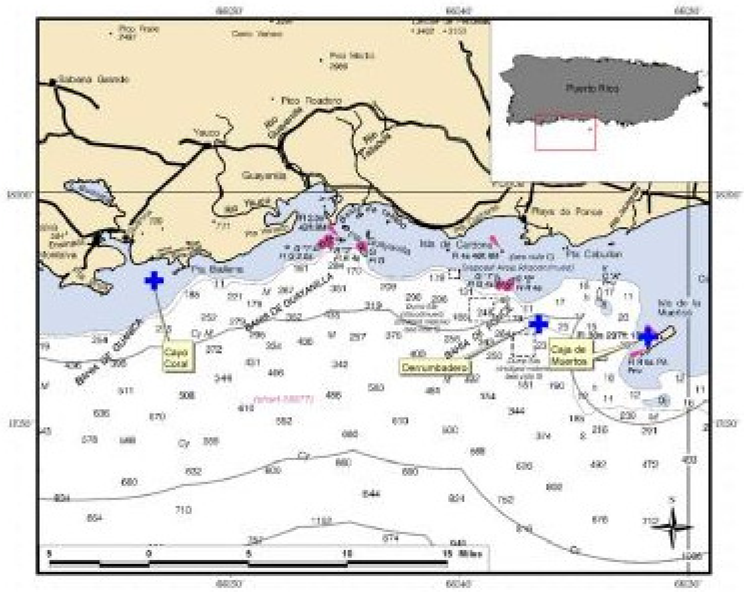

Figure 79: Location of south coast reef sites, Cayo Coral (Guanica), Derrumbadero and West Reef of Isla Caja de Muerto (Ponce) (García-Sais, 2008, p. 7)

Tres Palmas Reef System – Rincon

Location

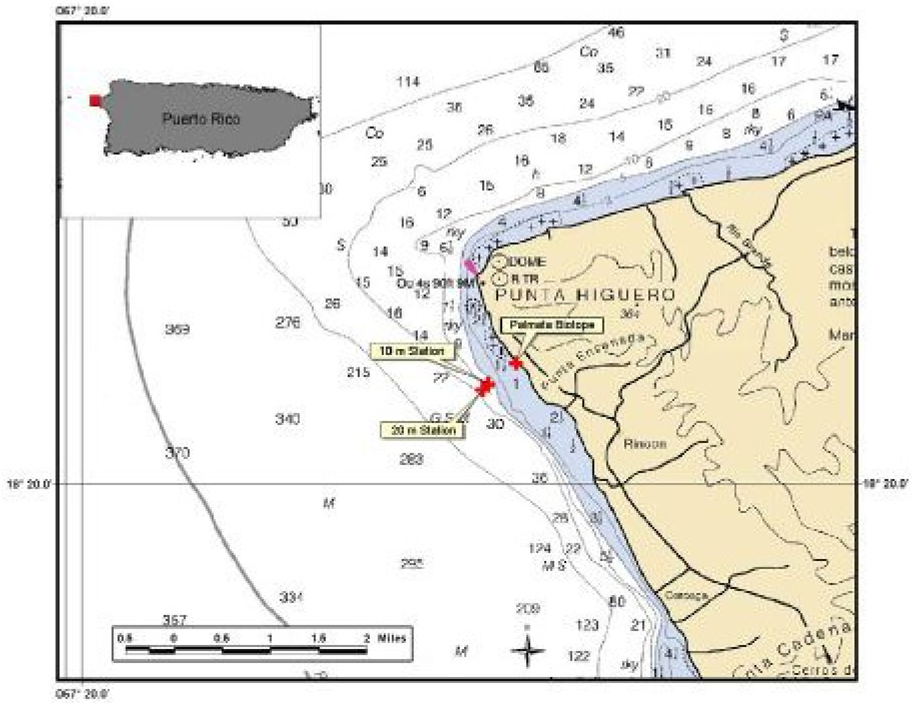

Figure 80: Location of coral reef survey stations off Tres Palmas, Rincon (García-Sais, 2008, p. 9)

Tres Palmas 2-5 m

Table 4: Coral Data Tres Palmas 2-5m (García-Sais, 2011, p. 9)

	Transects					
	1	2	3	4	5	**MEAN**
Rugosity (m)	2.6	5.0	1.7	2.2	2.4	**2.8**
SUBSTRATE CATEGORY						
Abiotic						
Reef Overhangs	22.9	16.4	22.8	22.0	5.7	**18.0**
Sand				4.1	2.3	**1.3**
Gaps				1.7		**0.3**
Total Abiotic	22.9	16.4	22.8	27.8	7.9	**19.6**
Benthic Algae						
Turf-mixed assemblage	48.5	26.1	43.1	46.7	77.3	**48.3**
Total Benthic Algae	48.5	26.1	43.1	46.7	77.3	**48.3**
Gorgonians		0.9				
Total gorgonians	0.0	0.9	0.0	0.0	0.0	**0.2**
Zoanthids						
Palythoa caribaeorum	15.9					**3.2**
Live Stony Corals						
Acropora palmata	10.6	55.6	24.6	24.4	2.7	**23.6**
Diploria strigosa	2.1	1.0	2.7		7.4	**2.6**
Montastraea cavernosa					3.4	**0.7**
Montastraea annularis			3.4			**0.7**
Porites astreoides			0.6	1.2	1.3	**0.6**
Diploria clivosa			2.7			**0.5**
Total Stony Corals	12.8	56.6	34.0	25.6	14.8	**28.7**

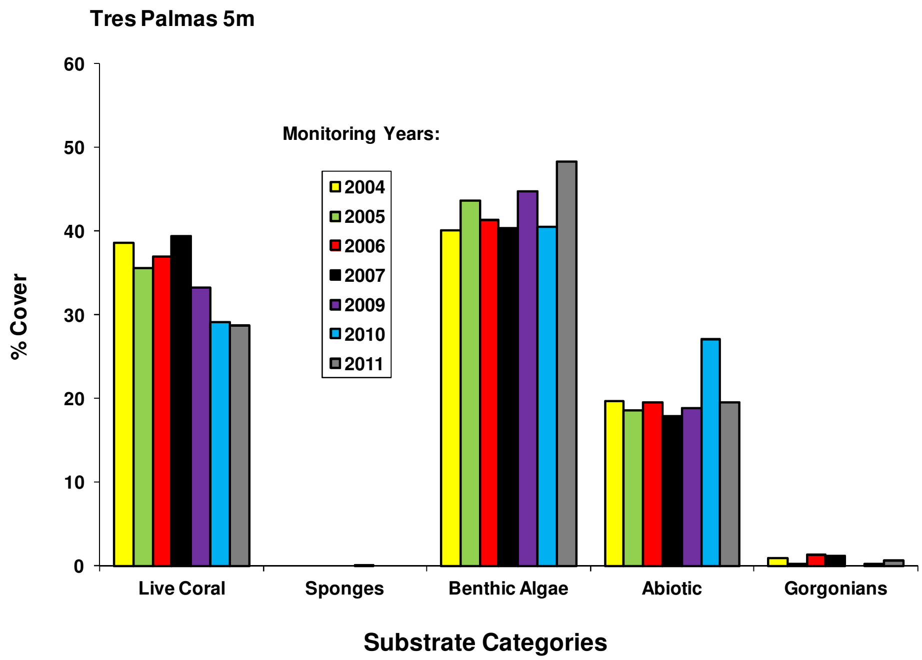

Figure 81: Monitoring trends (2004 – 2011) of mean substrate cover by sessile-benthic categories at Tres Palmas Reef, Rincon, 2 - 5 m depth. (García-Sais, 2011, p. 11)

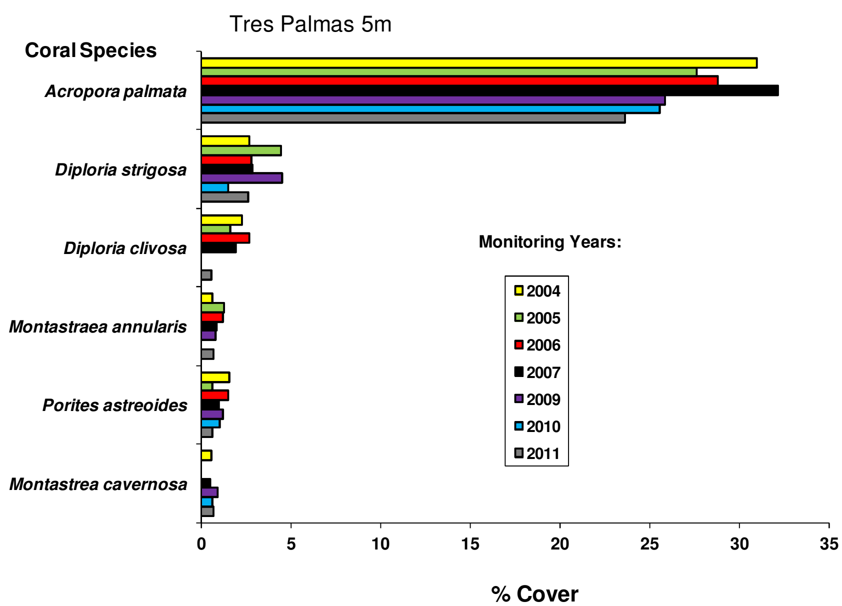

Figure 82: Monitoring trends (2004 – 2011) of mean substrate cover by stony coral species at Tres Palmas Reef, Rincon, 2 - 5 m depth. (García-Sais, 2011, p. 11)

Table 5: Taxonomic composition and abundance of fishes within belt-transects at Tres Palmas Reef 5m, Rincon. September 2011. Depth: 2-5 m (García-Sais, 2011, p. 13)

		TRANSECTS					
		1	2	3	4	5	
		(Individuals/30 m2)					
SPECIES	**COMMON NAME**						**MEAN**
Stegastes dorsopunicans	Dusky Damselfish	10	16	18	13	12	**13.8**
Thalassoma bifasciatum	Bluehead Wrasse	10	0	15	0	0	**5**
Ophioblennius atlanticus	Redlip Blenny	8	5	6	2	3	**4.8**
Halichoeres maculipina	Clown Wrasse	10	5	2	2	0	**3.8**
Microspathodon chrysurus	Yellowtail Damselfish	5	6	2	2	3	**3.6**
Acanthurus coeruleus	Blue Tang	3	0	0	5	3	**2.2**
Abudefduf sexatilis	Sargent Major	3	0	1	0	0	**0.8**
Acanthures bahianus	Ocean Surgeon	3	1	0	0	0	**0.8**
Pempheris schomburgki	Glasseye Sweeper	2	0	0	2	0	**0.8**
Sparisoma aurofrenatum	Redband Parrotfish	4	0	0	0	0	**0.8**
Bodianus rufus	Spanish Hogfish	1	0	0	2	0	**0.6**
Caranx ruber	Bar Jack	1	0	0	2	0	**0.6**
Sparisoma rubripinne	Yellowtail Parrotfish	0	0	1	2	0	**0.6**
Amblycirrhitus pinos	Redspotted Hawkfish	3	0	0	0	0	**0.6**
Haemulon flavolineatum	French Grunt	0	0	0	2	0	**0.4**
Halichoeres bivittatus	Slipery Dick	0	1	0	0	1	**0.4**
Halichoeres garnoti	Yellowhead Wrasse	0	0	0	2	0	**0.4**
Mulloidichthys martinicus	Yellow Goatfish	0	0	0	2	0	**0.4**
Sargocentron vexillarium	Dusky Squirrelfish	0	0	0	1	0	**0.2**
Holocentrus rufus	Longspine Squirrelfish	0	1	0	0	0	**0.2**
Kyphosys sectatrix	Bermuda Chub	1	0	0	0	0	**0.2**
Scarus vetula	Queen Parrotfish	0	0	1	0	0	**0.2**
Sparisoma viride	Stoplight Parrotfish	1	0	0	0	0	**0.2**
Stegastes leucostictus	Beaugregory	1	0	0	0	0	**0.2**
Scarus iserti	Stripped Parrotfish	1	0	0	0	0	**0.2**
	TOTAL INDIVIDUALS	67	35	46	39	22	**41.8**
	TOTAL SPECIES	16	7	8	13	5	**9.8**

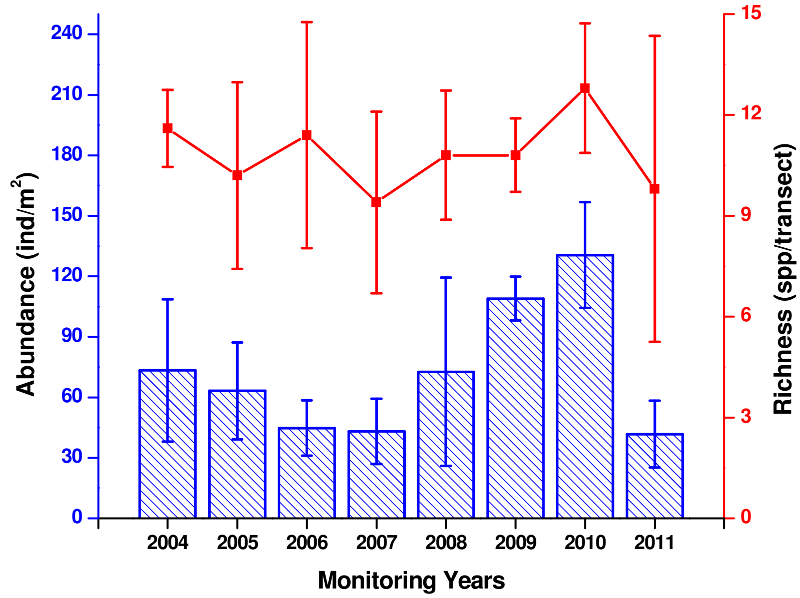

Figure 83: Monitoring trends (2004 – 2011) of fish species richness and abundance at Tres Palmas Reef, Rincon 2-5 m. (García-Sais, 2011, p. 14)

Tres Palmas 10 m

Table 6: Percent substrate cover by sessile-benthic categories at Tres Palmas Reef, Rincon. July 2011. Depth: 10 m (García-Sais, 2011, p. 20)

	TRANSECT					
	1	2	3	4	5	**MEAN**
Rugosity (m)	1.8	2.2	2.2	1.4	1.2	**1.7**
SUBSTRATE CATEGORY						
Abiotic						
Reef Overhangs	4.2	2.2		3.4	0.6	**2.1**
Total Abiotic	4.2	2.2	0.0	3.4	0.6	**2.1**
Benthic Algae						
Turf-mixed assemblage	82.6	71.0	63.3	65.0	63.7	**69.1**
Galaxaura sp.	0.6	0.7		0.6	0.4	**0.5**
Dictyota sp.			1.7			**0.3**
Halimeda sp.	0.5					**0.1**
Total Benthic Algae	83.7	71.7	65.0	65.6	64.1	**70.0**
Gorgonians						
Total gorgonians	24	28	24	18	22	**23.2**
Sponges	3.0	0.6	9.3	2.4	3.7	**3.8**
Xestospongia muta	1.2	2.9				**0.8**
Total sponges	4.2	3.5	9.3	2.4	3.7	**4.6**
Cyanobacteria		1.2	5.4		1.1	**1.5**
Live Stony Corals						
Montastraea cavernosa	2.1	8.2	7.1	6.2	18.2	**8.4**
Porites astreoides		3.7	3.2	2.4	5.3	**2.9**
Colpophyllia natans		0.5		9.3		**2.0**
Agaricia agaricites	0.5	3.0	2.8	1.2		**1.5**
Montastraea annularis	3.8	2.2		0.6		**1.3**
Siderastrea siderea		1.0	1.4	2.0	2.1	**1.3**
Diploria strigosa		1.9	0.7	1.3	1.3	**1.0**
Dendrogyra cylindrus				4.6		**0.9**
Diploria labyrinthiformis			2.5		1.9	**0.9**
Millepora alcicornis		0.4	1.7		0.9	**0.6**
Madracis decactis	0.5	0.6		0.4	0.6	**0.4**
Meandrina meandrites			0.9			**0.2**
Stephanocoenia intersepta	0.7					**0.1**
Siderastrea radians				0.6		**0.1**
Total Stony Corals	7.6	21.4	20.4	28.6	30.4	**21.7**

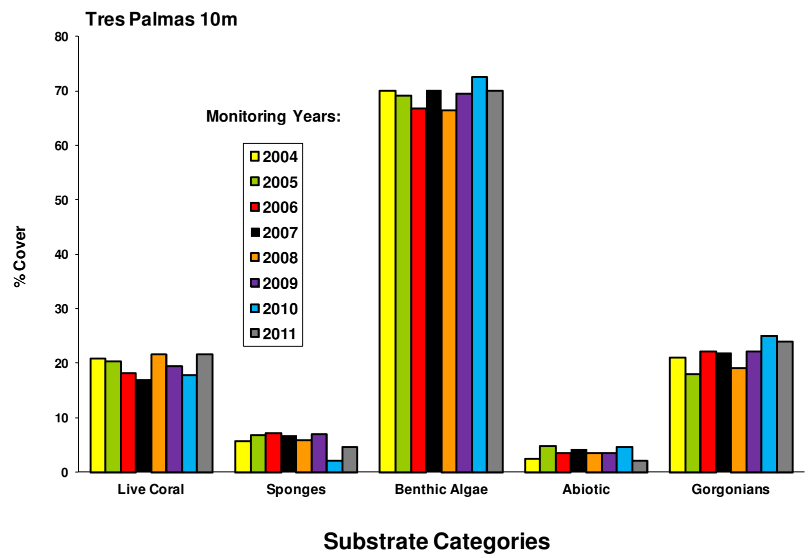

Figure 84: Monitoring trends (2004 – 2011) of mean substrate cover by sessile-benthic categories at Tres Palmas Outer Patch Reef – 10 m (García-Sais, 2011, p. 22)

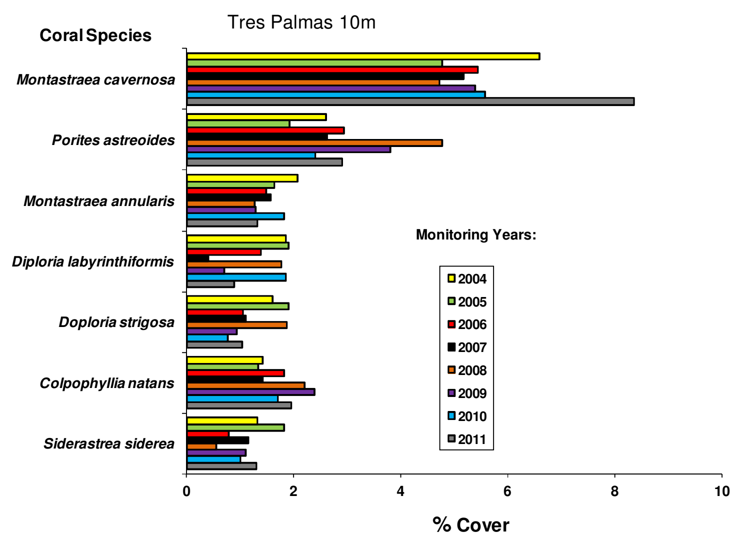

Figure 85: Monitoring trends (2004 – 2011) of mean substrate cover by stony coral species at Tres Palmas Outer Patch Reef – 10 m. (García-Sais, 2011, p. 22)

Table 7: Taxonomic composition and bundance of fishes within belt-transects at Tres Palmas Reef 10m Rincon, july 2011. Depth: 10m (García-Sais, 2011, p. 24)

SPECIES	COMMON NAME	TRANSECTS 1 (individuals/30 m2)	2	3	4	5	MEAN
Thalassoma bifasciatum	Bluehead Wrasse	40	37	30	32	17	**31.2**
Stegastes partitus	Bicolor Damselfish	20	25	22	47	19	**26.6**
Sparisoma viride	Stoplight Parrotfish	8	3	4	1	3	**3.8**
Cephalopholis fulva	Coney	2	4	4	2	4	**3.2**
Gobiosoma evelynae	Sharknose Goby	1	2	4	4	2	**2.6**
Halichoeres garnoti	Yellow-head Wrasse	5	2	4	1	0	**2.4**
Scarus iserti	Striped Parrotfish	2	0	3	1	5	**2.2**
Acanthurus chirurgus	Doctorfish	1	4	1	1	2	**1.8**
Halichoeres maculipinna	Clown Wrasse	2	1	1	3	2	**1.8**
Chaetodon capistratus	Four eye Butterflyfish	2	0	4	1	1	**1.6**
Canthigaster rostrata	Caribbean Puffer	0	4	1	1	1	**1.4**
Serranus tigrinus	Harlequin Bass	0	3	1	2	1	**1.4**
Chromis cyanea	Blue Chromis	0	0	0	4	0	**0.8**
Holocentrus rufus	Squirrelfish	0	1	1	0	1	**0.6**
Acanthurus coeruleus	Blue Tang	0	1	1	0	0	**0.4**
Amblycirrhitus pinos	Redspotted Hawkfish	1	0	0	1	0	**0.4**
Scarus taeniopterus	Princess Parrotfish	0	1	0	0	1	**0.4**
Sparisoma aurofrenatum	Redband Parrotfish	1	0	1	0	0	**0.4**
Chaetodon striatus	Banded Butterflyfish	0	0	0	0	1	**0.2**
Coryphopterus glaucofraenum	Bridled Goby	0	0	0	1	0	**0.2**
Coryphopterus lipernes	Peppermint Goby	0	0	0	1	0	**0.2**
Malacoctenus triangulatus	Saddled Blenny	0	0	0	1	0	**0.2**
Platophrys lunatus	Peacock Flounder	0	0	0	0	1	**0.2**

Microspathodon chrysurus	Yellowtail Damselfish	0	0	1	0	0	**0.2**
Ophioblennius atlanticus	Redlip Blenny	0	0	1	0	0	**0.2**
	TOTAL INDIVIDUALS	85	88	84	104	61	**84.4**
	TOTAL SPECIES	12	13	17	17	15	**14.8**

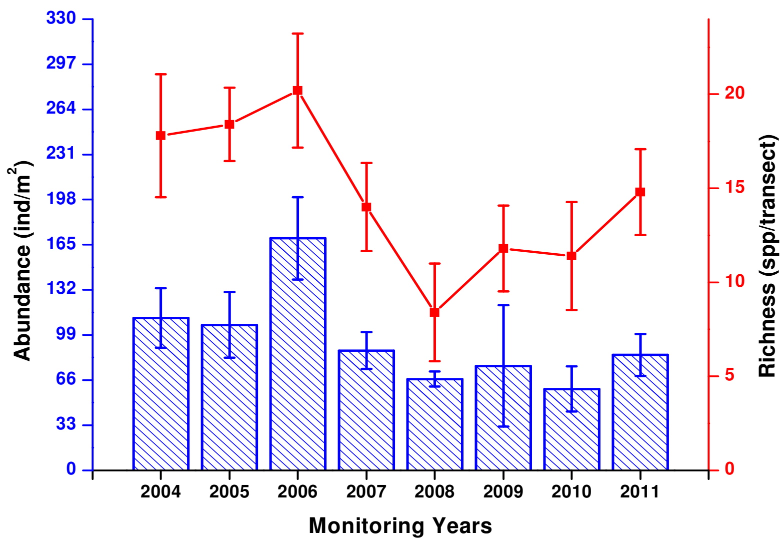

Figure 86: Monitoring trends (2004 – 2011) of fish species richness and abundance at Tres Palmas Outer Shelf Patch Reef, 10 m, Rincon. (García-Sais, 2011, p. 25)

Tres Palmas 20 m

Table 8: Percent substrate cover by sessile-benthic categories at Tres Palmas Reef, Rincon. July 2011. Depth: 20 m (García-Sais, 2011, p. 31)

	TRANSECT					
	1	2	3	4	5	**MEAN**
Rugosity (m)	2.55	3.31	3.58	2.30	2.35	**2.8**
SUBSTRATE CATEGORY						
Abiotic						
Reef Overhangs			16.71	11.23	6.07	**6.8**
Total Abiotic	0.00	0.00	16.71	11.23	6.07	**6.8**
Benthic Algae						
Turf-mixed assemblage	65.47	61.16	42.32	53.62	56.92	**55.9**
Lobophora variegata	1.12	2.78	5.01	3.58	3.97	**3.3**
Dictyota sp.		1.73		2.60	2.51	**1.4**
Amphiroa sp.		1.73		1.95	0.34	**0.8**
Total Benthic Algae	66.59	67.40	47.33	61.75	63.74	**61.4**
Erect Gorgonians	14	12	18	11	7	**12.4**
Encrusting Gorgonians						
Erythropodium caribaeorum	1.57		1.99	1.72		**1.1**
Sponges	16.59	2.40	3.58	3.91	5.10	**6.3**
Xestospongia muta			6.16			**1.2**
Total sponges	16.59	2.40	9.74	3.91	5.10	**7.6**
Cyanobacteria		2.40	3.50		0.91	**1.4**
Live Stony Corals						
Montastraea annularis	1.99	8.64	20.53	7.49	11.17	**10.0**
Agaricia agaricites	5.82	2.33		2.03	1.82	**2.4**
Porites astreoides		4.30		4.48	2.43	**2.2**
Meandrina meandrites	1.12	1.80	4.38	1.83	0.46	**1.9**
Montastraea cavernosa	1.57	2.03	2.24	1.38		**1.4**
Siderastrea siderea	1.80	4.43			0.68	**1.4**
Colpophyllia natans		4.06			1.71	**1.2**
Diploria strigosa	1.12				3.64	**1.0**
Leptoseris cucullata			0.58	0.34	1.71	**0.5**
Agaricia grahamae				1.95		**0.4**
Madracis decactis				1.38	0.57	**0.4**
Porites colonensis			0.67	0.57		**0.2**
Madracis sp.	0.79					**0.2**
Millepora alcicornis	0.34	0.21				**0.1**
Agaricia lamarcki			0.34			**0.1**
Total Stony Corals	14.55	27.80	28.74	21.45	24.19	**23.4**

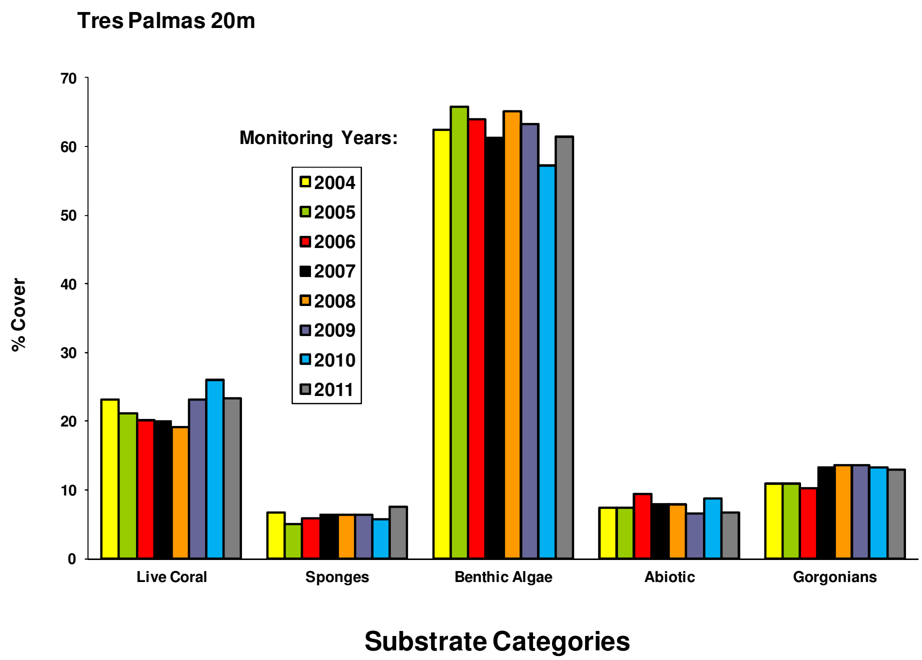

Figure 87: Monitoring trends (2004 – 2011) of mean substrate cover by sessile-benthic categories at Tres Palmas Reef – 20 m. (García-Sais, 2011, p. 33)

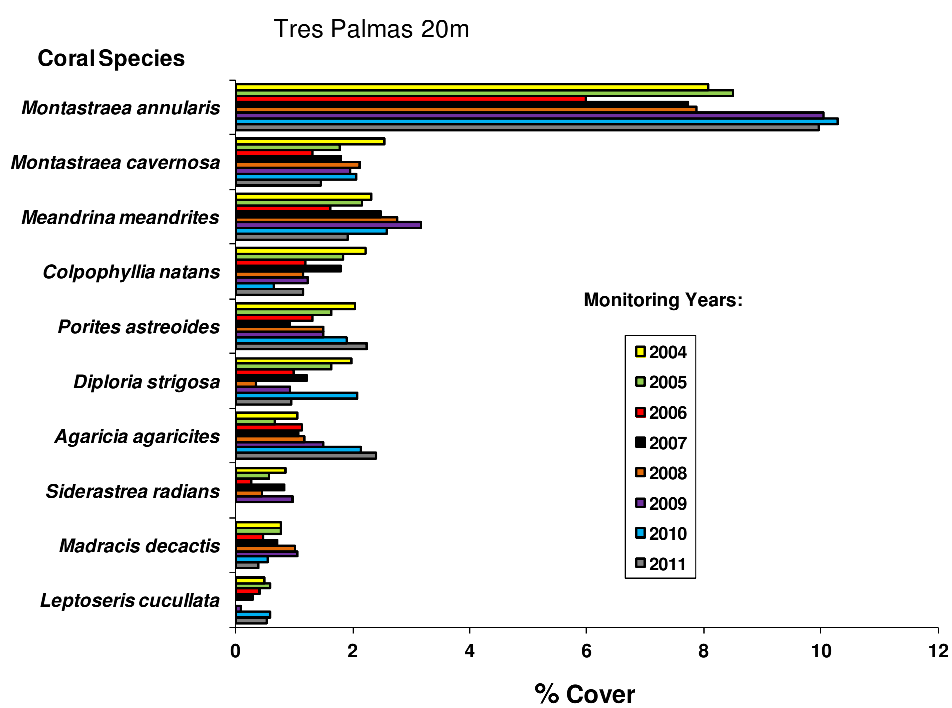

Figure 88: Monitoring trends (2004 – 2011) of mean substrate cover by stony coral species at Tres Palmas Reef – 20 m. (García-Sais, 2011, p. 33)

Table 9: Taxonomic composition and abundance of fishes within belt-transects at the shelf-edge reef off Tres Palmas, Rincón. July, 2011. Depth: 20m (García-Sais, 2011, p. 35)

		TRANSECTS					
		1	2	3	4	5	
		(Individuals/30 m2)					
SPECIES	**COMMON NAME**						**MEAN**
Coryphopterus personatus	Masked Goby	30	24	64	40	8	**33.2**
Clepticus parrae	Creole wrasse	0	65	30	0	20	**23.0**
Coryphopterus lipernes	Peppermint goby	13	25	25	25	21	**21.8**
Thalassoma bifasciatum	Bluehead Wrasse	6	40	12	29	13	**20.0**
Chromis cyanea	Blue Chromis	1	22	20	0	50	**18.6**
Stegastes partitus	Bicolor Damselfish	13	28	15	9	24	**17.8**
Chromis multilineata	Brown chromis	0	5	14	0	10	**5.8**
Halichoeres garnoti	Yellow-head Wrasse	9	3	6	2	4	**4.8**
Sparisoma viride	Stoplight Parrotfish	3	0	3	2	11	**3.8**
Gobiosoma evelynae	Sharknose Goby	1	2	4	3	4	**2.8**
Stegastes leucostictus	Beau Gregory	5	4	2	2	1	**2.8**
Cephalopholis cruentatus	Graysby	4	1	4	1	2	**2.4**
Myripristis jacobus	Blackbar Soldierfish	0	0	7	3	2	**2.4**
Canthigaster rostrata	Caribbean Puffer	1	3	3	2	1	**2.0**
Scarus taeniopterus	Princess Parrotfish	1	0	4	0	4	**1.8**
Acanthurus chirurgus	Doctorfish	0	4	1	1	2	**1.6**
Haemulon flavolineatum	French grunt	0	3	1	1	1	**1.2**
Haemulon melanorum	Cottonwick	0	5	0	0	0	**1.0**
Melichthys niger	Black Durgon	0	0	4	1	0	**1.0**
Neoniphon marianus	Longspine squirrelfish	0	2	2	0	0	**0.8**
Sparisoma aurofrenatum	Redband Parrotfish	0	0	1	2	1	**0.8**
Cephalopholis fulva	Coney	1	0	0	2	0	**0.6**
Chaetodon capistratus	Four-eye Butterflyfish	0	0	0	2	1	**0.6**
Amblycirrhitus pinos	Redspotted Hawkfish	0	0	0	1	1	**0.4**
Caranx crysos	Blue runner	0	0	0	0	2	**0.4**
Chaetodon sedentarius	Reef Butterflyfish	0	0	2	0	0	**0.4**
Holacanthus tricolor	Rock beauty	0	1	0	1	0	**0.4**
Serranus tigrinus	Harlequin Bass	1	0	0	0	1	**0.4**
Pseudupeneus maculatus	Spotted Goatfish	1	0	1	0	0	**0.4**
Coryphopterus glaucofraenum	Bridled Goby	0	0	0	1	1	**0.4**
Acanthurus coeruleus	Blue Tang	0	0	0	0	1	**0.2**
Acanthurus bahianus	Ocean Surgeon	0	0	1	0	0	**0.2**
Bodianus rufus	Spanish Hogfish	0	1	0	0	0	**0.2**

Epinephelus guttatus	Red hind	0	0	1	0	0	**0.2**
Chaetodon striatus	Banded Butterflyfish	0	0	1	0	0	**0.2**
Gymnothorax moringa	Golden moray	0	1	0	0	0	**0.2**
Holocentrus rufus	Squirrelfish	1	0	0	0	0	**0.2**
Hypoplectrus chlorurus	Yellowtail hamlet	0	0	1	0	0	**0.2**
Hypoplectrus nigricans	Black Hamlet	0	0	0	0	1	**0.2**
Hypoplectrus unicolor	Butter hamlet	0	1	0	0	0	**0.2**
Pomacanthus arcuatus	Gray Angelfish	0	1	0	0	0	**0.2**
Pomacanthus paru	French Angelfish	0	0	0	1	0	**0.2**
	TOTAL INDIVIDUALS	91	241	229	131	187	**175.8**
	TOTAL SPECIES	16	21	26	21	25	**21.8**

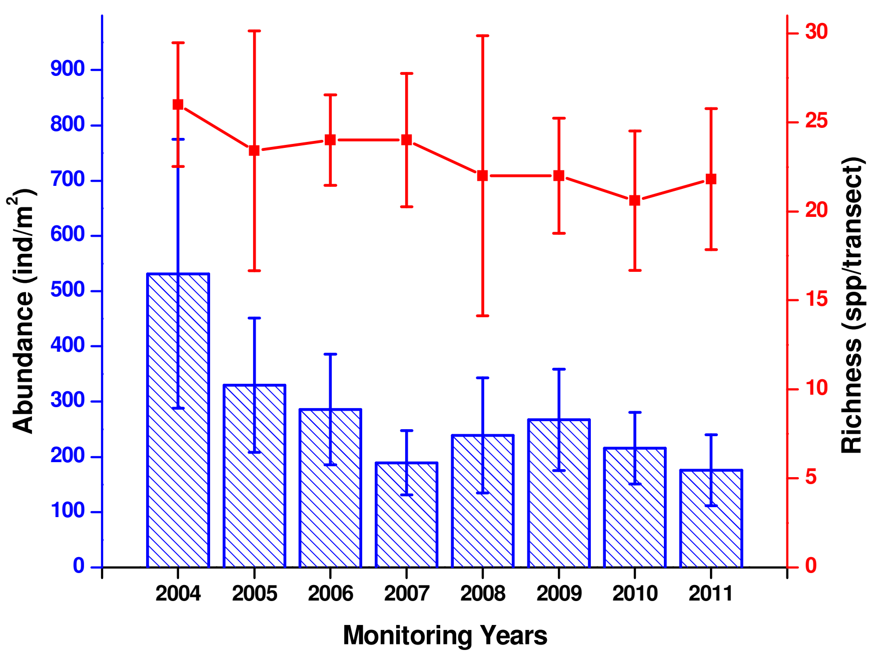

Figure 89: Monitoring trends (2004 – 2011) of fish species richness and abundance at Tres Palmas Shelf Edge Reef, Rincon, 20 m (García-Sais, 2011, p. 36)

Puerto Canoas – Isla Desecheo

Desecheo 30 m

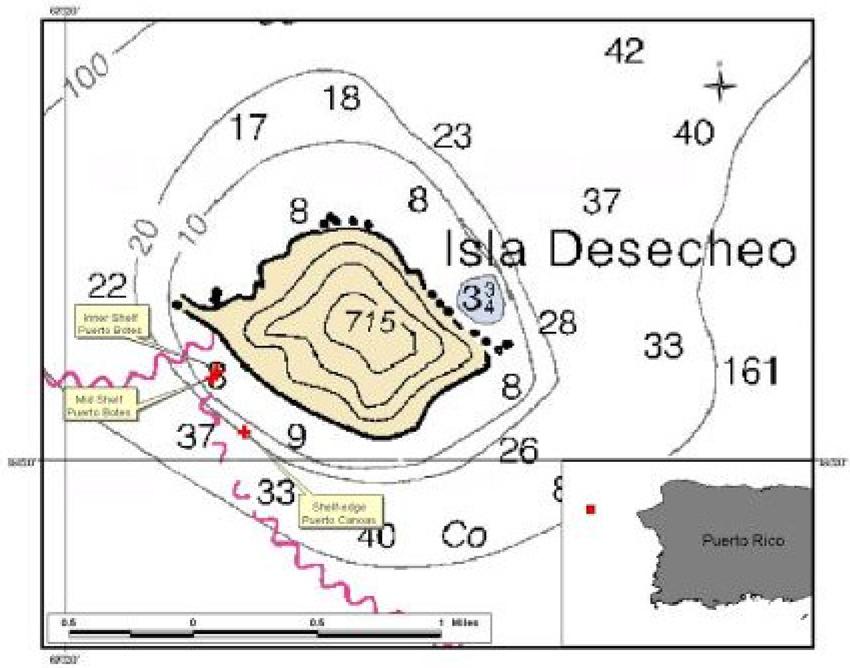

Figure 90: Location of coral reef survey stations at Puerto Canoas/Botes, Isla Desecheo (García-Sais, 2011, p. 43)

Table 10: Percent substrate cover by sessile-benthic categories at the shelf-edge Reef Puerto Canoas, Isla Desecheo during September 2011. Depth: 30m (García-Sais, 2011, p. 44)

	Transects					
	1	2	3	4	5	**MEAN**
Rugosity (m)	1.65	1.23	5.07	3.55	3.39	**3.0**
SUBSTRATE CATEGORY						
Abiotic						
Reef Overhangs	8.50	4.39	29.00	20.37	3.66	**13.2**
Gaps			0.37			**0.1**
Total Abiotic	8.50	4.39	29.37	20.37	3.66	**13.3**
Benthic Algae						
Lobophora variegata	10.99		16.06	35.65	17.33	**16.0**
Lobophora and Dictyota	24.03	27.09			18.82	**14.0**
Turf-mixed assemblage	15.02	4.55	18.98	8.41	8.96	**11.2**
Coralline algae	2.92	6.86			1.87	**2.3**
Dictyota sp.				2.36		**0.5**
Wrangelia bicuspidata			0.93			**0.2**
Total Benthic Algae	52.96	38.50	35.97	46.42	46.98	**44.2**
Sponges	5.58	14.53	13.01	9.37	9.71	**10.4**
Cyanobacteria	8.84	7.40	3.05	3.32	14.34	**7.4**
Live Stony Corals						
Montastraea annularis	7.12	18.98	11.28	11.22	17.25	**13.2**
Agaricia agaricites	5.06	4.01	1.66	4.06	4.31	**3.8**
Porites astreoides	2.15	5.88	2.06	1.35	3.81	**3.1**
Colpophyllia natans	7.90	5.53				**2.7**
Agaricia tenuifolia			2.92			**0.6**
Meandrina meandrites				2.29		**0.5**
Porites porites	1.93					**0.4**
Agaricia grahamae			0.65	1.03		**0.3**
Eusmilia fastigiata		0.71				**0.1**
Madracis decactis				0.52		**0.1**
Total Stony Corals	24.16	35.11	18.57	20.47	25.37	**24.7**

Coral Species Outside Transects: *Agaricia sp., Diploria labyrinthiformis, Isophyllastrea rigida, Montastraea cavernosa, Mycetophyllia lamarki, Stylaster roseus*

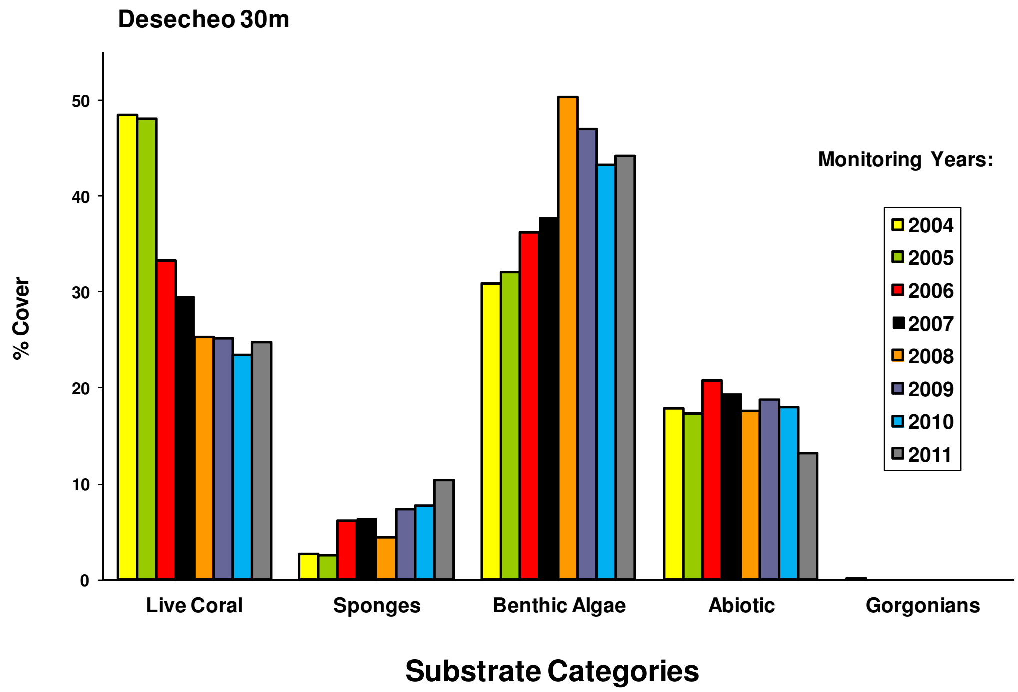

Figure 91: Monitoring trends (2004 – 2011) of substrate cover by sessile-benthic categories at Puerto Canoas Reef, Desecheo Island – 30 m (García-Sais, 2011, p. 46)

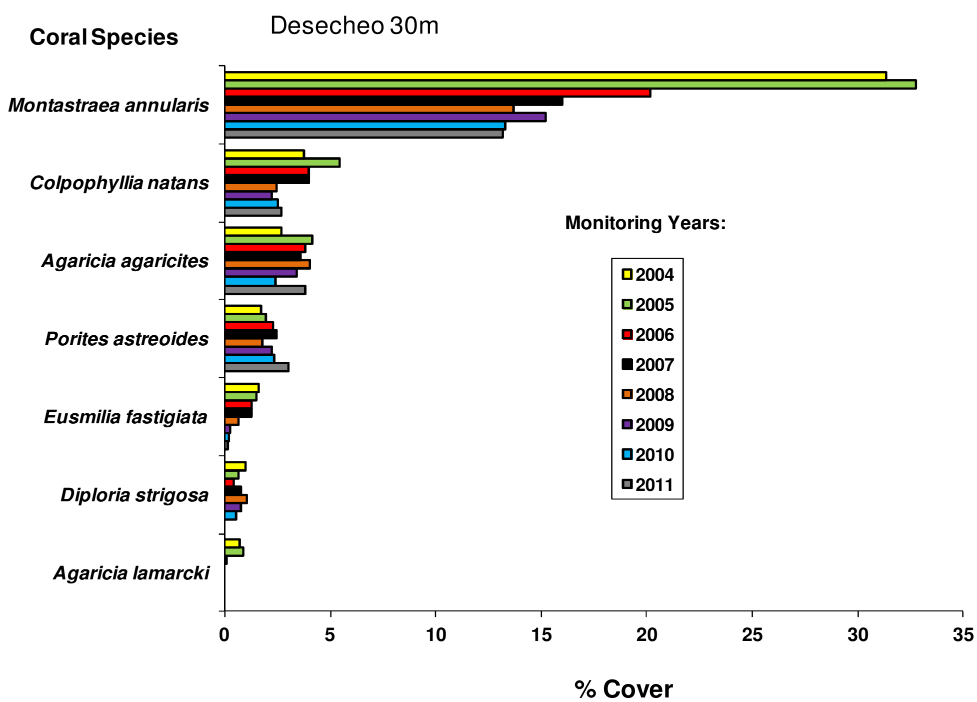

Figure 92: Monitoring trends (2004-2011) of mean substrate cover by stony coral species at Puerto Canoas Reef, Desecheo Island – 30 m (García-Sais, 2011, p. 46)

Table 11: Taxonomic composition and abundance of fishes within belt-transects at Puerto Canoas Reef 30 m, Isla Desecheo. June, 2011. Depth: 30m (García-Sais, 2011, p. 47)

SPECIES	COMMON NAME	TRANSECTS 1	2	3	4	5	MEAN
		(Individuals/30 m2)					
Clepticus parrae	Creole Wrasse	200	40	65	0	15	**64.0**
Coryphopterus personatus	Masked Goby	30	10	20	20	100	**36.0**
Chromis cyanea	Blue Chromis	10	30	37	20	45	**28.4**
Kyphosus bermudensis	Sea Chub	50	12	62	2	0	**25.2**
Gramma loreto	Fairy Basslet	25	23	30	3	24	**21.0**
Chromis multilineata	Brown Chromis	50	4	14	8	6	**16.4**
Coryphopterus lipernes	Peppermint Goby	20	22	11	5	16	**14.8**
Caranx ruber	Bar Jack	50	0	0	0	0	**10.0**
Halichoeres garnoti	Yellow-head Wrasse	5	5	9	8	2	**5.8**
Mulloidichthys martinicus	Yellow Goatfish	0	0	0	0	28	**5.6**
Stegastes partitus	Bicolor Damselfish	4	4	15	0	5	**5.6**
Thalassoma bifasciatum	Bluehead Wrasse	2	6	8	0	11	**5.4**
Scarus iserti	Stripped Parrotfish	5	2	7	5	2	**4.2**
Caranx latus	Horse-eye Jack	15	0	0	0	0	**3.0**
Gobiosoma evelynae	Sharknose Goby	5	2	2	0	6	**3.0**
Halichoeres maculipinna	Clown Wrasse	5	5	5	0	0	**3.0**
Sparisoma aurofrenatum	Redband Parrotfish	6	1	4	1	1	**2.6**
Lutjanus apodus	Schoolmaster Snapper	0	1	0	5	6	**2.4**
Epinephelus cruentatus	Graysby	2	2	4	0	3	**2.2**
Acanthurus coeruleus	Blue Tang	1	1	1	3	0	**1.2**
Melichthys niger	Black Durgon	0	4	0	2	0	**1.2**
Sparisoma viride	Stoplight Parrotfish	3	0	1	1	1	**1.2**
Coryphopterus glaucophraenum	Briddled Goby	1	1	1	1	1	**1.0**
Paranthias fucifer	Creolefish	0	1	0	2	2	**1.0**
Pterois volitans	Lionfish	2	2	1	0	0	**1.0**
Stegastes planifrons	Threespot Damselfish	2	2	0	0	1	**1.0**
Microspathodon chrysurus	Yellowtail Damselfish	0	0	1	1	1	**0.6**
Bodianus rufus	Spanish Hogfish	1	1	0	0	0	**0.4**
Canthigaster rostrata	Caribbean Puffer	0	0	1	0	1	**0.4**
Chaetodon striatus	Banded Butterflyfish	0	0	1	0	1	**0.4**
Chaetodon capistratus	Four-eye Butterflyfish	0	2	0	0	0	**0.4**
Neoniphon marianus	Longspine Squirrelfish	0	1	0	0	1	**0.4**
Sparisoma rubripinne	Yellowtail Parrotfish	0	0	1	0	1	**0.4**
Anisotremus suranimense	Black Margate	0	0	1	0	0	**0.2**
Amblycirrhitus pinos	Redspotted Hawkfish	0	0	0	0	1	**0.2**
Epinephelus striatus	Nassau Grouper	1	0	0	0	0	**0.2**
Epinephelus fulva	Coney	0	0	1	0	0	**0.2**
Holacanthus tricolor	Rock Beauty	0	0	0	1	0	**0.2**
Holocentrus adcencionis	Squirrelfish	0	1	0	0	0	**0.2**
Lactophrys triqueter	Smooth Trunkfish	0	1	0	0	0	**0.2**
	TOTAL INDIVIDUALS	**495**	**186**	**303**	**88**	**281**	**270.6**
	TOTAL SPECIES	**24**	**27**	**25**	**17**	**25**	**23.6**

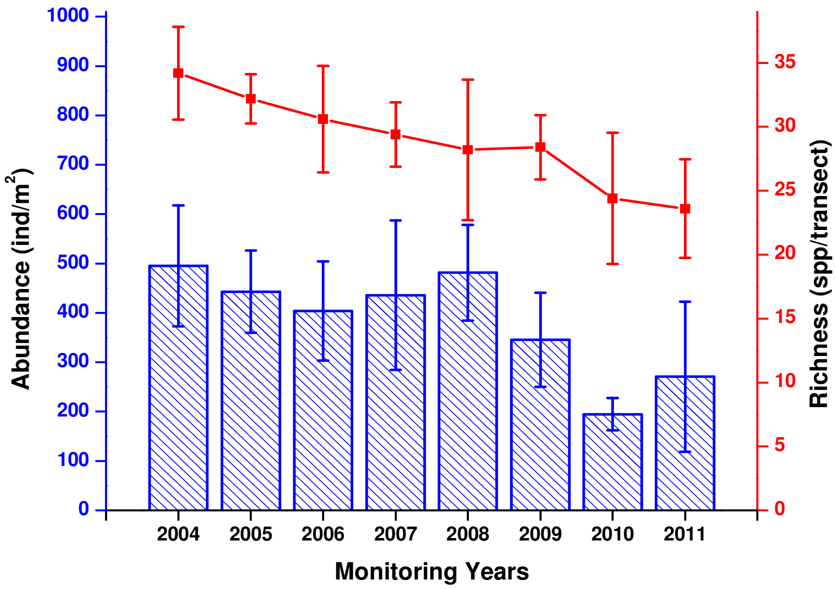

Figure 93: Monitoring trends (2004 – 2011) of fish species richness and abundance at Puerto Canoas Reef, Isla Desecheo, 30m (García-Sais, 2011, p. 49)

Puerto Botes – Isla Desecheo

Desecheo 20 m

Table 12: Percent substrate cover by sessile-benthic categories at Desecheo Reef. (García-Sais, 2011, p.55)

	TRANSECTS					
	1	2	3	4	5	**MEAN**
Rugosity (m)	4.56	2.85	4.23	2.06	4.73	**3.7**
SUBSTRATE CATEGORY						
Abiotic						
Reef Overhangs	14.4	12.7	9.0	4.5		**8.1**
Gaps		5.5	0.8		1.0	**1.4**
Sand				5.8	1.2	**1.4**
Total Abiotic	14.4	18.2	9.8	10.3	2.2	**11.0**
Benthic Algae						
Turf-mixed assemblage	50.8	47.2	47.2	35.4	59.0	**47.9**
Amphiroa sp.				6.4	0.6	**1.4**
Lobophora and Dictyota	21.6	18.9	9.4	7.1	6.5	**12.7**
Lobophora variegata	1.9	4.3	9.7	5.8	8.0	**5.9**
Dictyota sp.	3.7	2.0	5.6			**2.2**
Total Benthic Algae	78.0	72.4	71.9	54.8	74.1	**70.2**
Sponges		3.0	4.9	5.2	1.9	**3.0**
Cyanobacteria	2.5	4.1	2.2	4.7	11.9	**5.1**
Live Stony Corals						
Porites porites			3.2	14.4	0.8	**3.7**
Montastraea annularis	2.7	0.9	1.2	2.9	1.9	**1.9**
Agaricia agaricites	0.7		1.1	2.3	3.3	**1.5**
Porites astreoides		1.6		4.3		**1.2**
Montastraea cavernosa			0.9		3.1	**0.8**
Meandrina meandrites			1.5	1.2	0.9	**0.7**
Agaricia tenuifolia	1.7		1.6			**0.7**
Millepora alcicornis			0.7			**0.1**
Eusmilia fastigiata			0.6			**0.1**
Leptoseris cucullata	0.5					**0.1**
Total Stony Corals	5.6	2.4	10.7	25.1	9.9	**10.7**

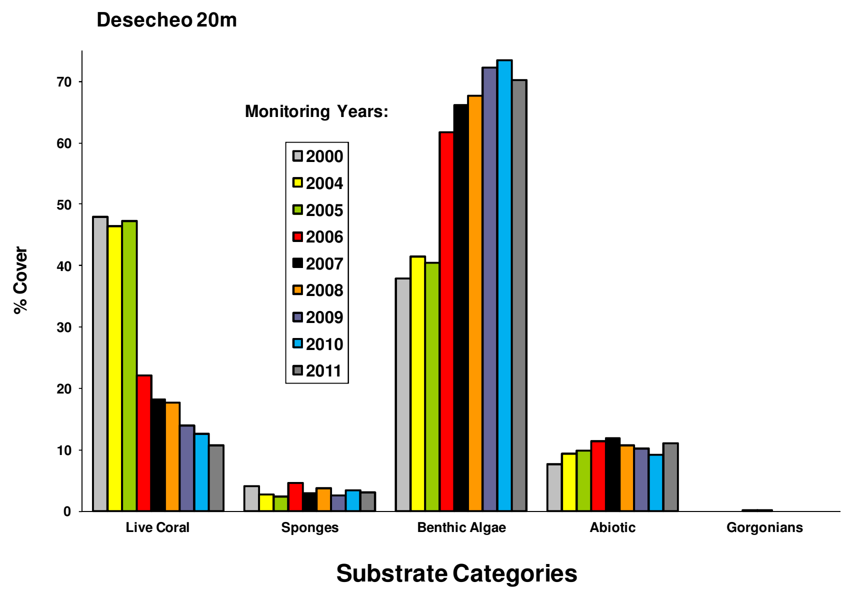

Figure 94: Monitoring trends (2000 – 11) of mean substrate cover by sessile-benthic categories at Puerto Botes Reef, Desecheo Island – 20 m. (García-Sais, 2011, p. 57)

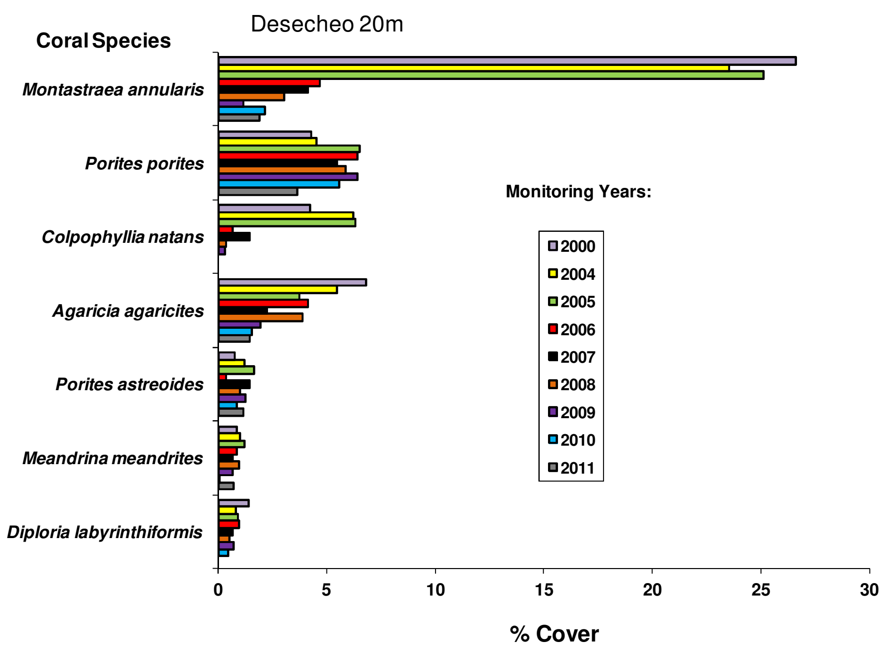

Figure 95: Monitoring trends (2000 – 11) of mean substrate cover by stony coral species at Puerto Botes Reef, Desecheo Island – 20 m. (García-Sais, 2011, p. 57)

Table 13: Taxonomic composition and abundance of fishes within belt-transects at Puerto Botes Reef 20m, Isla Desecheo, July 2011 (García-Sais, 2011, p. 59)

		TRANSECTS					
		1	2	3	4	5	
SPECIES	**COMMON NAME**	**Individuals/30m²**					**MEAN**
Chromis cyanea	Blue Chromis	60	50	36	56	62	**52.8**
Clepticus parrae	Creole Wrasse	30	33	64	0	7	**26.8**
Stegastes partitus	Bicolor Damselfish	23	8	7	50	22	**22.0**
Thalassoma bifasciatum	Bluehead Wrasse	10	15	36	16	19	**19.2**
Gobiosoma evelynae	Sharknose Goby	12	11	11	9	13	**11.2**
Halichoeres garnoti	Yellow-head Wrasse	8	7	13	12	9	**9.8**
Coryphopterus lipernes	Peppermint Goby	4	5	9	16	13	**9.4**
Chromis multilineata	Brown Chromis	6	25	5	2	0	**7.6**
Halichoeres maculipinna	Clown Wrasse	5	5	4	4	3	**4.2**
Sparisoma aurofrenatum	Redband Parrotfish	11	0	5	0	0	**3.2**
Sparisoma radians	Bucktooth Parrotfish	6	0	4	1	0	**2.2**
Coryphopterus personatus	Masked Goby	0	1	0	0	8	**1.8**
Epinaphelus fulva	Coney	4	1	2	1	0	**1.6**
Acanthurus coeruleus	Blue Tang	1	1	1	1	2	**1.2**
Epinephelus cruentatus	Graysby	1	1	0	2	2	**1.2**
Gramma loreto	Fairy Basslet	1	1	2	0	2	**1.2**
Microspathodon chrysurus	Yellowtail Damselfish	1	3	0	1	1	**1.2**
Sparisoma viride	Stoplight Parrotfish	0	0	0	2	4	**1.2**
Amblycirrhitus pinos	Redspotted Hawkfish	1	1	1	0	2	**1.0**
Holocentrus rufus	Squirrelfish	3	0	1	0	1	**1.0**
Kyphosus bermudensis	Sea Chub	0	2	1	1	1	**1.0**
Melichthys niger	Black Durgon	2	0	2	1	0	**1.0**
Myripristis jacobus	Blackbar Soldierfish	0	3	1	1	0	**1.0**
Scarus taeniopterus	Princess Parrotfish	1	1	2	1	0	**1.0**
Ptoris volitans	Lionfish	0	3	2	0	0	**1.0**
Coryphopterus glaucophraenum	Briddled Goby	1	0	1	0	2	**0.8**
Bodianus rufus	Spanish Hogfish	0	1	1	0	1	**0.6**
Chaetodon capistratus	Four-eye Butterflyfish	1	0	1	1	0	**0.6**
Neoniphon marianus	Longspine Squirrelfish	0	2	0	0	1	**0.6**
Haemulon flavolineatum	French Grunt	0	0	1	0	2	**0.6**
Holacanthus tricolor	Rock Beauty	0	1	0	1	1	**0.6**
Scarus iserti	Stripped Parrotfish	0	0	0	1	2	**0.6**
Pomacanthus paru	French Angelfish	0	2	0	0	0	**0.4**
Ocyurus crysurus	Yellowtail Snapper	1	0	1	0	0	**0.4**
Serranus tigrinus	Harlequin Bass	0	0	0	2	0	**0.4**
Scarus iserti	Stripped Parrotfish	0	2	0	0	0	**0.4**

Acanthurs bahianus	Ocean Surgeon	0	0	1	0	0	**0.2**
Acanthostracion quadricornis	Scrawled Cowfish	0	0	0	1	0	**0.2**
Table 19. Continued							
Canthigaster rostrata	Caribbean Puffer	0	0	0	1	0	**0.2**
Caranx crysos	Bule Runner	0	0	0	0	1	**0.2**
Haemulon macrustomus	Smanish Grunt	1	0	0	0	0	**0.2**
Lactophrys triqueter	Smooth Trunkfish	0	0	0	0	1	**0.2**
Hypleurochilus bermudensis	Barred Blenny	0	0	1	0	0	**0.2**
Sparisoma rubripinne	Yellowtail Parrotfish	0	0	1	0	0	**0.2**
Scomberomorus regalis	Cero	0	0	1	0	0	**0.2**
	TOTAL INDIVIDUALS	**194**	**185**	**218**	**184**	**182**	**192.6**
	TOTAL SPECIES	**24**	**25**	**30**	**24**	**25**	**25.6**

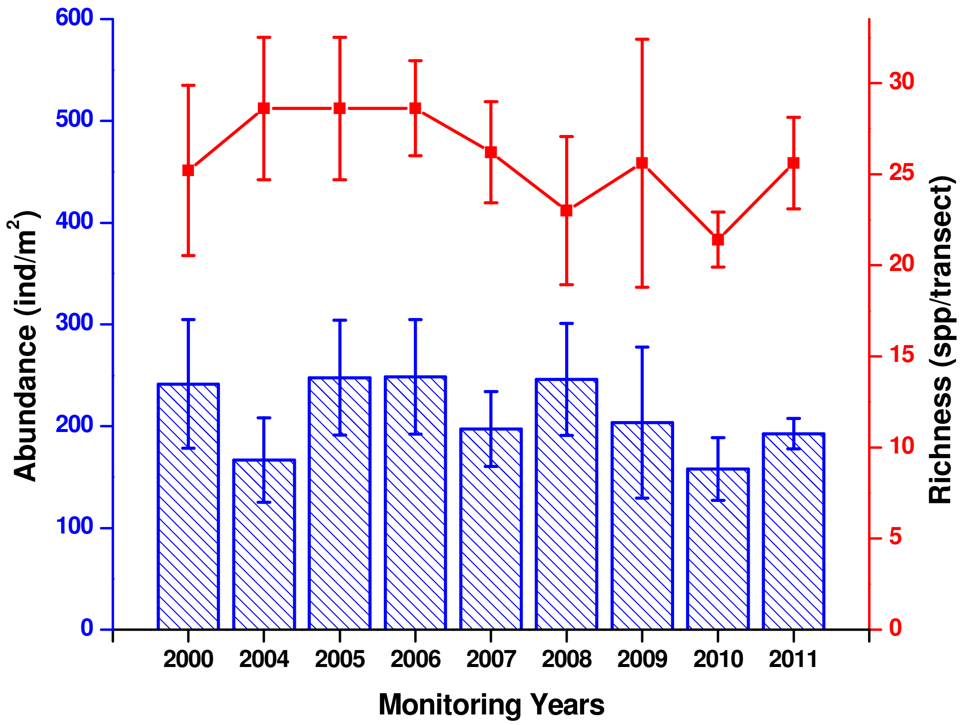

Figure 96: Monitoring trends (2000 – 2011) of fish species richness and abundance at the Mid-Shelf Reef, Puerto Botes, 20 m, Isla Desecheo (García-Sais, 2011, p. 60)

Desecheo 15 m

Table 14: Percent substrate cover by sessile-benthic categories at Desecheo Reef, 15 m (García-Sais, 2011, p. 67)

Depth: 15 m	TRANSECT					
	1	2	3	4	5	**MEAN**
Rugosity (m)	3.6	3.8	3.2	2.4	4.1	**3.4**
SUBSTRATE CATEGORY						
Abiotic						
Reef Overhangs	12.4	7.9	8.9	0.9	2.8	**6.6**
Sand	16.2	9.3	15.4	15.5	3.1	**11.9**
Total Abiotic	28.6	17.2	24.3	16.4	5.9	**18.5**
Benthic Algae						
Lobophora and Dictyota	8.0	37.3	38.4	36.7	24.6	**29.0**
Turf-mixed assemblage	23.4	18.8	15.1	23.8	47.1	**25.6**
Dictyota sp.	24.3	12.8	4.1			**8.2**
Amphiroa sp.	0.5			5.0		**1.1**
Total Benthic Algae	56.2	68.9	57.5	65.5	71.7	**64.0**
Gorgonians						
Sponges	6.1	3.7	1.7	3.6	11.5	**5.3**
Cyanobacteria	0.5		7.9	7.0	1.2	**3.3**
Live Stony Corals						
Porites astreoides	2.5	7.3	3.7	1.3		**3.0**
Montastraea cavernosa	2.1	1.0	1.8	1.4	2.6	**1.8**
Montastraea annularis			1.5	2.1	4.1	**1.5**
Agaricia agaricites		0.8		1.7	1.5	**0.8**
Siderastrea siderea	2.0		1.6			**0.7**
Diploria strigosa					1.4	**0.3**
Eusmilia fastigiata				1.3		**0.3**
Madracis decactis	0.7	0.2				**0.2**
Diploria labyrinthiformis	0.9					**0.2**
Millepora alcicornis	0.4					**0.1**
Leptoseris cucullata		0.4				**0.1**
Porites porites		0.4				**0.1**
Total Stony Corals	8.6	10.2	8.6	7.6	9.7	**8.9**

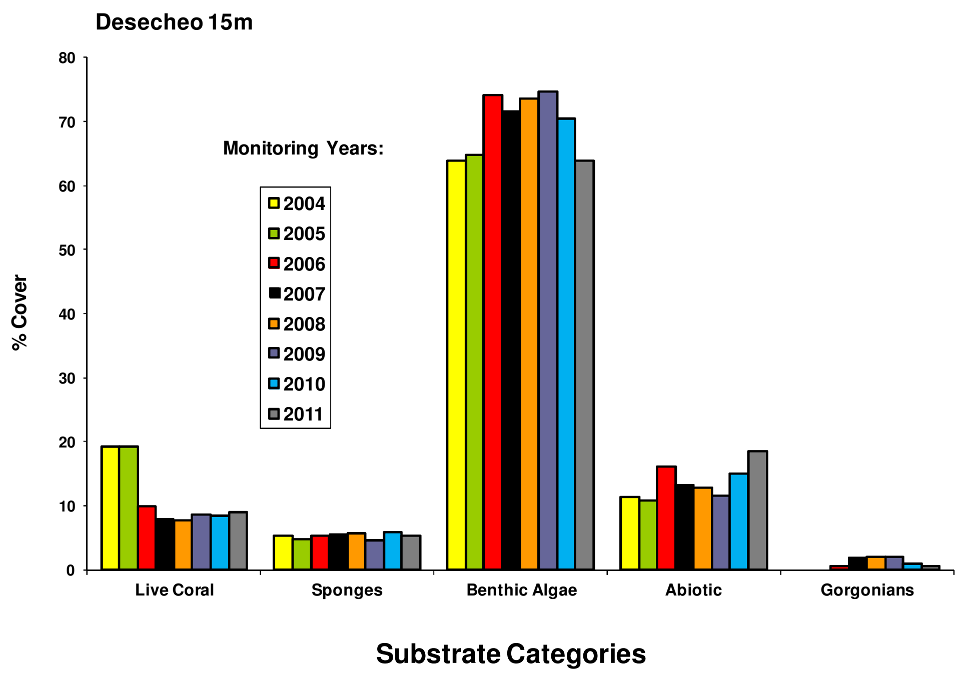

Figure 97: Monitoring trends (2004 -2011) of mean substrate cover by sessile-benthic categories at Puerto Botes Inner Shelf Reef, Desecheo Island – 15 m. (García-Sais, 2011, p. 69)

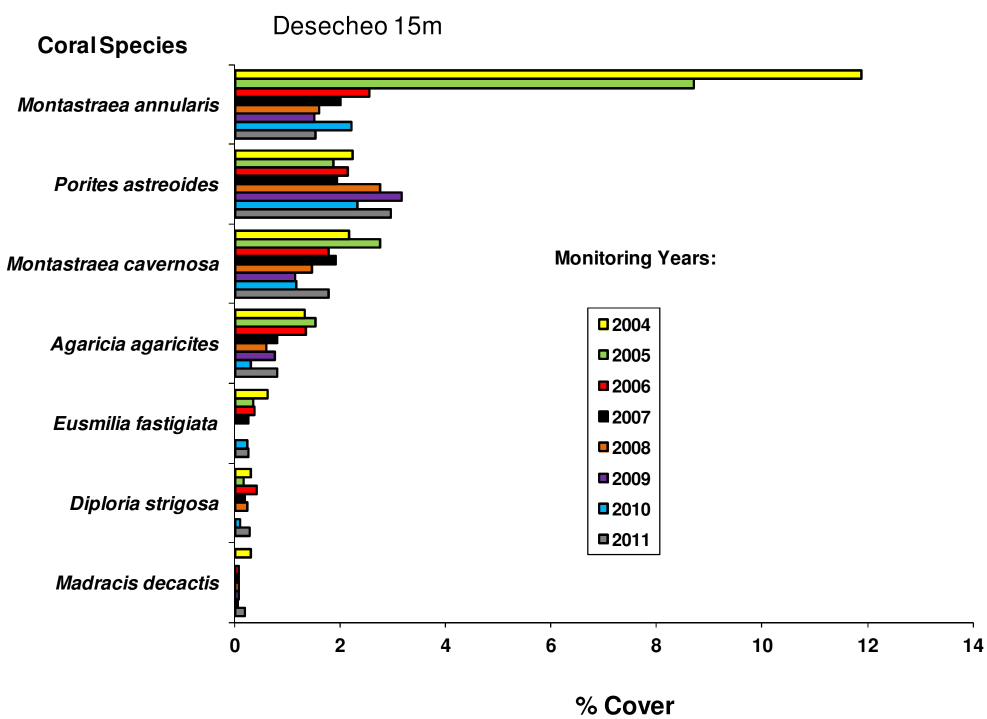

Figure 98: Monitoring trends (2004 -2011) of mean substrate cover by stony coral species at Puerto Botes Inner Shelf Reef, Desecheo Island – 15 m. (García-Sais, 2011, p. 69)

Table 15: Taxonomic composition and abundance of fishes within belt-transects at the Inner Shelf Reef off Puerto Botes, 15 m Isla Desecheo, July, 2011 (García-Sais, 2011, p. 71)

Depth: 15m		TRANSECTS					
		1	**2**	**3**	**4**	**5**	
SPECIES	**COMMON NAME**	**Individuals/30m^2**					**MEAN**
Chromis cyanea	Blue Chromis	22	62	35	41	44	**40.8**
Stegastes partitus	Bicolor Damselfish	56	44	45	28	0	**34.6**
Thalassoma bifasciatum	Bluehead Wrasse	50	15	15	45	43	**33.6**
Halichoeres garnoti	Yellow-head Wrasse	15	9	10	17	9	**12.0**
Gobiosoma evelynae	Sharknose Goby	22	7	3	2	0	**6.8**
Mulloides martinicus	Yellowtail Goatfish	0	25	0	0	0	**5.0**
Epinephelus fulva	Coney	6	4	7	2	2	**4.2**
Sparisoma radians	Bucktooth Parrotfish	6	5	1	1	0	**2.6**
Halichoeres maculipinna	Clown Wrasse	4	1	5	1	1	**2.4**
Scarus taeniopterus	Princess Parrotfish	2	1	3	1	5	**2.4**
Scarus iserti	Stripped Parrotfish	0	8	2	1	0	**2.2**
Acanthurus coeruleus	Blue Tang	1	4	2	1	2	**2.0**
Microspathodon chrysurus	Yellowtail Damselfish	1	1	3	1	4	**2.0**
Chromis multilineata	Brown Chromis	0	4	4	1	0	**1.8**
Lutjanus apodus	Schoolmaster	0	2	7	0	0	**1.8**
Sparisoma aurofrenatum	Redband Parrotfish	3	1	2	1	2	**1.8**
Clepticus parrae	Creole Wrasse	0	0	2	0	5	**1.4**
Myripristis jacobus	Blackbar Soldierfish	0	2	3	0	2	**1.4**
Amblycirrhitus pinnos	Redspotted Hawkfish	0	1	0	1	4	**1.2**
Holocentrus rufus	Squirrelfish	1	1	0	1	3	**1.2**
Coryphopterus lipernes	Peppermint Goby	0	1	2	0	2	**1.0**
Coryphopterus glaucophraenum	Goby	1	1	1	1	0	**0.8**
Bodianus rufus	Spanish Hogfish	0	1	2	0	0	**0.6**
Epinephelus cruentatus	Graysby	0	0	0	1	1	**0.4**
Chaetodon capistratus	Four-eye Butterflyfish	0	2	0	0	0	**0.4**
Chaetodon striatus	Banded Butterflyfish	0	0	2	0	0	**0.4**
Gramma loreto	Fairy Basslet	0	0	0	0	2	**0.4**
Acanthostracion polygonia	Honeycomb Cowfish	1	0	1	0	0	**0.4**
Lactophrys triqueter	Smooth Trunkfish	0	0	1	0	1	**0.4**
Sparisoma viride	Stoplight Parrotfish	0	0	1	0	1	**0.4**
Sparisoma rubripine	Yellowtail Parrotfish	1	0	1	0	0	**0.4**
Acanthurus bahianus	Ocean Surgeon	0	0	1	0	0	**0.2**
Halichoeres poegy	Blackear Wrasse	1	0	0	0	0	**0.2**
Holacanthus tricolor	Rock Beauty	0	0	1	0	0	**0.2**
Acanthurus chirurgus	Doctorfish	0	0	0	0	1	**0.2**
Melichthys niger	Black Durgon	1	0	0	0	0	**0.2**
Serranus tigrinus	Harlequin Bass	1	0	0	0	0	**0.2**
Acanthemblemaria aspera	Roughead Blenny	0	0	0	1	0	**0.2**
	TOTAL INDIVIDUALS	195	202	162	148	134	**168.2**
	TOTAL SPECIES	19	23	27	19	19	**21.4**

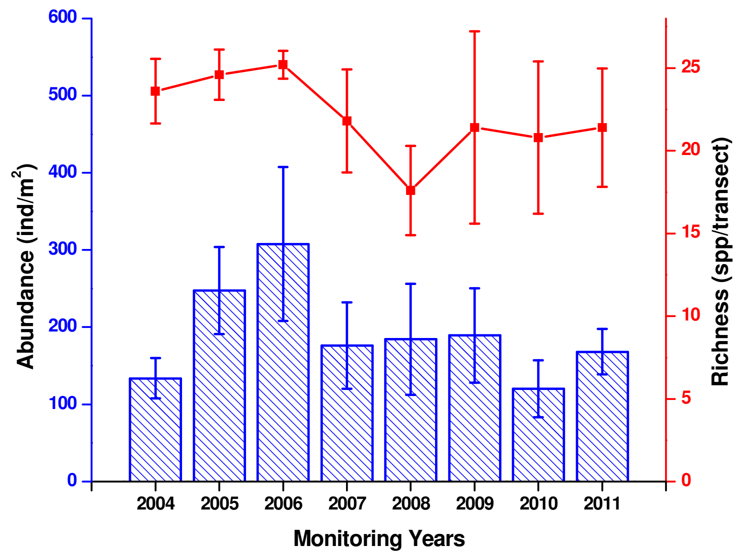

Figure 99: Monitoring trends (2004 – 2011) of fish species richness and abundance Inner Shelf Reef, Puerto Botes, 15 m depth, Isla Desecheo. (García-Sais, 2011, p. 72)

Tourmaline Reef – Mayaguez Bay

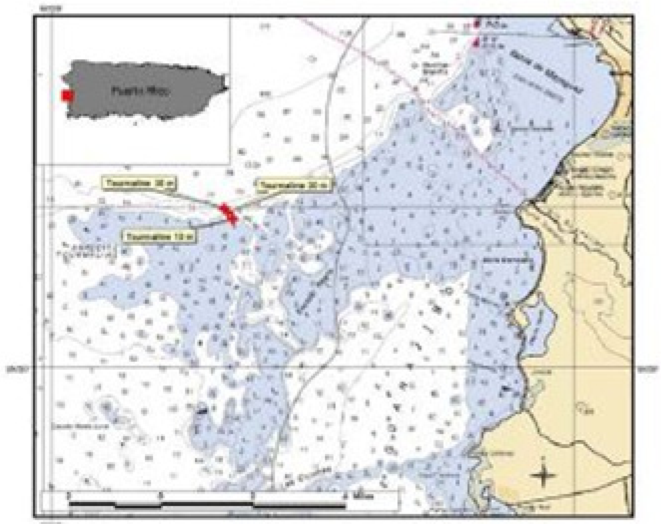

Figure 100: Location of coral reef survey stations at Tourmaline Reef, off Mayaguez Bay (García-Sais, 2011, p. 78)

Tourmaline 30 m

Table 16: Percent substrate cover by sessile-benthic categories at Tourmaline Reef, Mayaguez. June 2011, Depth 30m (García-Sais, 2011, p. 80)

	1	**2**	**3**	**4**	**5**	**MEAN**
Rugosity (m)	6.51	4.34	6.00	5.13	3.93	**5.2**
SUBSTRATE CATEGORY						
Abiotic						
Reef Overhangs	9.8	30.8	37.1	29.6	25.0	**26.5**
Gap	0.3					**0.1**
Silt	2.6	6.4	2.1		4.0	**3.0**
Total Abiotic	12.7	37.2	39.2	29.6	28.9	**29.5**
Benthic Algae						
Turf-mixed assemblage	46.2	37.1	42.7	50.8	42.3	**43.8**
Dictyota sp.				1.1		**0.2**
Total Benthic Algae	46.2	37.1	42.7	52.0	42.3	**44.0**
Encrusting Gorgonians						**0.0**
Erythropodium caribaeorum	13.3	0.6	3.9	2.9	0.9	**4.3**
Briareum asbestinum		0.4				**0.1**
Total encrusting gorgonians	13.3	1.0	3.9	2.9	0.9	**4.4**
Sponges	6.7	2.4		3.2	0.4	**2.6**
Cyanobacteria	0.6				1.8	**0.5**
Live Stony Corals						
Montastraea annularis	5.4	6.0	8.7	7.0	10.6	**7.5**
Agaricia spp.	6.3	10.3	3.0	4.8	10.7	**7.0**
Montastraea cavernosa	1.4	0.4	2.1		3.5	**1.5**
Madracis formosa	0.8	2.9				**0.7**
Porites astreoides	2.1	0.4		0.4		**0.6**
Stephanocoenia intersepta		1.0	0.4		0.8	**0.4**
Mycetophyllia sp.	2.1					**0.4**
Siderastrea siderea	1.4					**0.3**
Porites colonensis		1.0				**0.2**
Siderastrea radians		0.3				**0.1**
Total Stony Corals	19.4	22.2	14.3	12.3	25.6	**18.8**
Total Erect Gorgonians (# col/transect)	18	10	15	16	18	**15.4**

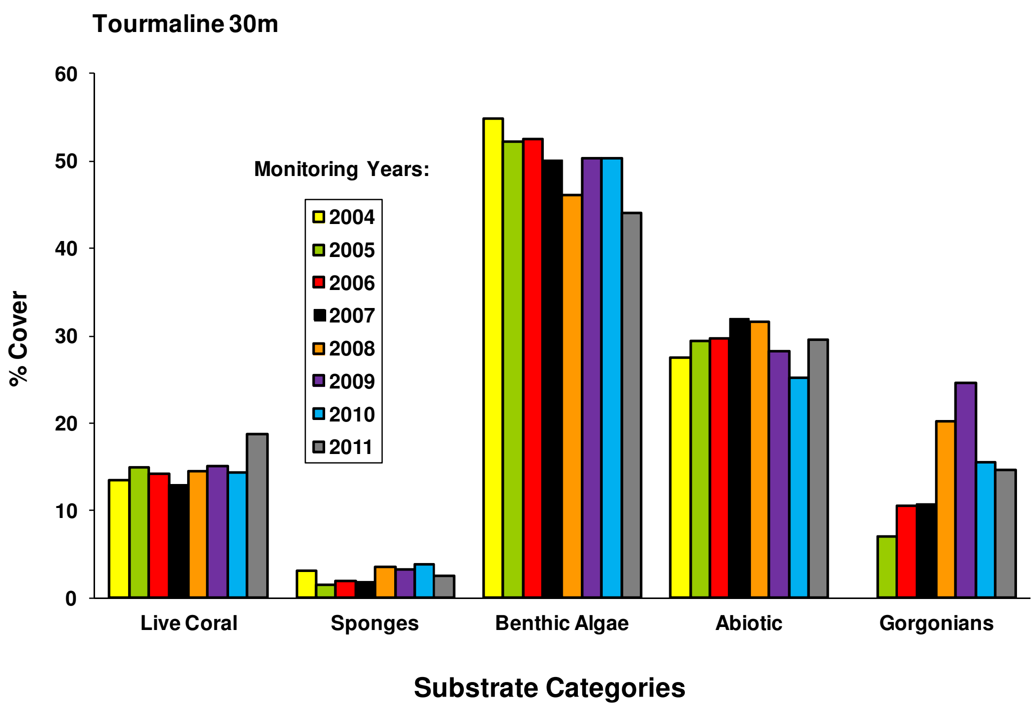

Figure 101: Monitoring trends (2004 – 2011) of mean substrate cover by sessile-benthic categories at Tourmaline Shelf-edge Reef – 30 m, Mayaguez Bay. (García-Sais, 2011, p. 82)

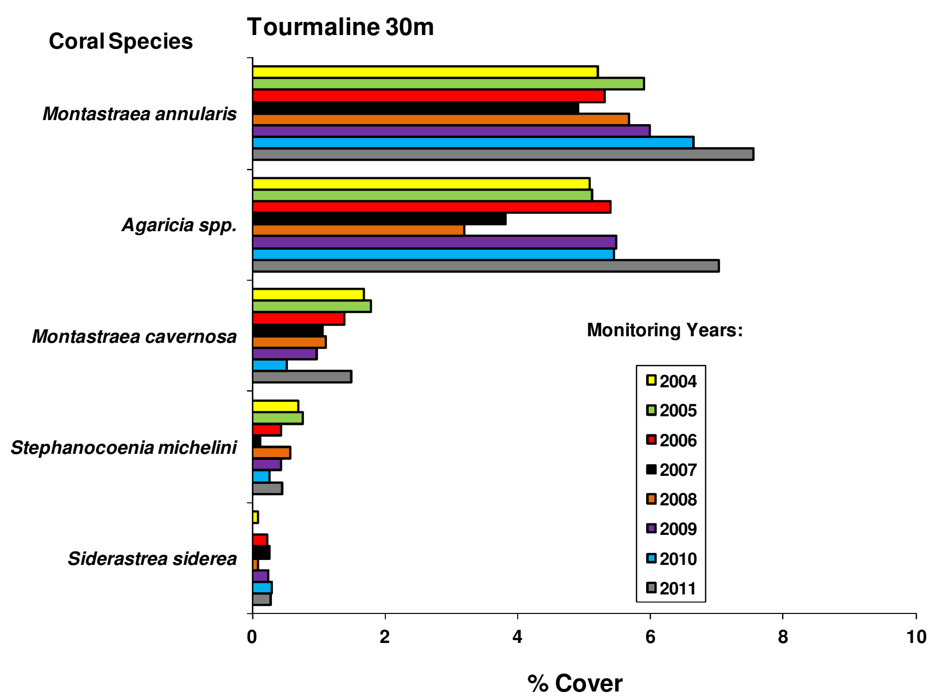

Figure 102: Monitoring trends (2004 – 2011) of mean substrate cover by stony coral species at Tourmaline Reef – 30 m, Mayaguez Bay (García-Sais, 2011, p. 82)

Table 17: Taxonomic composition and abundance of fishes within belt-transects at the Tourmaline Shelf-Edge Reef, 30m. Mayaguez, July 2011 (García-Sais, 2011, p. 83)

Depth: 30m		Transects					
		1	2	3	4	5	
		(Individuals/30 m²)					
SPECIES	**COMMON NAME**						**MEAN**
Coryphopterus personatus	Masked Goby	500	350	360	320	280	**362.0**
Clepticus parrae	Creole Wrasse	105	25	120	32	60	**68.4**
Coryphopterus lipernes	Peppermint Goby	8	25	35	17	56	**28.2**
Chromis cyanea	Blue Chromis	15	0	23	9	17	**12.8**
Gramma loreto	Fairy Basslet	7	6	8	14	1	**7.2**
Chromis insolata	Sunshine Chromis	5	10	6	5	0	**5.2**
Myripristis jacobus	Blackbar Soldierfish	5	6	3	2	1	**3.4**
Stegastes partitus	Bicolor Damselfish	7	2	5	2	1	**3.4**
Scarus iserti	Stripped Parrotfish	0	1	3	7	4	**3.0**
Ocyurus chrysurus	Yellowtail Snapper	12	0	0	0	0	**2.4**
Stegastes leucostictus	Beau Gregory	2	2	2	4	2	**2.4**
Gobiosoma evelynae	Sharknose Goby	0	5	2	2	0	**1.8**
Halichoeres garnoti	Yellow-head Wrasse	3	2	1	2	1	**1.8**
Thalassoma bifasciatum	Bluehead Wrasse	0	1	3	2	3	**1.8**
Canthigaster rostrata	Caribbean Puffer	1	1	3	1	2	**1.6**
Epinephelus cruentatus	Graysby	2	3	1	2	0	**1.6**
Lutjanus synagris	Lane Snapper	0	0	4	4	0	**1.6**
Chaetodon capistratus	Four-eye Butterflyfish	0	3	2	2	0	**1.4**
Neoniphon marianus	Longspine Squirrelfish	0	2	1	1	0	**0.8**
Haemulon aurolineatum	Tomtate	2	1	1	0	0	**0.8**
Hypoplectrus puella	Barred Hamlet	1	0	1	1	1	**0.8**
Mulloides martinicus	Yellowtail Goatfish	3	1	0	0	0	**0.8**
Coryphopterus glaucofraenum	Briddled Goby	0	3	0	0	0	**0.6**
Haemulon flavolineatum	French Grunt	1	1	1	0	0	**0.6**
Sparisoma viride	Stoplight Parrotfish	0	1	0	2	0	**0.6**
Liopropoma rubre	Swiss Guard Basslet	0	1	0	1	1	**0.6**
Chaetodon aculeatus	Longsnout Butterflyfish	0	2	0	0	0	**0.4**
Holacanthus tricolor	Rock Beauty	1	1	0	0	0	**0.4**
Sparisoma aurofrenatum	Redband Parrotfish	0	0	1	1	0	**0.4**
Acanthurus coeruleus	Blue Tang	0	0	0	0	1	**0.2**
Caranx crysos	Blue Runner	1	0	0	0	0	**0.2**
Caranx ruber	Bar Jack	1	0	0	0	0	**0.2**
Epinephelus fulva	Coney	1	0	0	0	0	**0.2**
Hypoplectrus unicolor	Butter Hamlet	1	0	0	0	0	**0.2**
Pomacanthus arcuatus	Grey Angelfish	1	0	0	0	0	**0.2**

Pseudupeneus maculatus	Spotted Goatfish	1	0	0	0	0	**0.2**
Serranus baldwini	Lantern Bass	0	1	0	0	0	**0.2**
Sparisoma radians	Bucktooth Parrotfish	1	0	0	0	0	**0.2**
	TOTAL INDIVIDUALS	687	456	586	433	431	**518.6**
	TOTAL SPECIES	25	25	22	22	15	**21.8**

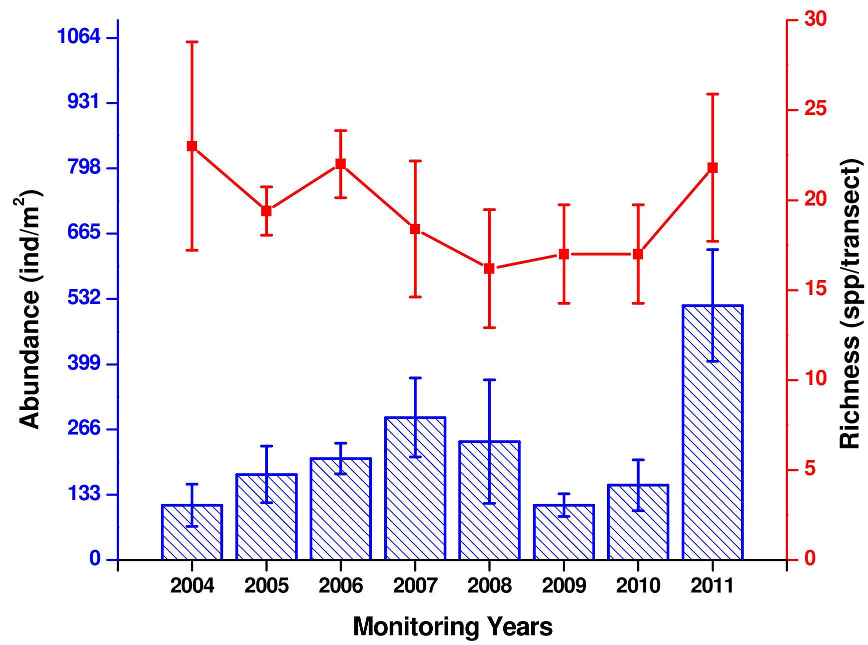

Figure 103: Monitoring trends (2004 – 2011) of fish species richness and abundance at Shelf-edge Reef Tourmaline, 30 m, Mayaguez Bay (García-Sais, 2011, p. 85)

Tourmaline 20 m

Table 18: Percent substrate cover by sessile-benthic categories at Tourmaline Reef, 20 m Mayaguez. June 2011, Depth 20m (García-Sais, 2011, p. 91)

Depth: 20 m	1	2	3	4	5	**MEAN**
Rugosity (m)	3.51	4.82	4.10	6.01	4.56	**4.60**
SUBSTRATE CATEGORY						
Abiotic						
Reef Overhangs	11.3	21.6	14.3	27.1	32.2	**21.3**
Gaps			0.5		1.3	**0.4**
Sand				3.0		**0.6**
Total Abiotic	11.3	21.6	14.8	30.2	33.5	**22.2**
Benthic Algae						
Turf-mixed assemblage	26.9	31.2	19.1	22.6	14.8	**22.9**
Lobophora variegata	27.1	15.3	29.2	15.7	23.7	**22.2**
Coralline algae	1.9		1.2			**0.6**
Dictyota sp.				1.3	1.7	**0.6**
Total Benthic Algae	55.9	46.5	49.5	39.6	40.2	**46.3**
Encrusting Gorgonians						
Erythropodium caribaeorum	4.4	3.6	6.7	3.8	1.9	**4.1**
Briareum asbestinum		2.0				**0.4**
Total Encrusting Gorgonians	4.4	5.7	6.7	3.8	1.9	**4.5**
Sponges					1.4	**0.3**
Cyanobacteria		0.5	2.0	0.8		**0.6**
Live Stony Corals						
Montastraea annularis	21.6	18.7	15.6	22.2	16.1	**18.8**
Montastraea cavernosa	2.2		7.4		3.7	**2.7**
Porites astreoides		1.6	1.9	0.9	1.6	**1.2**
Siderastrea siderea	2.3			1.4	1.7	**1.1**
Colpophyllia natans		2.9				**0.6**
Meandrina meandrites		1.6		0.6		**0.4**
Madracis decactis		0.9		0.4		**0.3**
Agaricia lamarcki	0.8		0.5			**0.3**
Madracis auretenra	1.3					**0.3**
Diploria labyrinthiformis			1.1			**0.2**
Millepora alcicornis	0.3		0.3			**0.1**
Mycetophyllia			0.3			**0.1**
juvenile coral				0.2		**0.03**
Total Stony Corals	28.5	25.8	27.1	25.7	23.2	**26.1**

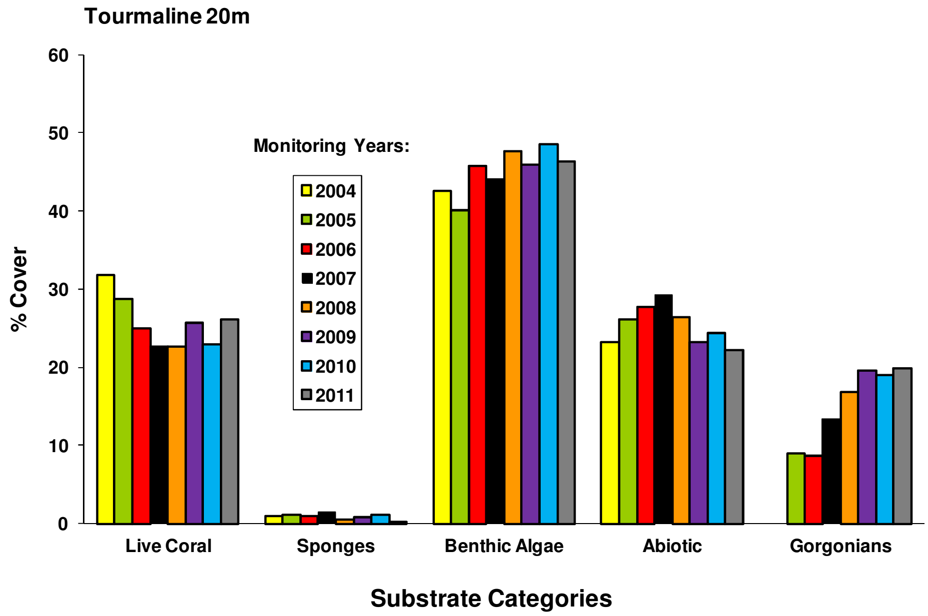

Figure 104: Monitoring trends (2004 – 2011) of mean substrate cover by sessile-benthic categories at Tourmaline Outer Shelf Reef – 20 m, Mayaguez Bay (García-Sais, 2011, p. 93)

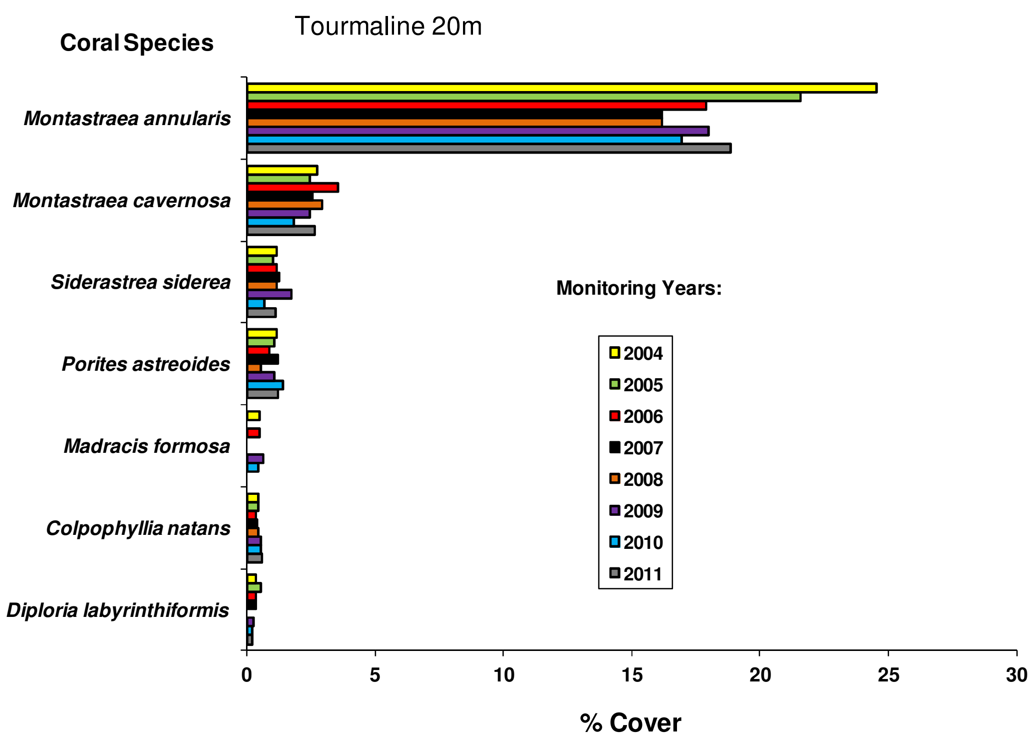

Figure 105: Monitoring trends (2004 – 2011) of mean substrate cover by stony coral species at Tourmaline Outer Shelf Reef – 20 m, Mayaguez Bay. (García-Sais, 2011, p. 93)

Table 19: Taxonomic composition and abundance of fishes within belt-transects at Tourmaline Outer Shelf Reef 20 m, Mayaguez, June, 2011, Depth 20m (García-Sais, 2011, p. 95)

Depth: 20m		TRANSECTS					
		1	2	3	4	5	
		(Individuals/30 m^2)					
SPECIES	**COMMON NAME**						**MEAN**
Coryphopterus personatus	Masked Goby	320	350	260	310	250	**298.0**
Chromis cyanea	Blue Chromis	16	15	34	30	0	**19.0**
Coryphopterus lipernes	Peppermint Goby	12	5	17	14	20	**13.6**
Gramma loreto	Fairy Basslet	6	6	12	15	12	**10.2**
Clepticus parrae	Creole Wrasse	0	10	30	6	0	**9.2**
Thalassoma bifasciatum	Bluehead Wrasse	13	10	2	16	0	**8.2**
Halichoeres garnoti	Yellow-head Wrasse	3	5	3	6	3	**4.0**
Scarus iserti	Stripped Parrotfish	0	13	0	0	6	**3.8**
Sparisoma viride	Stoplight Parrotfish	2	3	1	9	4	**3.8**
Myripristis jacobus	Blackbar Soldierfish	0	0	5	4	6	**3.0**
Chaetodon capistratus	Four-eye Butterflyfish	0	2	2	2	6	**2.4**
Stegastes leucostictus	Beau Gregory	2	2	2	3	3	**2.4**
Canthigaster rostrata	Caribbean Puffer	1	3	0	1	6	**2.2**
Gobiosoma evelynae	Sharknose Goby	2	0	3	4	2	**2.2**
Stegastes partitus	Bicolor Damselfish	2	2	1	2	4	**2.2**
Ocyurus chrysurus	Yellowtail Snapper	10	0	0	0	0	**2.0**
Scarus taeniopterus	Princess Parrotfish	0	0	4	2	3	**1.8**
Acanthurus coeruleus	Blue Tang	0	1	4	0	2	**1.4**
Cephalopholis cruentatus	Graysby	1	1	2	0	3	**1.4**
Coryphopterus glaucofraenum	Briddled Goby	0	1	1	0	1	**0.6**
Holacanthus tricolor	Rock Beauty	0	1	1	1	0	**0.6**
Equetus punctatus	Spotted Drum	0	1	0	1	0	**0.4**
Flammeo marianus	Longspine Squirrelfish	0	1	0	0	1	**0.4**
Holocentrus rufus	Squirrelfish	0	1	0	0	1	**0.4**
Mulloides martinicus	Yellowtail Goatfish	0	1	0	0	1	**0.4**
Sparisoma aurofrenatum	Redband Parrotfish	1	0	0	1	0	**0.4**
Acanthurus bahianus	Ocean Surgeon	0	0	1	0	0	**0.2**
Anisotremus virginicus	Porkfish	0	0	0	0	1	**0.2**
Aulostomus maculatus	Trumpetfish	0	0	0	0	1	**0.2**
Haemulon flavolineatum	French Grunt	0	0	1	0	0	**0.2**
Hypoplectrus nigricans	Black Hamlet	0	0	0	1	0	**0.2**
Hypoplectrus unicolor	Butter Hamlet	1	0	0	0	0	**0.2**
Lachnolaimus maximus	Hogfish	1	0	0	0	0	**0.2**

Liopropoma rubre	Swiss Guard Basslet	1	0	0	0	0	**0.2**

Table 31. Continued

Caranx crysos	Blue Runner	0	0	0	0	1	**0.2**
Pseudupeneus maculatus	Spotted Goatfish	0	0	0	0	1	**0.2**
Synodus intermedius	Sand Diver	1	0	0	0	0	**0.2**
	TOTAL INDIVIDUALS	**395**	**434**	**386**	**428**	**338**	**396.2**
	TOTAL SPECIES	**18**	**21**	**20**	**19**	**23**	**20.2**

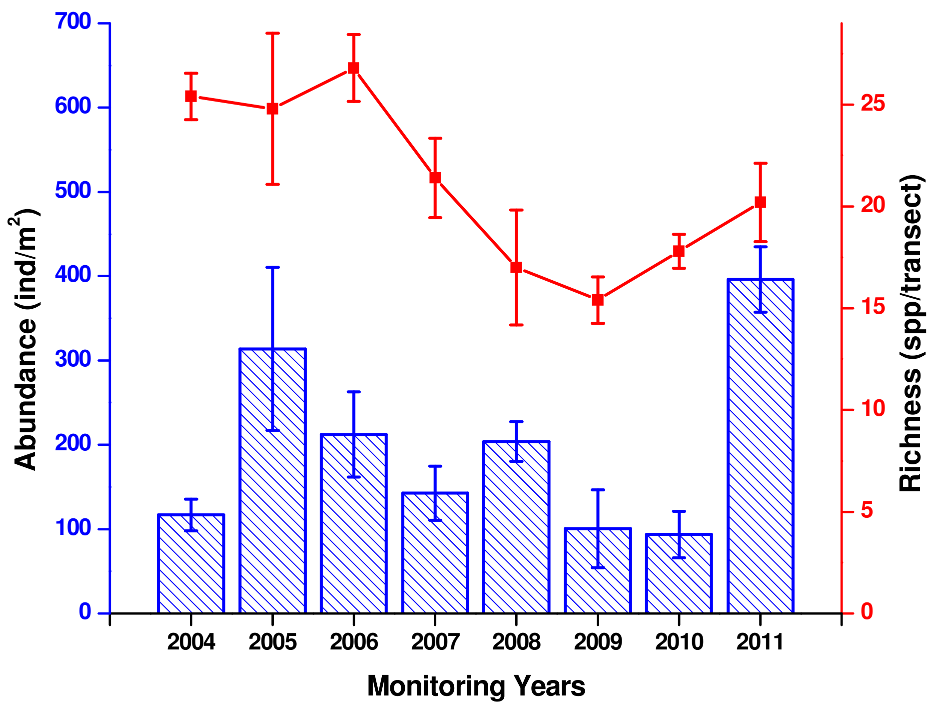

Figure 106: Monitoring trends (2004 – 2011) of fish species richness and abundance at outer shelf reef Tourmaline, 20 m, Mayaguez. (García-Sais, 2011, p. 96)

Tourmaline 10 m

Table 20: Percent substrate cover by sessile-benthic categories at Tourmaline reef, Mayaguez, 10m, June 2011 (García-Sais, 2011, p. 103)

Depth: 10 m	TRANSECTS					
	1	2	3	4	5	**MEAN**
Rugosity (m)	3.00	5.04	2.63	2.94	3.52	**3.43**
SUBSTRATE CATEGORY						
Abiotic						
Reef Overhangs		14.0	1.1	4.6	4.7	**4.9**
Total Abiotic	0.0	14.0	1.1	4.6	4.7	**4.9**
Benthic Algae						
Turf-mixed assemblage	59.9	56.7	47.2	21.6	47.4	**46.5**
Halimeda tuna		0.6	1.7			**0.4**
Dictyota sp.	0.4				0.7	**0.2**
Total Benthic Algae	60.4	57.2	48.9	21.6	48.1	**47.2**
Encrusting Gorgonians		0.9				**0.2**
Briareum asbestinum		2.5				**0.5**
Erythropodium caribaeorum	8.5	0.4	2.9		2.2	**2.8**
Total Encrusting Gorgonians	8.5	3.8	2.9	0.0	2.2	**3.5**
Erect Gorgonians	36	31	25	35	34	**32.2**
Sponges			0.9	0.7		**0.3**
Zoanthids		1.4			2.4	**0.8**
Cyanobacteria			1.1			**0.2**
Live Stony Corals						
Madracis auretenra				52.5		**10.5**
Montastraea annularis	8.5	7.1	11.5	13.3	5.4	**9.1**
Porites porites	4.5		5.2	2.4	21.9	**6.8**
Porites astreoides	5.9	2.5	8.8	2.3	5.6	**5.0**
Dendrogyra cylindrus		4.9			5.4	**2.1**
Agaricia grahamae	1.2	4.2	3.8		1.0	**2.0**
Agaricia agaricites	5.9	2.8			0.9	**1.9**
Colpophyllia natans	0.9		7.4			**1.6**
Meandrina meandrites	1.1	0.8	2.9	1.3	1.0	**1.4**
Montastraea cavernosa	0.3	1.1	1.9			**0.7**
Diploria labyrinthiformis	2.3					**0.5**
Acropora cervicornis			2.2			**0.4**
Agaricia lamarcki		0.3			0.8	**0.2**
Porites divaricata				0.7	0.4	**0.2**
Porites colonensis				0.9		**0.2**
Diploria strigosa	0.7					**0.1**
Millepora alcicornis			0.6			**0.1**
Eusmilia fastigiata			0.5			**0.1**
Millepora complanata			0.5			**0.1**
Total Stony Corals	31.1	23.6	45.2	73.3	42.6	**43.2**

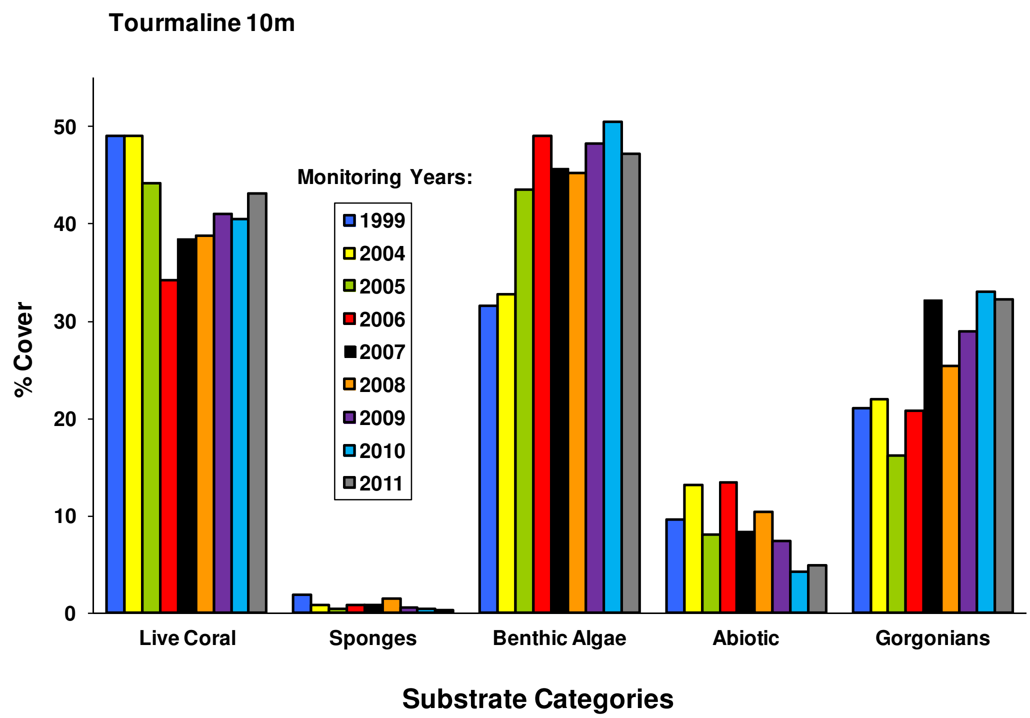

Figure 107: Monitoring trends (1999 – 2011) of mean substrate cover by sessile-benthic categories at Tourmaline Reef – 10 m, Mayaguez. (García-Sais, 2011, p. 105)

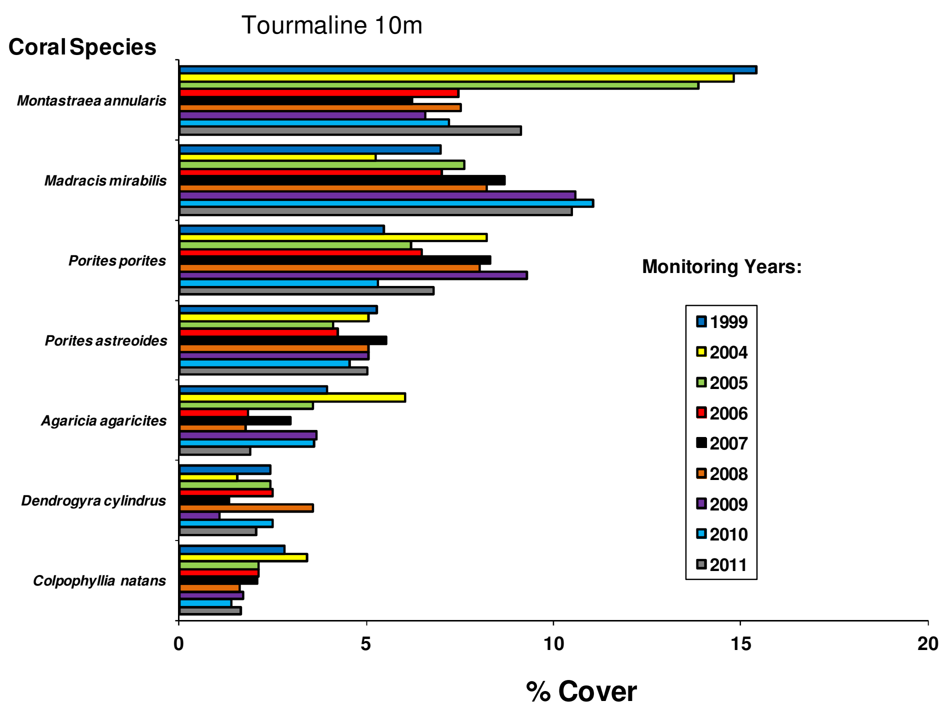

Figure 108: Monitoring trends (1999 – 2011) of mean cover by stony coral species at Tourmaline Reef – 10 m, Mayaguez. (García-Sais, 2011, p. 105)

Table 21: Taxonomic composition and abundance of fishes within belt-transects at the Tourmaline Outer Shelf Reef, 10m Mayaguez, June 2011 (García-Sais, 2011, p. 107)

Depth: 10m		TRANSECTS					
		1	2	3	4	5	
		Individuals/30m^2					
SPECIES	**COMMON NAME**						**MEAN**
Thalassoma bifasciatum	Bluehead Wrasse	0	30	25	36	16	**21.4**
Chromis cyanea	Blue Chromis	0	33	17	50	0	**20.0**
Stegastes partitus	Bicolor Damselfish	4	1	13	29	13	**12.0**
Scarus iserti	Stripped Parrotfish	3	11	2	11	18	**9.0**
Coryphopterus personatus	Masked Goby	2	0	3	15	0	**4.0**
Halichoeres garnoti	Yellow-head Wrasse	2	3	8	0	7	**4.0**
Sparisoma viride	Stoplight Parrotfish	6	3	4	4	3	**4.0**
Stegastes leucostictus	Beau Gregory	5	4	1	2	7	**3.8**
Sparisoma aurofrenatum	Redband Parrotfish	4	1	2	0	0	**1.4**
Haemulon flavolineatum	French Grunt	0	3	1	2	0	**1.2**
Canthigaster rostrata	Caribbean Puffer	2	0	1	0	1	**0.8**
Chaetodon capistratus	Four-eye Butterflyfish	0	0	0	2	2	**0.8**
Gobiosoma evelynae	Sharknose Goby	1	3	0	0	0	**0.8**
Holacanthus tricolor	Rock Beauty	0	1	2	1	0	**0.8**
Myripristis jacobus	Blackbar Soldierfish	0	4	0	0	0	**0.8**
Scarus taeniopterus	Princess Parrotfish	2	0	0	0	2	**0.8**
Acanthurus bahianus	Ocean Surgeon	0	0	1	1	1	**0.6**
Coryphopterus lipernes	Peppermint Goby	0	1	1	0	1	**0.6**
Flammeo marianus	Longspine Squirrelfish	0	0	0	2	1	**0.6**
Gramma loreto	Fairy Basslet	0	3	0	0	0	**0.6**
Pomacanthus arcuatus	Grey Angelfish	0	2	1	0	0	**0.6**
Holocentrus rufus	Squirrelfish	1	1	0	0	0	**0.4**
Ophioblennius atlanticus	Redlip Blenny	0	2	0	0	0	**0.4**
Serranus tigrinus	Harlequin Bass	1	0	0	1	0	**0.4**
Acanthurus chirurgus	Doctorfish	0	0	1	0	0	**0.2**
Acanthurus coeruleus	Blue Tang	0	0	1	0	0	**0.2**
Amblycirrhitus pinos	Redspotted Hawkfish	1	0	0	0	0	**0.2**
Caranx crysos	Blue Runner	1	0	0	0	0	**0.2**
Cephalopholis cruentatus	Graysby	0	0	1	0	0	**0.2**
Holocanthus ciliaris	Queen Angelfish	0	0	0	1	0	**0.2**
Hypoplectrus nigricans	Black Hamlet	0	0	0	0	1	**0.2**
Hypoplectrus chlorurus	Yellowtail Hamlet	0	0	1	0	0	**0.2**
Mycrospathodon chrysurus	Yellowtail Damselfish	0	0	1	0	0	**0.2**
Pomacanthus paru	French Angelfish	0	0	1	0	0	**0.2**
	TOTAL INDIVIDUALS	35	106	88	157	73	**91.8**
	TOTAL SPECIES	14	17	21	14	13	**15.8**

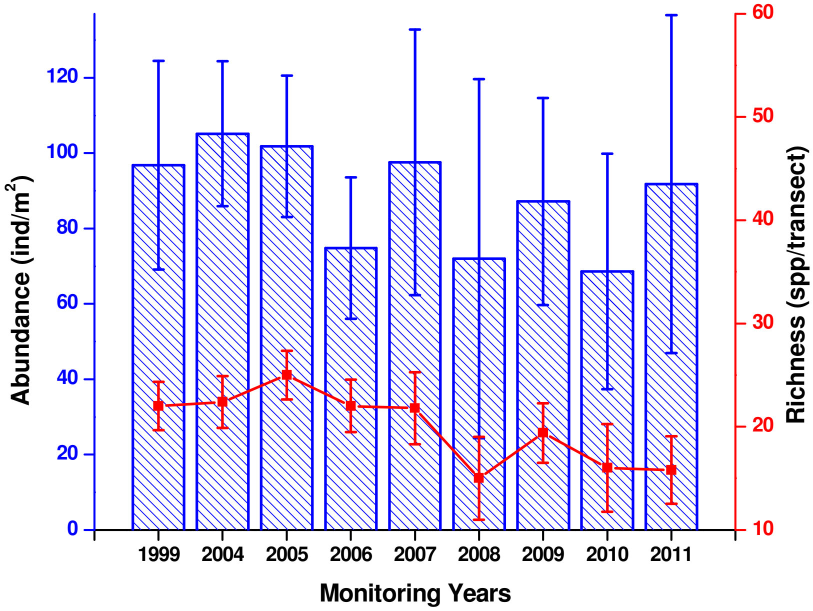

Figure 109: Monitoring trends (2004 – 2011) of fish species richness and abundance at Outer Shelf Reef Tourmaline, 10 m, Mayaguez. (García-Sais, 2011, p. 109)

West Reef -Isla Caja de Muerto

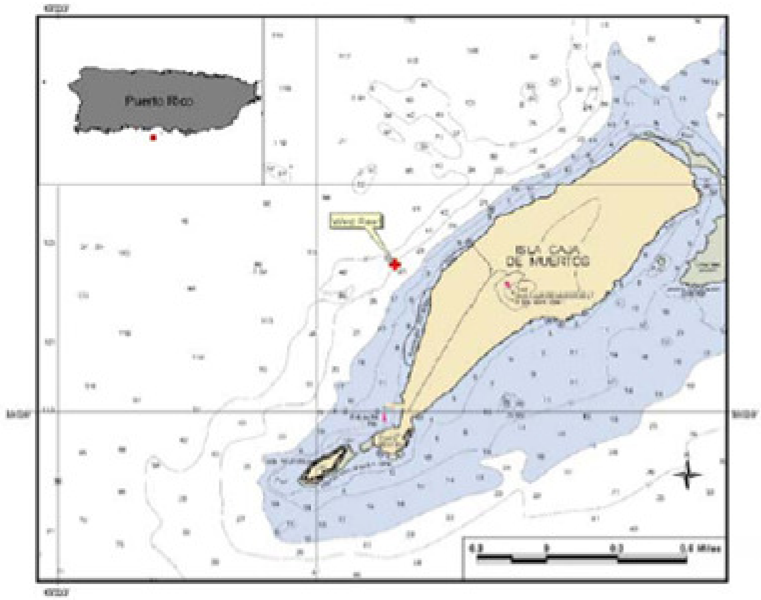

Figure 110: Location of coral survey stations at West Reef, Isla Caja de Muerto, Ponce (García-Sais, 2011, p. 134)

Table 22: Percent substrate cover by sessile-benthic categories at Caja de Muerto Reef, Ponce. July, 2011 (García-Sais, 2011, p. 136)

	Transects					
	1	2	3	4	5	**MEAN**
Rugosity (m)	3.79	5.68	6.61	5.17	6.35	**5.52**
SUBSTRATE CATEGORY						
Abiotic						
Reef Overhangs	8.6	16.0	23.7	22.3	26.8	**19.5**
Silt	8.2	11.6	6.0	3.7	6.4	**7.2**
Rubble		3.1	6.4	5.6		**3.0**
Total Abiotic	16.8	30.7	36.0	32.5	33.1	**29.8**
Benthic Algae						
Turf-mixed assemblage	69.0	51.7	44.1	46.2	54.3	**53.0**
Halimeda sp.				5.7		**1.1**
Total Benthic Algae	69.0	51.7	44.1	51.9	54.3	**54.2**
Encrusting Gorgonians						
Erythropodium caribaeorum	0.5					**0.1**
Total Encrusting Gorgonians	0.5	0.0	0.0	0.0	0.0	**0.1**
Erect Gorgonians (# colonies/transect)	26	16	20	25	29	**23.2**
Sponges	5.4	0.6	1.5	0.5	0.8	**1.8**
Xestospongia muta			3.6			**0.7**
Total Sponges	5.9	0.6	5.1	0.5	0.8	**2.5**
Cyanobacteria	5.1	2.2	1.4	3.6	1.0	**2.7**
Live Stony Corals						
Montastraea annularis	0.9	8.4	5.0	2.6	1.5	**3.7**
Montastraea cavernosa		3.4	0.9	3.4	3.1	**2.2**
Porites astreoides		1.3	2.1	0.7	4.6	**1.7**
Siderastrea siderea	0.9	1.2	2.7	2.2	0.4	**1.5**
Siderastrea radians	1.0	0.5	1.2			**0.5**
Meandrina meandrites				1.3		**0.3**
Dendrogyra cylindrus			1.3			**0.3**
Millepora alcicornis	0.4		0.3	0.3	0.3	**0.2**
Agaricia agaricites				0.4	0.3	**0.1**
Stephanocoenia intersepta					0.5	**0.1**
Madracis decactis				0.5		**0.1**
Total Stony Corals	3.3	14.8	13.4	11.4	10.7	**10.7**

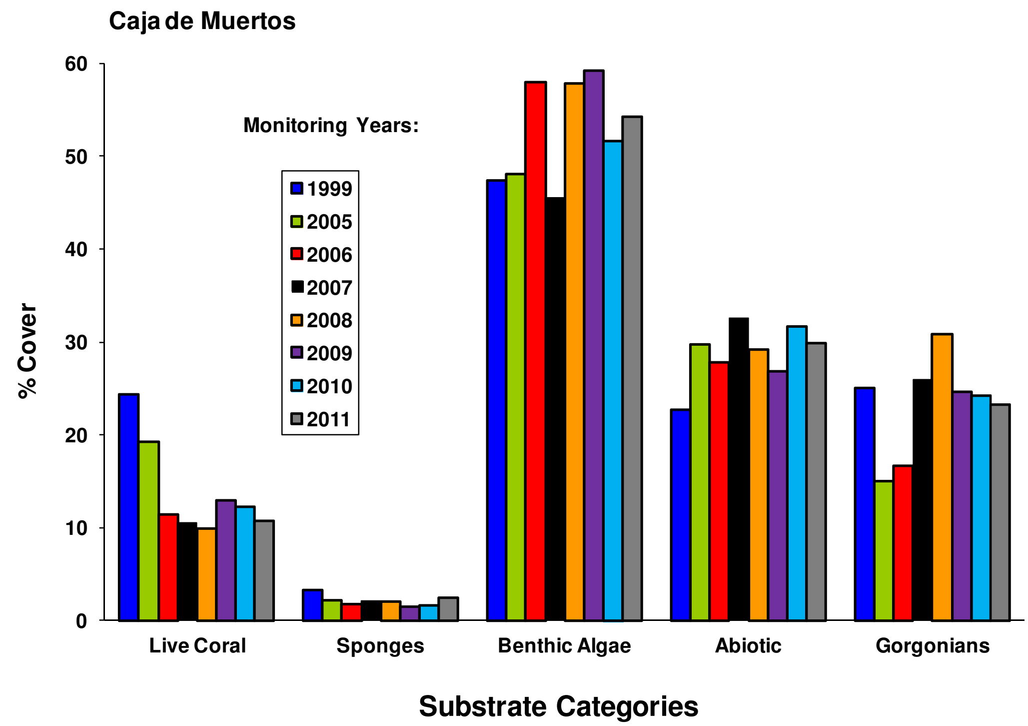

Figure 111: Monitoring trends (1999 - 2011) of mean substrate cover by sessile-benthic categories at West Reef, Isla Caja de Muerto, Ponce. (García-Sais, 2011, p. 138)

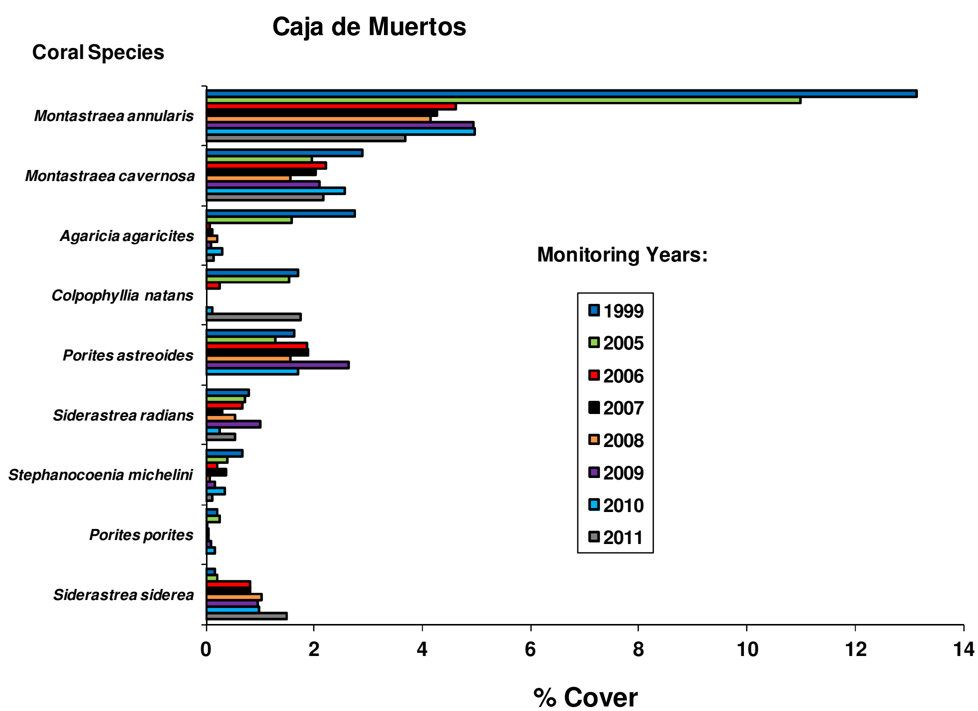

Figure 112: Monitoring trends (1999 – 2011) of mean substrate cover by stony coral species at West Reef, Isla Caja de Muerto, Ponce. (García-Sais, 2011, p. 138)

Table 23: Taxonomic composition and abundance of fishes within belt-transects at West Reef Caja de Muertos, Ponce. April, 2011 (García-Sais, 2011, p. 140)

Depth: 8 – 10 m

SPECIES	COMMON NAME	TRANSECTS 1	2	3	4	5	MEAN
		(individuals/30 m2)					
Coryphopterus personatus	Masked Goby	150	65	125	145	80	**113.0**
Thalassoma bifasciatum	Bluehead Wrasse	18	45	4	17	0	**16.8**
Scarus iserti	Stripped Parrotfish	12	4	3	13	3	**7.0**
Stegastes partitus	Bicolor Damselfish	10	6	10	8	0	**6.8**
Stegastes planifrons	Yellow-eye Damselfish	7	4	2	4	3	**4.0**
Sparisoma aurofrenatum	Redband Parrotfish	3	1	5	1	3	**2.6**
Stegastes dorsopunicans	Dusky Damselfish	1	7	1	4	0	**2.6**
Gobiosoma evelynae	Sharknose Goby	0	0	0	8	2	**2.0**
Myripristis jacobus	Blackbar Soldierfish	2	1	5	1	0	**1.8**
Chaetodon capistratus	Four-eye Butterflyfish	2	1	2	2	1	**1.6**
Stegastes leucostictus	Beau Gregory	1	0	0	3	4	**1.6**
Acanthurus chirurgus	Doctorfish	1	2	1	1	2	**1.4**
Canthigaster rostrata	Caribbean Puffer	2	1	1	2	1	**1.4**
Haemulon aurolineatum	Tomtate	0	0	5	0	1	**1.2**
Acanthurus coeruleus	Blue Tang	0	1	1	1	1	**0.8**
Cephalopholis cruentatus	Graysby	3	0	0	1	0	**0.8**
Coryphopterus lipernes	Peppermint Goby	0	0	0	1	3	**0.8**
Haemulon flavolineatum	French Grunt	1	0	1	2	0	**0.8**
Bodianus rufus	Spanish Hogfish	0	0	0	3	0	**0.6**
Chromis cyanea	Blue Chromis	0	2	0	1	0	**0.6**
Halichoeres garnoti	Yellow-head Wrasse	2	1	0	0	0	**0.6**
Lutjanus apodus	Schoolmaster	0	0	0	3	0	**0.6**
Lutjanus mahogoni	Mahogani Snapper	0	0	3	0	0	**0.6**
Scarus taeniopterus	Princess Parrotfish	0	0	0	1	2	**0.6**
Holocentrus rufus	Squirrelfish	1	1	0	0	0	**0.4**
Hypoplectrus chlorurus	Yellowtail Hamlet	0	0	0	1	1	**0.4**
Hypoplectrus puella	Barred Hamlet	1	0	0	0	1	**0.4**
Pseudupeneus maculatus	Spotted Goatfish	0	1	1	0	0	**0.4**
Synodus intermedius	Sand Diver	0	0	1	0	1	**0.4**
Acanthurus bahianus	Ocean Surgeon	1	0	0	0	0	**0.2**
Anisotremus virginicus	Porkfish	0	0	1	0	0	**0.2**
Aulostomus maculatus	Trumpetfish	1	0	0	0	0	**0.2**
Carangoides ruber	Bar Jack	0	0	0	1	0	**0.2**
Chaetodon striatus	Banded Butterflyfish	0	0	0	0	1	**0.2**

Pterois volitans	Lionfish	0	0	0	1	0	**0.2**
Gymnothorax moringa	Golden moray	1	0	0	0	0	**0.2**
Haemulon macrostomum	Spanish Grunt	0	0	1	0	0	**0.2**
Pomacanthus arcuatus	Gray Angelfish	0	0	0	0	1	**0.2**
Pomacanthus paru	French Angelfish	0	0	0	1	0	**0.2**
Lutjanus griseous	Gray Snapper	0	0	0	0	1	**0.2**
Microspathodon chrysurus	Yellowtail Damselfish	0	0	0	0	1	**0.2**
Serranus tigrinus	Harlequin Bass	1	0	0	0	0	**0.2**
Sparisoma radians	Bucktooth Parrotfish	0	0	0	0	1	**0.2**
Sparisoma viride	Stoplight Parrotfish	0	0	0	0	1	**0.2**
Heteropricantus cruentatus	Glasseye Snapper	0	0	1	0	1	**0.4**
Hypoplectrus sp	Hamlet Hybrid	0	0	1	0	0	**0.2**
Diodon histrix	Porcupinefish	0	0	0	1	0	**0.2**
Sargocentron vexillarium	Dusky Squirrelfish	0	0	0	0	1	**0.2**
	TOTAL INDIVIDUALS	221	143	175	227	117	**176.6**
	TOTAL SPECIES	21	16	21	25	24	**21.4**

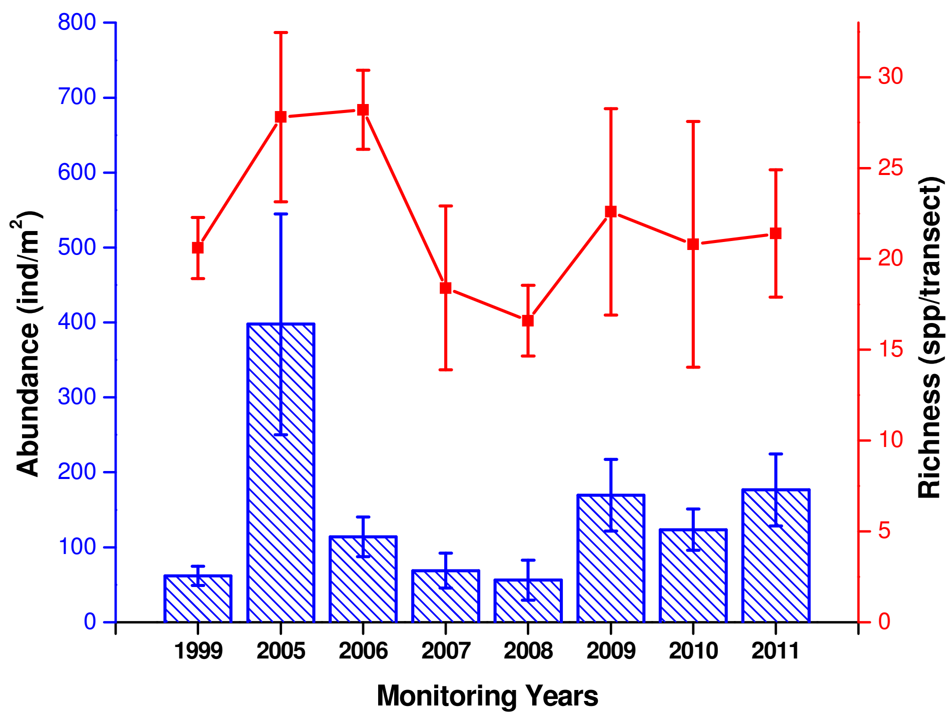

Figure 113: Monitoring trends (1999 – 2011) of fish species richness and abundance at West Reef, Isla Caja de Muerto, Ponce (García-Sais, 2011, p. 141)

Derrumbadero Reef – Ponce

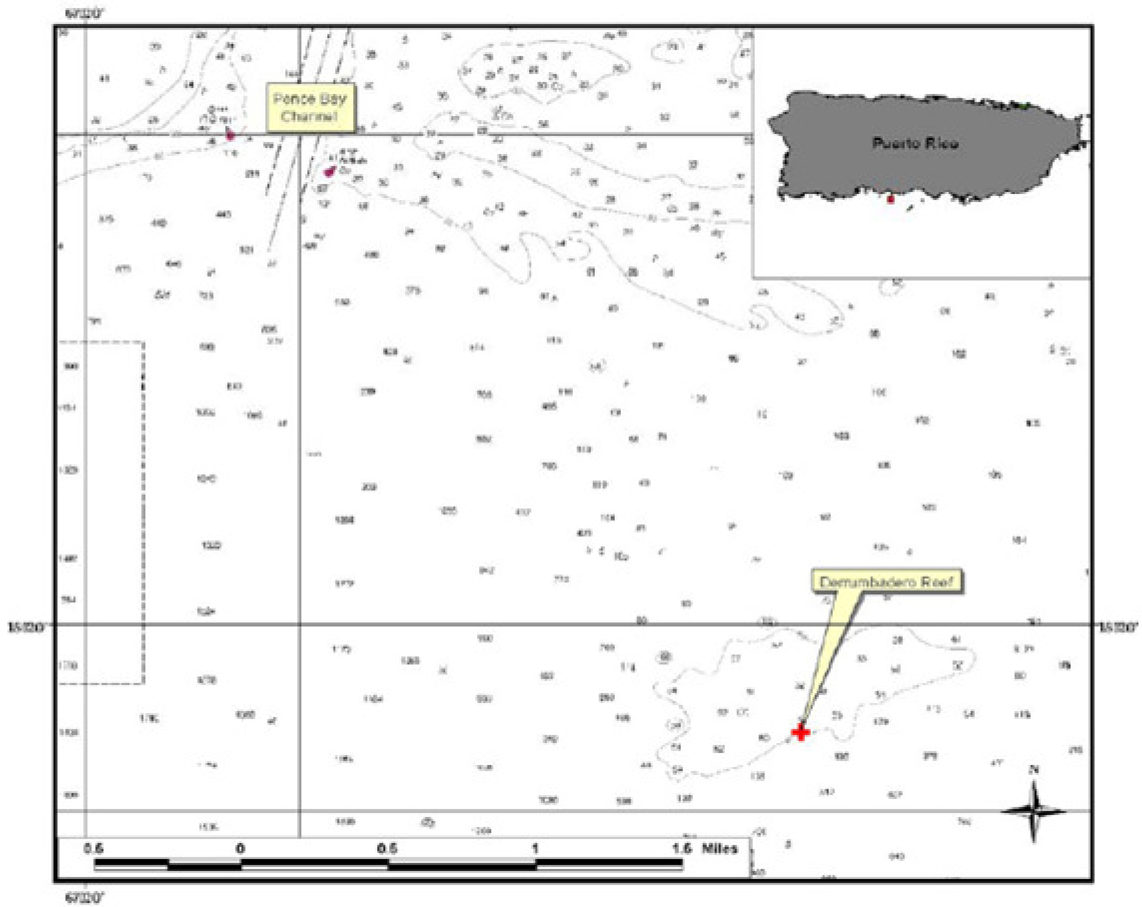

Figure 114: Location of the coral reef monitoring station at Derrumbadero Reef, Ponce (García-Sais, 2011, p. 148)

Table 24: Percent substrate cover by sessile-benthic categories at Derrumbadero Reef, Ponce Depth: 20m. July 2011 (García-Sais, 2011, p. 149)

	TRANSECTS					
	1	**2**	**3**	**4**	**5**	**MEAN**
Rugosity (m)	3.59	3.58	2.73	3.00	3.54	**3.29**
SUBSTRATE CATEGORY						
Abiotic						
Reef Overhangs	18.6	16.2	1.3	3.5	10.6	**10.0**
Rubble	1.8				0.9	
Sand			1.1			**0.2**
Total Abiotic	20.3	16.2	2.4	3.5	11.6	**10.8**
Benthic Algae						
Turf-mixed assemblage	32.8	46.5	53.0	46.3	30.7	**41.8**
Lobophora variegata	18.9	20.1	17.1	20.3	35.1	**22.3**
Dictyota sp.	10.8	3.3	3.5	2.2	2.5	**4.5**
Coralline algae			3.2	3.0		**1.2**
Halimeda discoidea		1.0				**0.2**
Total Benthic Algae	62.4	70.9	76.8	71.8	68.3	**70.0**
Encrusting Gorgonians						
Erythropodium caribaeorum		5.0	0.6			**1.1**
Total Encrusting Gorgonians	0.3	5.0	0.6	0.0	0.0	**1.2**
Erect Gorgonians (#colonies/transect)	27	39	31	37	20	**30.8**
Sponges	2.6	2.5	4.6	5.0	1.3	**3.2**
Cyanobacteria	1.6				1.6	**0.6**
Live Stony Corals						
Montastraea annularis	8.9	1.0	7.4	5.7	9.6	**6.5**
Porites astreoides	2.4	2.5	2.8	2.7	2.3	**2.5**
Montastraea cavernosa			2.7	4.2	3.1	**2.0**
Agaricia agaricites	0.5	0.6	1.4	4.0	1.5	**1.6**
Colpophyllia natans				2.2		**0.4**
Meandrina meandrites				0.6	0.9	**0.3**
Diploria strigosa			1.3			**0.3**
Diploria labyrinthiformis		0.8				**0.2**
Madracis decactis	0.6					**0.1**
Millepora alcicornis				0.4		**0.1**
Agaricia grahamae	0.4					**0.1**
Eusmilia fastigiata		0.4				**0.1**
Total Stony Corals	12.8	5.4	15.5	19.7	17.4	**14.2**

Table 25: Taxonomic composition and abundance of fishes within belt-transects at Derrumbadero Reef, Ponce. July 2011 (García-Sais, 2011, p. 153)

Depth: 20m

SPECIES	COMMON NAME	TRANSECTS 1	2	3	4	5	MEAN
		(Individuals/30 m²)					
Coryphopterus personatus	Masked Goby	46	22	73	4	31	**35.2**
Chromis cyanea	Blue Chromis	10	8	38	1	14	**14.2**
Thalassoma bifasciatum	Bluehead Wrasse	8	2	18	12	5	**9.0**
Coryphopterus lipernes	Peppermint Goby	13	2	5	7	17	**8.8**
Stegastes partitus	Bicolor Damselfish	12	9	3	7	13	**8.8**
Scarus iserti	Stripped Parrotfish	0	12	8	7	5	**6.4**
Gobiosoma evelynae	Sharknose Goby	10	3	1	4	8	**5.2**
Scarus taeniopterus	Princess Parrotfish	8	5	2	3	1	**3.8**
Clepticus parrae	Creole Wrasse	5	0	0	0	12	**3.4**
Sparisoma aurofrenatum	Redband Parrotfish	2	7	1	2	2	**2.8**
Halichoeres garnoti	Yellow-head Wrasse	2	1	3	2	1	**1.8**
Holocentrus rufus	Squirrelfish	1	3	1	3	1	**1.8**
Myripristis jacobus	Blackbar Soldierfish	5	0	0	0	4	**1.8**
Acanthurus chirurgus	Doctorfish	1	1	0	1	3	**1.2**
Stegastes leucostictus	Beau Gregory	1	1	2	1	1	**1.2**
Sparisoma radians	Bucktooth Parrotfish	1	0	2	2	0	**1.0**
Sparisoma viride	Stoplight Parrotfish	0	0	1	2	2	**1.0**
Acanthurus coeruleus	Blue Tang	0	1	1	1	1	**0.8**
Chaetodon capistratus	Four-eye Butterflyfish	1	0	2	1	0	**0.8**
Acanthurus bahianus	Ocean Surgeon	0	0	3	0	0	**0.6**
Caranx crysos	Blue runner	0	0	0	3	0	**0.6**
Cephalopholis cruentatus	Graysby	1	0	0	0	2	**0.6**
Haemulon flavolineatum	French Grunt	1	0	0	0	2	**0.6**
Melichthys niger	Black Durgon	0	0	0	0	3	**0.6**
Canthigaster rostrata	Caribbean Puffer	0	0	0	0	2	**0.4**
Chaetodon aculeatus	Longsnout Butterflyfish	1	0	1	0	0	**0.4**
Chromis multilineata	Brown Chromis	2	0	0	0	0	**0.4**
Neoniphon marianus	Longspine	0	0	1	0	1	**0.4**

	Squirrelfish						
Hypoplectrus chlorurus	Yellowtail Hamlet	0	0	2	0	0	**0.4**
Hypoplectrus puella	Barred Hamlet	0	0	1	1	0	**0.4**
Hypoplectrus unicolor	Butter Hamlet	1	0	0	0	1	**0.4**
Pomacanthus paru	French Angelfish	0	2	0	0	0	**0.4**
Anisotremus virginicus	Porkfish	0	0	0	0	1	**0.2**
Aulostomus maculatus	Trumpetfish	1	0	0	0	0	**0.2**
Carangoides ruber	Bar Jack	0	0	0	0	1	**0.2**
Table 51. Continued							
Chaetodon striatus	Banded Butterflyfish	0	0	1	0	0	**0.2**
Coryphopterus glaucofraenum	Bridled Goby	1	0	0	0	0	**0.2**
Equetus lanceolatus	Jacknife	0	0	0	0	1	**0.2**
Gymnothorax moringa	Golden moray	0	0	0	1	0	**0.2**
Haemulon sciurus	Bluestriped Grunt	0	0	0	0	1	**0.2**
Hypoplectrus nigricans	Black Hamlet	0	0	0	1	0	**0.2**
Mulloides martinicus	Yellowtail Goatfish	1	0	0	0	0	**0.2**
Lutjanus apodus	Schoolmaster Snapper	0	0	0	0	1	**0.2**
Ophioblennius atlanticus	Redlip Blenny	0	0	0	0	1	**0.2**
Ocyurus chrysurus	Yellowtail Snapper	1	0	0	0	0	**0.2**
Sphyraena barracuda	Great Barracuda	0	1	0	0	0	**0.2**
	TOTAL INDIVIDUALS	136	80	170	66	138	**118.0**
	TOTAL SPECIES	25	16	22	21	29	**22.6**

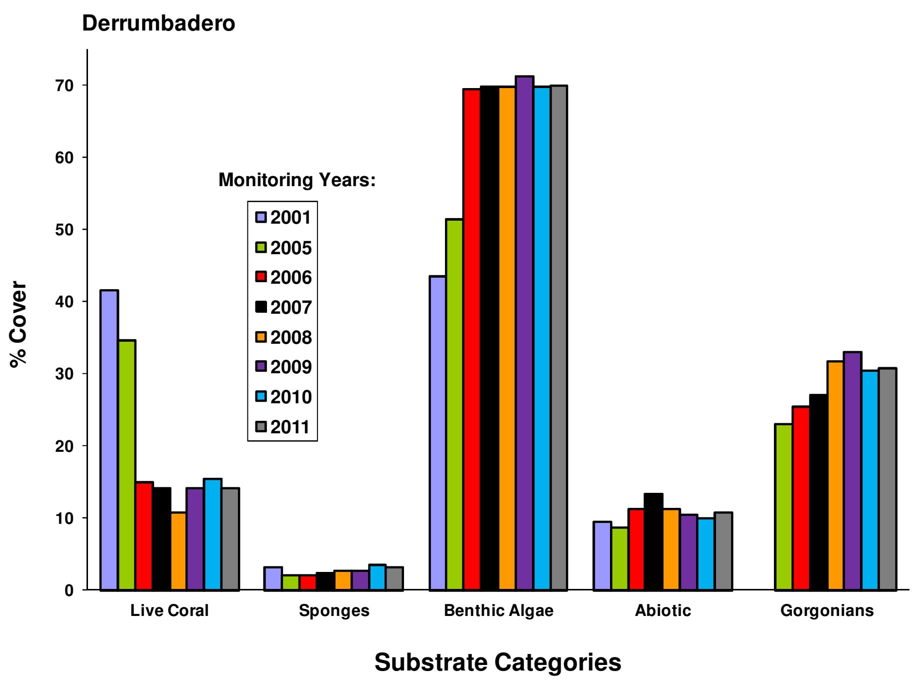

Figure 115: Monitoring trends (2001 – 2011) of mean substrate cover by sessile-benthic categories at Derrumbadero Reef, Ponce (García-Sais, 2011, p. 151)

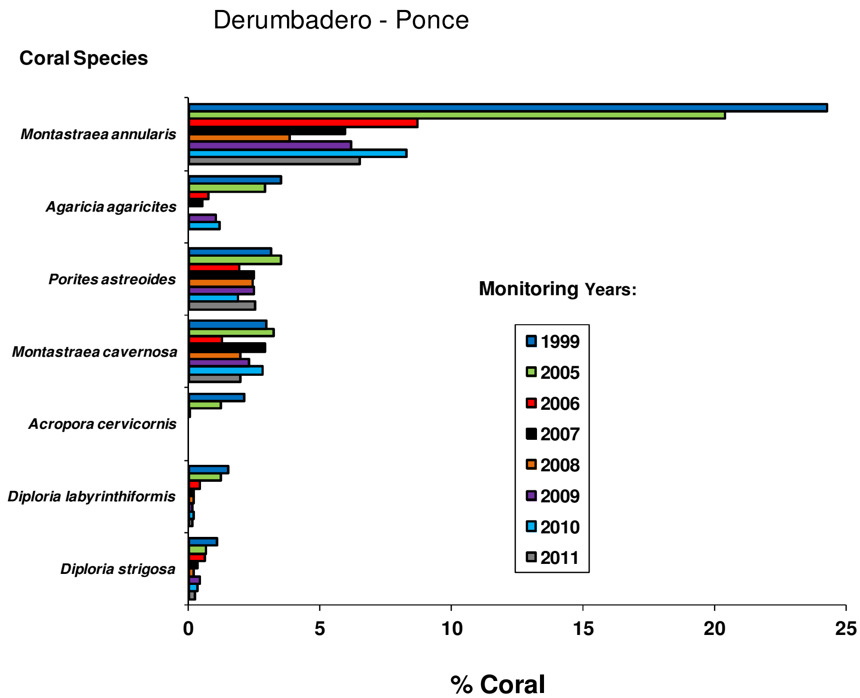

Figure 116: Monitoring trends (2001 – 2011) of mean substrate cover by coral species at Derrumbadero Reef, Ponce. (García-Sais, 2011, p. 151)

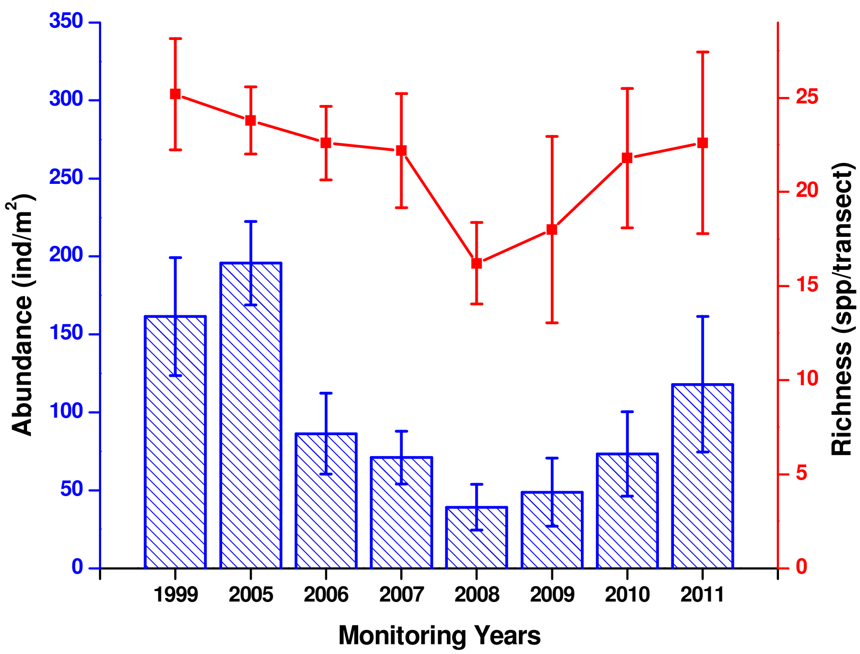

Figure 117: Monitoring trends (1999 – 2011) of fish species richness and abundance at Derrumbadero Reef, Ponce (García-Sais, 2011, p. 155)

El Seco Reef, Southeast Vieques

Table 26: Percent substrate cover by sessile-benthic categories at El Seco Reef, Vieques. October 2011 (García-Sais, 2011, p. 170)

	TRANSECTS					
						% Cover
Substrate categories	1	2	3	4	5	Mean
Abiotic						
Sand	2.3	0.3	0.3	3.0	1.0	**1.4**
Total Abiotic	2.3	0.3	0.3	3.0	1.0	**1.4**
Benthic Algae						
Turf Algae	27.7	24.0	29.0	32.3	34.7	**29.5**
Lobophora variegata	14.0	13.0	5.7	9.0	5.7	**9.5**
Coralline algae	6.0	2.7	4.3	5.0	5.0	**4.6**
Calcareous algae						
Halimeda sp.				0.3	0.3	**0.1**
Total Benthic Algae	47.7	39.7	39.0	46.7	45.7	**43.7**
Sponges	1.0	2.3	5.0	4.0	4.7	**3.4**
Encrusting Gorgonians	0.0	1.3	0.0	0.0	0.0	**0.3**
Erect Gorgonians						**0.2**
Cyanobacteria	8.7	5.0	5.3	6.3	6.0	**6.3**
Hydrocorals						
Millepora alcicornis		0.3			0.3	**0.1**
Scleractinian Corals						
Montastraea franksi	34.0	40.3	44.3	31.0	31.7	**36.3**
Porites astreoides	2.0	2.0	1.3	2.3	0.3	**1.6**
Agaricia lamarcki	0.7	1.7	2.3	2.3	0.7	**1.5**

Diploria strigosa				0.7	3.7	**0.9**
Montastraea cavernosa		1.7		0.3	1.0	**0.6**
Agaricia grahamae	0.7		0.3	1.0	1.0	**0.6**
Agaricia agaricites		0.3	0.7	1.0	0.7	**0.5**
unident coral	0.3	0.7			1.0	**0.4**
Siderastrea siderea		0.3	0.7		0.3	**0.3**
Porites furcata		0.7				**0.1**
Scolymia intersepta					0.3	**0.1**
Scolymia cubensis					0.3	**0.1**
Madracis decactis				0.3		**0.1**
Agaricia fragilis				0.33		**0.07**
Total Stony Corals	37.7	48.0	49.7	39.3	41.3	**43.1**

Depth: 35m		**TRANSECTS**					
		1	**2**	**3**	**4**	**5**	
		(Individuals/30 m^2)					
SPECIES	**Common Name**						**MEAN**
Clepticus parrae	Creole Wrasse	154	75	28	1	0	51.6
Coryphopterus personatus	Masked Goby	25	37	36	64	5	33.4
Chromis cyanea	Blue Chromis	12	10	1	3	1	5.4
Stegastes partitus	Bicolor Damselfish	6	5	8	2	5	5.2
Thalassoma bifasciatum	Bluehead Wrasse	5	13	1	1	2	4.4
Gramma loreto	Royal Gramma	1	7	1	4	6	3.8
Scarus taeniopterus	Princess Parrotfish	0	1	4	2	1	1.6
Halichoeres garnoti	Yellowhead Wrasse	1	1	1	2	2	1.4
Decapterus macarelus	Mackerel Scad	5	0	0	0	0	1.0
Acanthurus bahianus	Doctorfish	0	0	1	1	2	0.8

Canthigaster rostrata	Sharpnose Puffer	0	1	2	1	0	0.8
Bodianus rufus	Spanish Hogfish	0	2	0	1	0	0.6
Chaetodon aculeatus	Longsnout Butterflyfis	1	0	0	1	1	0.6
Coryphopterus lipernes	Peppermint Goby	0	0	0	0	3	0.6
Gobiosoma evelynae	Sharknose Goby	0	1	0	2	0	0.6
Sparisoma aurofrenatum	Redband Parrotfish	0	2	1	0	0	0.6
Sparisoma viride	Stoplight Parrotfish	1	0	0	2	0	0.6
Chaetodon capistratus	Four-eye Butterflyfish	0	1	0	0	1	0.4
Epinephelus cruentatus	Graysby	0	1	1	0	0	0.4
Epinephelus guttatus	Red Hind	0	1	0	1	0	0.4
Hypoplectrus chlorurus	Yellowtail Hamlet	0	1	0	1	0	0.4
Myripristis jacobus	Blackbar Soldierfish	2	0	0	0	0	0.4
Stegastes leucostictus	Beaugregory	0	0	1	0	1	0.4
Chromis insolata	Sunshine Chromis	1	0	0	0	0	0.2
Chromis multilineata	Brown Chromis	0	1	0	0	0	0.2
Haemulon flavolineatum	French Grunt	0	0	1	0	0	0.2
Holacanthus tricolor	Rock Beauty	0	0	0	1	0	0.2
Lutjanus cyanopterus	Cubera Snapper	0	1	0	0	0	0.2
Neoniphon marianus	Longjaw Squirrelfish	1	0	0	0	0	0.2
Pomacanthus arcuatus	Grey Angelfish	0	1	0	0	0	0.2
Scarus iserti	Striped Parrotfish	1	0	0	0	0	0.2
Scarus vetula	Queen Parrotfish	0	0	0	0	1	0.2
Sparisoma radians	Bucktooth Parrotfish	0	0	0	1	0	0.2
	TOTAL INDIVIDUALS	**216**	**162**	**87**	**91**	**31**	**117.4**
	TOTAL SPECIES	**15**	**19**	**14**	**18**	**13**	**15.8**

Isla de Mona

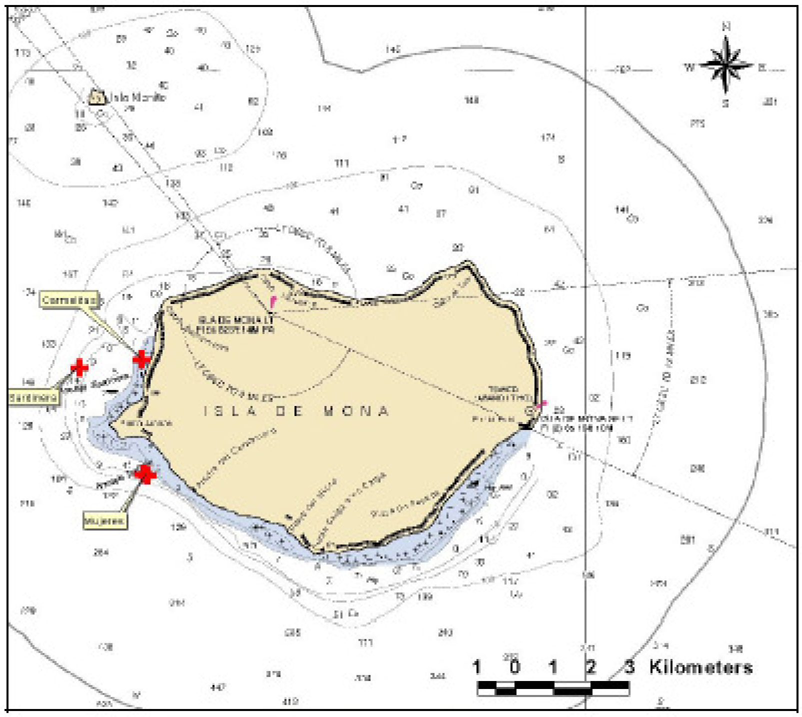

Figure 118: Location of reef sites surveyed at Isla de Mona Natural Reserve (García-Sais, 2008, p. 150)

3 locations

1. **Playa Mujeres Reef**
2. **Las Carmelitas Reef**
3. **Playa Sardinera Reef**

Not monitored in 2011 report, only in 2008

Playa Mujeres Reef

Table 27: Percent reef substrate cover by sessile-benthic categories at Playa Mujeres Reef, Mona Island. 20m, June 2008 (García-Sais, 2008, p. 151)

Depth:20 m	Transects					
	1	2	3	4	5	**MEAN**
Rugosity (m)	2.86	4.58	3.85	2.04	2.94	**3.25**
SUBSTRATE CATEGORY						
Abiotic						
Reef Overhangs	13.45	11.11	13.22	5.15	12.44	**11.07**
Sand*	0.99		1.52	1.66	4.02	**1.64**
Gaps	0.88	0.97			0.76	**0.52**
Total Abiotic	15.32	12.08	14.74	6.81	17.22	**13.23**
Benthic Algae						
Turf-mixed assemblage	37.09	31.76	57.37	80.56	64.65	**54.29**
Fleshy	31.03	32.10	6.00		2.18	**14.26**
Total Benthic Algae	68.12	63.86	63.37	80.56	66.83	**68.55**
Sponges	2.88	15.36	8.53	5.15	0.44	**6.47**
Cyanobacteria				0.35		**0.07**
Live Stony Corals						
Colpophyllia natans		1.55			12.28	**2.77**
Montastraea annularis	2.41	4.18	4.70	1.17		**2.49**
Porites astreoides	2.33	1.06	1.08	2.66	0.65	**1.56**
Agaricia agaricites	1.94		4.48		0.44	**1.37**
Siderastrea siderea	1.42		2.24		0.44	**0.82**
Diploria labyrinthiformis	2.30				0.98	**0.66**
Eusmilia fastigiata				3.28		**0.66**
Siderastrea radians	0.44	0.39	0.79		0.77	**0.48**
Montastraea cavernosa	1.53					**0.31**
Meandrina meandrites	1.32					**0.26**
Madracis decactis		1.03				**0.21**
Mycetophyllia aliciae		0.48				**0.10**
Total Stony Corals	13.69	8.69	13.29	7.11	15.56	**11.67**
Recently dead coral		2.40		18.94	13.36	**6.94**

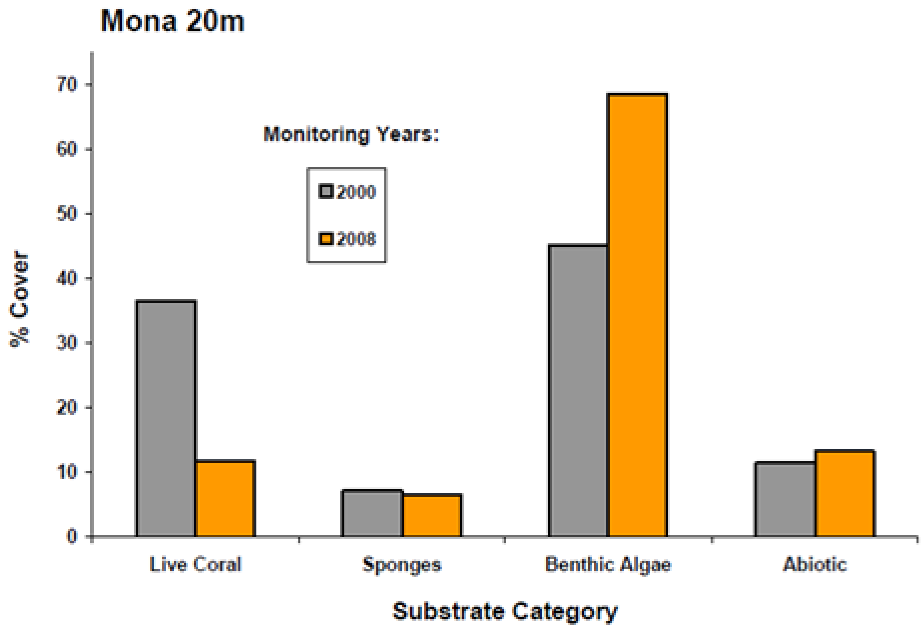

Figure 119: Monitoring tends (2000 and 2008) of mean substrate cover by sessile-benthic categories at Playa Mujeres Reef, Isla de Mona (García-Sais, 2008, p. 153)

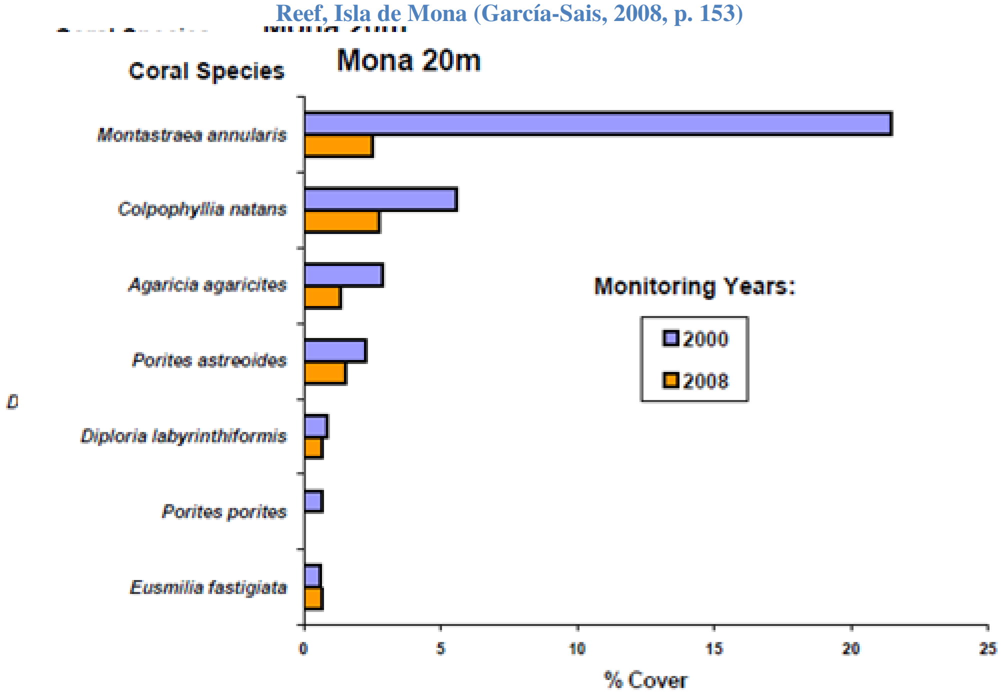

Figure 120: Monitoring trends (2000 to 2008) of mean substrate cover by coral species at Playa Mujeres Reef, Isla de Mona (García-Sais, 2008, p. 153)

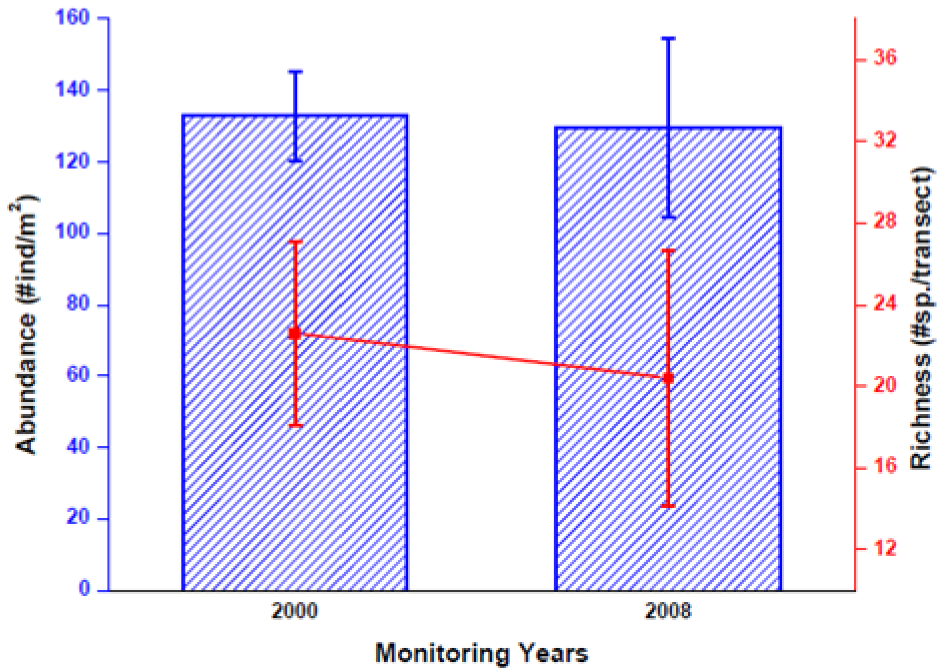

Figure 121: Monitoring trends (2000 to 2008) of fish species richness and abundance at Playa Mujeres Reef, Isla de Mona (García-Sais, 2008, p. 156)

Table 28: Taxonomic composition and abundance of fishes within belt-transects at Mujeres Reef, Isla de Mona. 20m. June, 2008 (García-Sais, 2008, p. 154)

Depth: 20m

SPECIES	COMMON NAME	Transects 1	2	3	4	5	MEAN
Chromis cyanea	Blue Chromis	32	50	6	30	40	31.6
Stegastes partitus	Bicolor Damselfish	28	12	32	28	14	22.8
Thalassoma bifasciatum	Bluehead Wrasse	13	16	6	6	16	11.4
Coryphopterus lipernes	Peppermint Goby	13	10	10	8	7	9.6
Chromis multilineata	Brown Chromis	15	6		7	5	6.6
Clepticus parrae	Creole Wrasse	20	8		1		5.8
Kyphosus sectatrix	Bermuda Chub		2		7	16	5
Halichoeres garnoti	Yellowhead Wrasse	8		4	1	5	3.6
Lutjanus apodus	Schoolmaster		8		9		3.4
Chaetodon capistratus	Foureye Butterflyfish	3	4	6	1	2	3.2
Gramma loreto	Fairy Basslet			9	7		3.2
Gobiosoma evelynae	Sharknose Goby	2	2	1	5	5	3
Scarus iserti	Striped Parrotfish	1	6	1	1	2	2.2
Stegastes planifrons	Threespot Damselfish		5	5			2
Sparisoma aurofrenatum	Redband Parrotfish			3	6	1	2
Myripristis jacobus	Blackbar Soldierfish				7	2	1.8
Coryphopterus personatus	Masked Goby	5			1		1.2
Stegastes adustus	Dusky Damselfish		6				1.2
Bodianus rufus	Spanish Hogfish		5				1
Epinephelus guttatus	Red Hind	3	1				0.8
Cephalopholis cruentatus	Graysby		1	1	2		0.8
Halichoeres bivittatus	Slippery Dick	1			1	1	0.6
Haemulon flavolineatum	French Grunt		1		1	1	0.6
Acanthurus coeruleus	Blue Tang			2	1		0.6
Holocentrus adscensionis	Squirrelfish				1	2	0.6
Holocentrus rufus	Squirrelfish				2	1	0.6
Holacanthus tricolor	Rockbeauty	1			1		0.4
Melichthys niger	Black Durgeon	1			1		0.4
Scarus taeniopterus	Princess Parrotfish	1		1			0.4
Sparisoma radians	Bucktooth Parrotfish				1	1	0.4
Apogon townsendi	Belted Cardinalfish					2	0.4
Neoniphon marianus	Longjaw Squirrelfish	1					0.2
Coryphopterus glaucofraenum	Bridled Goby		1				0.2
Calamus calamus	Saucereye Porgy		1				0.2
Bothus lunatus	Peacock Flounder			1			0.2
Acanthemblemaria spinosa	Sinyhead blenny					1	0.2
Malacoctenus triangulatus	Saddled Beinny					1	0.2
Mycteroperca tigris	Tiger Grouper				1		0.2
Gobiosoma saucrum	Leopard Goby				1		0.2
Gymnothorax moringa	Spotted Moray				1		0.2
Epinephelus adscensionis	Rock Hind				1		0.2

Las Carmelitas Reef

Table 29: Percent reef substrate cover by sessile-benthic categories at Las Carmelitas Reef, Isla de Mona, June 2008 (García-Sais, 2008, p. 161)

Depth: 10 m	Transects					
	1	2	3	4	5	MEAN
Rugosity (m)	2.44	5.65	2.85	2.52	0.66	**2.82**
SUBSTRATE CATEGORY						
Abiotic						
Reef Overhangs	14.95	18.43	13.15	8.55	10.98	**13.21**
Total Abiotic	14.95	18.43	13.15	8.55	10.98	**13.21**
Benthic Algae						
Turf-mixed assemblage	78.70	50.38	73.00	72.02	28.80	**60.58**
Fleshy	2.15	9.63	0.44	3.36	47.94	**12.70**
Calcareous			1.64			**0.33**
Total Benthic Algae	80.85	60.01	75.08	75.38	76.74	**73.61**
Cyanobacteria			4.20	4.40	5.25	**2.77**
Zoanthids		1.08				**0.22**
Live Stony Corals						
Porites astreoides	1.85	2.42	3.42	3.68	4.78	**3.23**
Montastraea annularis (complex)		12.12		1.01		**2.63**
Montastraea cavernosa		3.59	2.33	1.91		**1.57**
Agaricia agaricites	1.13	1.47		1.20	0.26	**0.81**
Agaricia tenuifolia			1.86			**0.37**
Porites divaricata				1.69		**0.34**
Siderastrea siderea				1.60		**0.32**
Agaricia grahamae	0.68	0.90				**0.32**
Diploria strigosa					1.45	**0.29**
Eusmilia fastigiata	0.57					**0.11**
Colpophyllia natans				0.56		**0.11**
Madracis decactis					0.53	**0.11**
Total Stony Corals	4.23	20.5	7.61	11.65	7.02	**10.20**
Recently dead coral	32.64	9.06	33.77			**15.09**

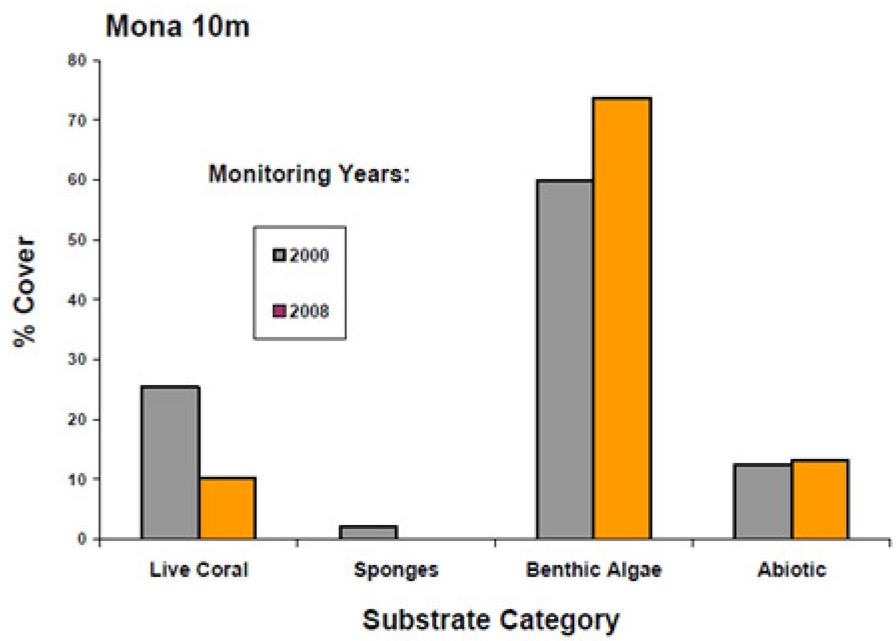

Figure 122: Monitoring trends (2008and 2008) of mean substrate cover by sessile-benthic categories at Las Carmelitas Reef, Isla de Mona (García-Sais, 2008, p. 163)

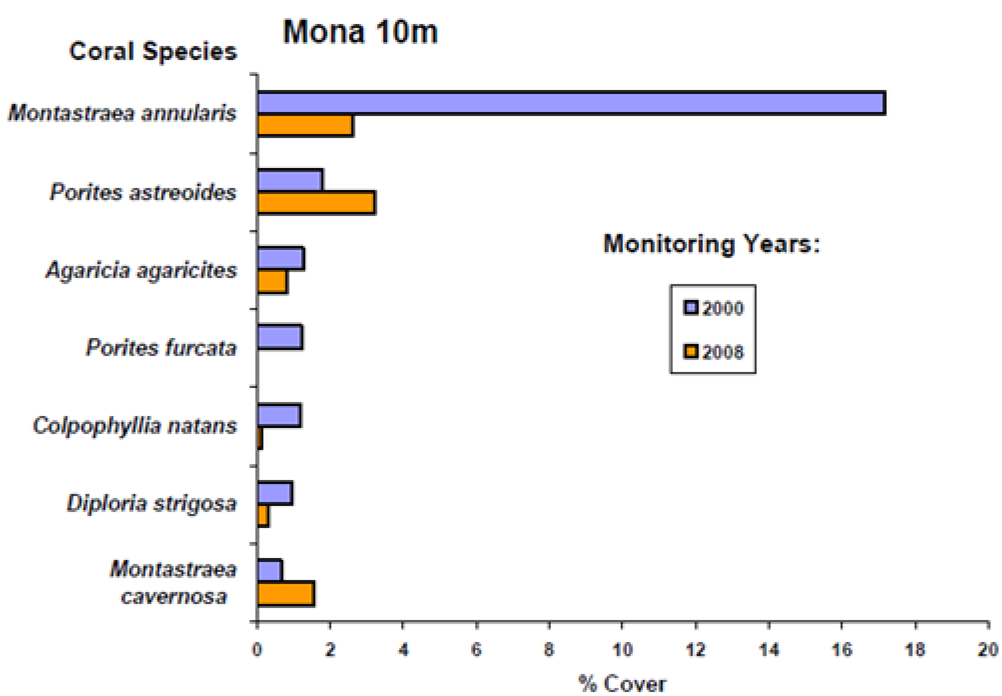

Figure 123: Monitoring trends (2000 to 2008) of mean substrate cover by coral species at Las Carmelitas Reef, Isla de Mona (García-Sais, 2008, p. 163)

Table 30: Taxonomic composition and abundance of fishes within belt-transects at Las Carmelitas Reef. 10m, Isla de Mona. June, 2008 (García-Sais, 2008, p. 165)

Depth: 10m

SPECIES	COMMON NAME	Transects 1	2	3	4	5	MEAN
Gramma loreto	Royal Gramma	15	38	50	30	6	**27.8**
Thalassoma bifaciatum	Bluehead Wrasse	17	46	32	7	17	**23.8**
Stegastes partitus	Bicolor Damselfish	14	5	6	13	6	**8.8**
Gobiosoma evelynae	Sharknose Goby	6	15	8	10	2	**8.2**
Chromis cyanea	Blue Chromis	4	6	10	18	1	**7.8**
Chromis multilineata	Brown Chromis	4	4	15	5	5	**6.6**
Halichoeres garnoti	Yellowhead Wrasse	3	6	5	3	5	**4.4**
Stegastes adustus	Dusky Damserfish	8	1	2		2	**2.6**
Stegastes leucostictus	Beaugregory		1	3	2	5	**2.2**
Coryphopterus personatus	Masked Goby		10				**2.0**
Scarus iserti	Striped Parrotfish	1	4	4			**1.8**
Acanthurus coeruleus	Blue Tang	1	2	3	2		**1.6**
Malacoctenus triangulatus	Saddled Blenny		4	1	1	2	**1.6**
Sparisoma viride	Stoplight Parrotfish	2	1	2	1	2	**1.6**
Sparisoma radians	Bucktooth Parrotfish	1	2		4		**1.4**
Microspathodon chrysurus	Yellowtail Damselfish	1	1	4		1	**1.4**
Bodianus rufus	Spanish Hogfish	1	4				**1.0**
Holocentrus adscensionis	Squirrelfish	1	3	1			**1.0**
Canthigaster rostrata	Caribbean Puffer	1	1	1	2		**1.0**
Acanthurus bahianus	Ocean Surgeonfish	2				1	**0.6**
Holacanthus tricolor	Rock Beauty	1	2				**0.6**
Haemulon flaveolineatum	French Grunt		2	1			**0.6**
Myripristis jacobus	Blackbar Soldierfish		2	1			**0.6**
Epinephelus adscencionis	Rock Hind		2				**0.4**
Pempheris schomburgki	Glassy Sweeper		2				**0.4**
Chaetodon striatus	Banded Butterflyfish				2		**0.4**
Halichoeres maculipinna	Clown Wrasse	1				1	**0.4**
Cephalopholis cruentatus	Graysby		1		1		**0.4**
Neoniphon marianus	Longspine Squirrelfish	1	1				**0.4**
Stegastes planifrons	Threespot Damselfish	1		1			**0.4**
Chaetodon capistratus	Foureye Butterflyfish	1					**0.2**
Abudefduf saxatilis	Sargent Major	1					**0.2**
Lutjanus apodus	Schoolmaster		1				**0.2**
Clepticus parrae	Creole Wrass		1				**0.2**
Halichoeres bivittatus	Slippery Dick				1		**0.2**
Epinephelus guttatus	Red Hind					1	**0.2**
	TOTAL INDIVIDUALS	88	168	150	102	57	**113.0**
	TOTAL SPECIES	23	28	19	16	15	**20.2**

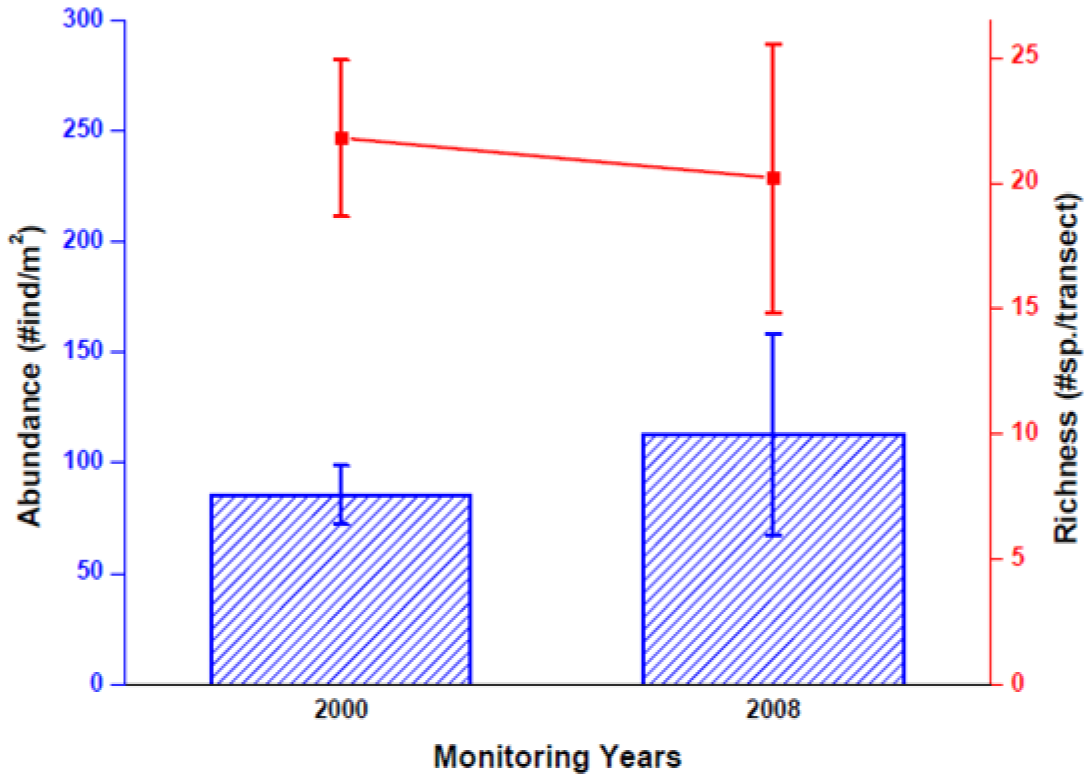

Figure 124: Monitoring trends (2000 to 2008) of fish species richness and abundance at Carmelitas Reef, Isla de Mona (García-Sais, 2008, p. 166)

Playa Sardinera Reef

Table 31: Percent reef substrate cover by sessile-benthic categories at Playa Sardinera, 30m, Mona Island. June 2008 (García-Sais, 2011, p. 171)

	Transects					
Depth: 30 m	1	2	3	4	5	MEAN
Rugosity (m)	2.23	3.14	2.80	3.94	3.56	3.13
SUBSTRATE CATEGORY						
Abiotic						
Reef Overhangs	10.71	11.79	12.93	13.41	21.37	14.04
Sand		1.29	3.17			0.89
Gaps		0.96	1.70		0.52	0.64
Total Abiotic	10.71	14.04	17.80	13.41	21.89	15.57
Benthic Algae						
Turf-mixed assemblage	57.73	56.05	57.67	51.33	28.96	50.35
Fleshy	4.50	8.97	10.44	14.27	25.35	12.71
Total Benthic Algae	62.23	65.02	68.11	65.60	54.31	63.05
Cyanobacteria	12.92	10.72	9.40	4.87	3.54	8.29
Sponges	7.60	6.77	1.61	15.34	6.78	7.62
Encrusting gorgonians		0.23				0.05
Live Stony Corals						
Montastraea annularis	1.96		1.70		9.95	2.72
Diploria strigosa		2.89				0.58
Montastraea cavernosa	2.07		0.68			0.55
Porites astreoides	1.50					0.30
Isophyllia rigida					1.25	0.25
Agaricia lamarcki					1.14	0.23
Agaricia agaricites		0.30		0.81		0.22
Stephanocoenia michelini	1.06					0.21
Meandrina meandrites					0.93	0.19
Leptoseris cucullata			0.68			0.14
Madracis decactis					0.21	0.04
Total Stony Corals	6.59	3.19	3.06	0.81	13.48	5.43
Erect Gorgonians (# col/transect)	11	9	5	14	7	9.2

Table 32: Taxonomic composition and abundancee of fishes within belt-transects at Playa Sardinera Reef, 30m, Isla de Mona. June, 2008 (García-Sais, 2011, p. 173)

Depth: 30m

SPECIES	COMMON NAME	Transects 1	2	3	4	5	MEAN
Chomis cyanea	Blue Chromis	60	42	64	75	25	53.2
Clepticus parrae	Creole Wrasse	50		100	48	60	51.6
Stegastes partitus	Bicolor Damselfish	32	42	24	43	32	34.6
Gobiosoma evelynae	Sharknose Goby	11	18	12	13	21	15.0
Gramma loreto	Fairy Basslet	13	2	10	13	34	14.4
Coryphopterus personatus	Masked Goby			10	15	30	11.0
Thalassoma bifasciatum	Bluehead Wrasse	15	7	4	6	11	8.6
Halichoeres garnoti	Yellow head Wrasse	5	4	10	3	5	5.4
Scarus iserti	Striped Parrotfish		1	2	1	13	3.4
Coryphopterus lipernes	Peppermint Goby	1				14	3.0
Chromis multilineata	Brown Chromis				6	7	2.6
Sparisoma aurofrenatum	Redband Parrotfish	2	3	1	1		1.4
Cephalopholis cruentatus	Graysby	2		3		1	1.2
Chromis insolata	Sunshinefish			1	1	4	1.2
Acanthurus bahianus	Ocean Surgeon	1	1			1	0.6
Holacanthus tricolor	Rock Beauty	1			1	1	0.6
Serranus dewegeri	Vieja	1	2				0.6
Neoniphon marianus	Longjaw Squirrelfish		1			2	0.6
Pomacanthus paru	French Angelfish					3	0.6
Myripristis jacobus	Blackbar Soldierfish					3	0.6
Holocentrus adscensionis	Longjaw Squirrelfish	1			1		0.4
Sparisoma viride	Stoplight Parrotfish	1				1	0.4
Acanthostracion polygonia	Honeycomb Cowfish	1			1		0.4
Chaetodon sedentarius	Reef Butterflyfish		2				0.4
Bodianus rufus	Spanish Hogfish			1		1	0.4
Epinephelus guttatus	Red Hind				1	1	0.4
Chaetodon capistratus	Foureye Butterflyfish					2	0.4
Cephalopholis fulva	Coney		1				0.2
Chaetodon aculeatus	Longsnout Butterflyfish		1				0.2
Acanthurus coeruleus	Blue Tang		1				0.2
Malacoctenus triangulatus	Saddled Blenny		1				0.2
Canthigaster rostrata	Caribbean Puffer		1				0.2
Sparisoma radians	Bucktooth Parrotfish				1		0.2
Haemulon flavolineatum	French Grunt					1	0.2
Halichoeres maculipinna	Clown Wrasse					1	0.2
Sphyraena barracuda	Greate Barracuda					1	0.2
Caranx lugubris	Black Jack					1	0.2
	TOTAL INDIVIDUALS	**197**	**130**	**242**	**230**	**276**	**215**
	TOTAL SPECIES	**16**	**17**	**15**	**18**	**26**	**18.4**

Cayo Coral – Guánica Natural Reserve

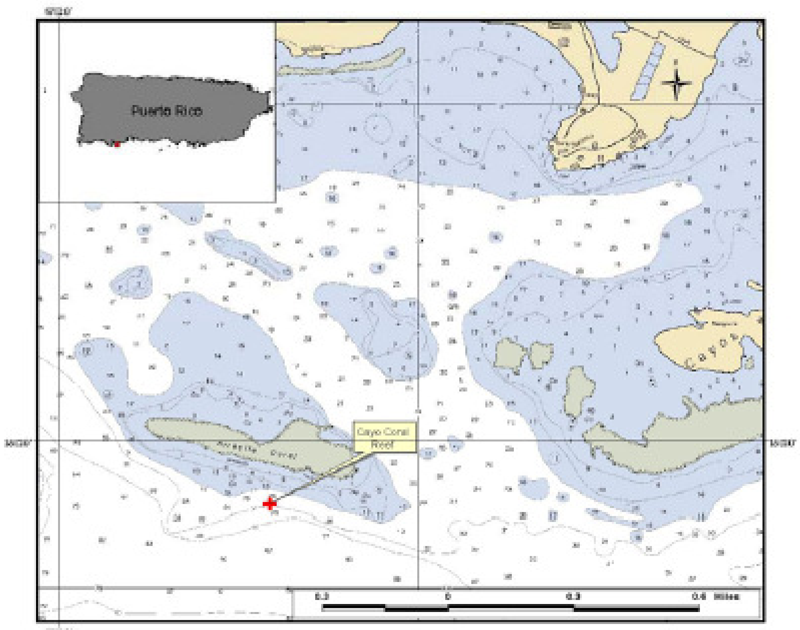

Figure 125: Location of coral reef survey stations at Cayo Coral reef, Guanica (García-Sais, 2011, p. 113)

Table 33: Percent substrate cover by sessile-benthic categories at Cayo Coral Reef, Guanica, 10 m. July 2011 (García-Sais, 2011, p. 115)

Depth: 10 m	TRANSECTS					
	1	2	3	4	5	MEAN
Rugosity (m)	2.23	4.83	3.55	4.17	4.69	3.89
SUBSTRATE CATEGORY						
Abiotic						
Reef Overhangs	14.9	19.7	10.6	18.0	9.9	14.6
Silt	1.2		10.2	12.9		4.8
Rubble	1.0			8.3	7.9	3.4
Total Abiotic	17.1	20.2	20.8	39.2	17.8	23.0
Benthic Algae						
Turf-mixed assemblage	65.3	60.8	54.4	46.8	70.4	59.5
Dictyota sp.	1.7			8.5		2.0
Halimeda discoidea					0.5	0.1
Total Benthic Algae	67.1	60.8	54.4	55.3	70.9	61.7
Encrusting Gorgonians						
Erythropodium caribaeorum	0.4	0.5		0.4		0.3
Total Encrusting Gorgonians	0.4	0.5	0.0	0.4	0.0	0.3
Sponges	3.4		2.9			1.3
Xestospongia muta	0.8					0.2
Total sponges	4.2	0.0	2.9	0.0	0.0	1.4
Anemone		0.5				0.1
Zoanthids		2.3	1.0		0.9	0.8
Live Stony Corals						
Montastraea annularis	3.4	5.4	2.9	1.7	6.1	3.9
Porites astreoides	1.0	2.5	2.6	2.0	3.0	2.2
Colpophyllia natans			8.6	0.6		1.8
Montastraea cavernosa	3.4	1.4	0.6	0.9	0.9	1.4
Siderastrea siderea		3.8	0.6			0.9
Porites divaricata			2.6			0.5
Diploria strigosa	1.4	1.0				0.5
Meandrina meandrites			2.0			0.4
Porites porites	0.6	1.0				0.3
Siderastrea radians	1.5					0.3
Madracis decactis			0.9			0.2
Agaricia agaricites		0.2			0.6	0.2
Eusmilia fastigiata		0.6				0.1
Total Stony Corals	11.3	15.8	20.8	5.2	10.5	12.7

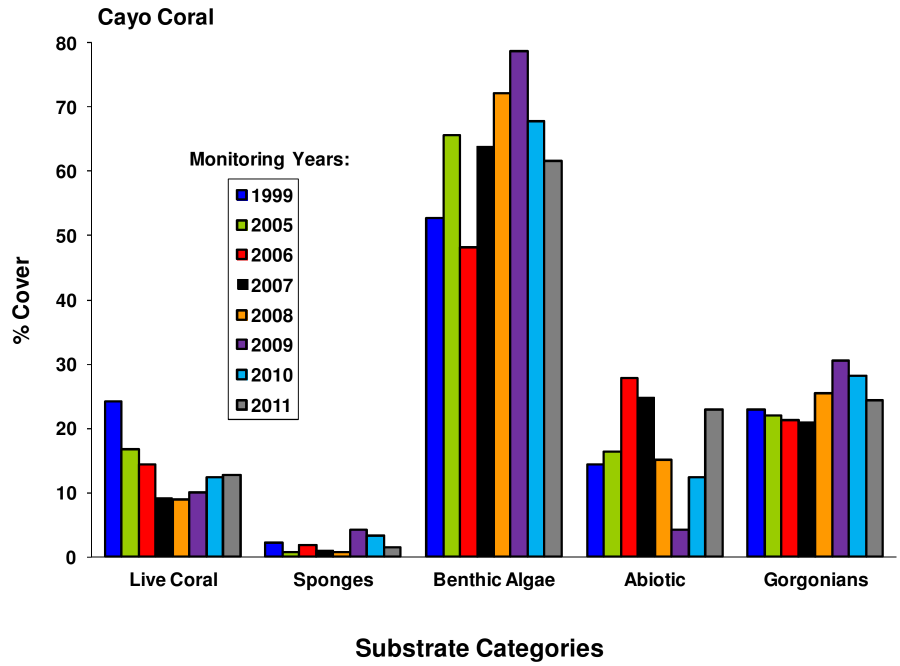

Figure 126: Monitoring trends (1999 – 2011) of mean substrate cover by sessile-benthic categories at Cayo Coral – 8 m, Guánica. (García-Sais, 2011, p. 117)

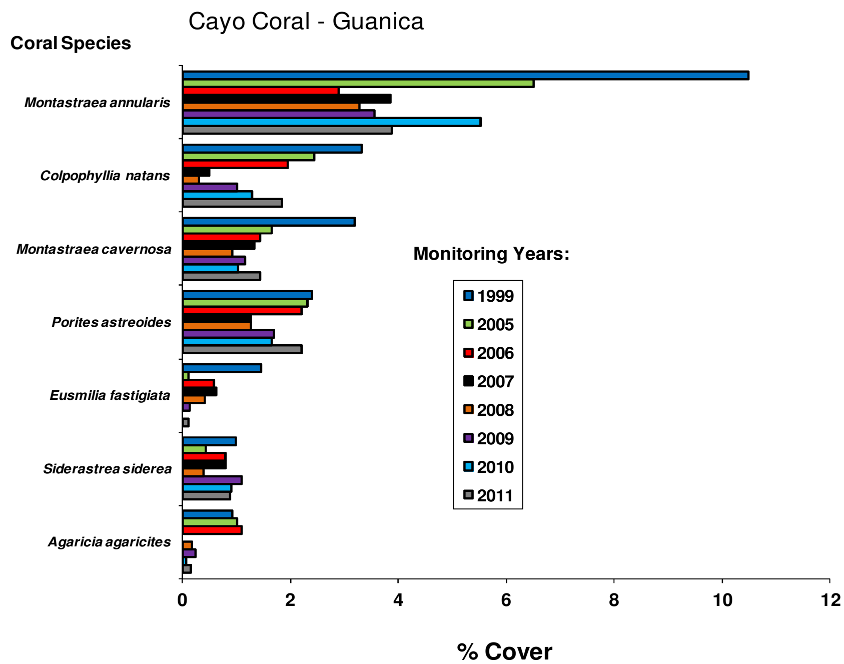

Figure 127: Monitoring trends (1999 – 2011) of mean substrate cover by stony coral species at Cayo Coral – 8 m, Guánica (García-Sais, 2011, p. 117)

Table 34: Taxonomic composition and abundance of fishes within belt-transects at Cayo Coral-Guanica, 7m, July 2011 (García-Sais, 2011, p. 118)

Depth: 8 - 10 m		TRANSECTS					
		1	2	3	4	5	
		(individuals/30 m^2)					
SPECIES	**COMMON NAME**						**MEAN**
Thalassoma bifasciatum	Bluehead Wrasse	0	6	7	16	5	**6.8**
Stegastes dorsopunicans	Dusky Damselfish	7	5	6	7	4	**5.8**
Gobiosoma evelynae	Sharknose Goby	1	5	9	2	6	**4.6**
Chaetodon capistratus	Four-eye Butterflyfish	2	1	1	5	2	**2.2**
Scarus iserti	Stripped Parrotfish	0	0	3	3	5	**2.2**
Microspathodon chrysurus	Yellowtail Damselfish	3	1	3	2	1	**2.0**
Chromis cyanea	Blue Chromis	4	0	1	1	3	**1.8**
Sparisoma viride	Stoplight Parrotfish	1	1	4	1	2	**1.8**
Stegastes leucostictus	Beau Gregory	2	1	1	2	3	**1.8**
Stegastes partitus	Bicolor Damselfish	2	1	0	1	5	**1.8**
Coryphopterus personatus	Masked Goby	7	0	0	0	0	**1.4**
Acanthurus bahianus	Ocean Surgeon	1	0	1	0	3	**1.0**
Sparisoma aurofrenatum	Redband Parrotfish	2	1	1	0	1	**1.0**

Canthigaster rostrata	Caribbean Puffer	1	0	1	2	0	**0.8**
Halichoeres garnoti	Yellow-head Wrasse	0	0	1	3	0	**0.8**
Holocentrus rufus	Squirrelfish	1	1	2	0	0	**0.8**
Acanthurus coeruleus	Blue Tang	0	0	1	0	2	**0.6**
Cephalopholis cruentatus	Graysby	1	1	1	0	0	**0.6**
Coryphopterus lipernes	Peppermint Goby	0	0	2	1	0	**0.6**
Haemulon flavolineatum	French Grunt	0	0	2	0	1	**0.6**
Sparisoma rubripinne	Yellowtail Parrotfish	0	3	0	0	0	**0.6**
Abudefduf sexatilis	Sergeant Major	0	0	1	0	1	**0.4**
Chaetodon striatus	Banded Butterflyfish	1	0	0	0	1	**0.4**
Coryphopterus glaucofraenum	Bridled Goby	0	1	0	1	0	**0.4**
Serranus tigrinus	Harlequin Bass	0	0	1	0	1	**0.4**
Scomberomorus regalis		2	0	0	0	0	**0.4**
Aulostomus maculatus	Trumpetfish	0	0	1	0	0	**0.2**
Bodianus rufus	Spanish Hogfish	0	0	0	0	1	**0.2**
Gramma loreto	Fairy Basslet	0	0	1	0	0	**0.2**
Equetus lanceolatus	Jacknife	0	0	1	0	0	**0.2**
Holacanthus ciliaris	Queen Angelfish	0	0	1	0	0	**0.2**
Hypoplectrus chlorurus	Yellowtail Hamlet	0	1	0	0	0	**0.2**
Hypoplectrus puella	Barred Hamlet	0	0	1	0	0	**0.2**
Neoniphon marianus	Longspine Squirrelfish	0	0	0	0	1	**0.2**
Mulloides martinicus	Yellowtail Goatfish	1	0	0	0	0	**0.2**
Pterois volitans	Lionfish	0	1	0	0	0	**0.2**

Table 36. Continued

Scarus taeniopterus	Princess Parrotfish	0	0	0	1	0	**0.2**
	TOTAL INDIVIDUALS	39	30	54	48	48	**43.8**
	TOTAL SPECIES	17	15	25	15	19	**18.2**

Table 35: Percent substrate cover by sessile-benthic categories at Cayo Aurora, Guanica. July 2011 (García-Sais, 2011, p. 127)

Depth: 2 - 5 m	**TRANSECT**					
	1	2	3	4	5	**MEAN**
Rugosity (m)	5.2	7.3	8.8	6.6	2.4	**6.1**
SUBSTRATE CATEGORY						
Abiotic						
Reef Overhangs	14.8	16.3	26.2	19.9	7.0	**16.8**
Gaps	2.8					**0.6**
Total Abiotic	17.6	16.3	26.2	19.9	7.0	**17.4**
Benthic Algae						
Turf-mixed assemblage	44.5	53.0	34.5	37.1	16.0	**37.0**

Coralline algae	0.9			1.3		**0.4**
Total Benthic Algae	45.5	53.0	34.5	38.4	16.0	**37.5**
Encrusting Gorgonians						
Erythropodium caribaeorum			1.5	1.8		**0.7**
Total Encrusting Gorgonians	0.0	0.0	1.5	1.8	0.0	**0.7**
Erect Gorgonians (# colonies/transect)	1	0	7	3	0	**2.2**
Sponges			1.5			**0.3**
Anthosigmella varians	3.8	1.6	9.0	2.1		**3.3**
Total Sponges	3.8	1.6	10.5	2.1	0.0	**3.6**
Zoanthids *Palythoa caribaeorum*	4.3		1.5	4.7		**2.1**
Live Stony Corals						
Acropora palmata	26.8	27.7	20.6	22.0	77.0	**34.8**
Siderastrea siderea	1.1	0.8	1.5	9.5		**2.6**
Diploria strigosa			3.0	2.0		**1.0**
Porites astreoides	0.9	0.6	0.7			**0.4**
Total Stony Corals	28.8	29.1	25.8	33.5	77.0	**38.8**

Table 36: Taxonomic composition and abundance of fishes within belt-transects at the fringing Elkhorn Coral Reef Cayo Aurora, Guanica. July 2011 (García-Sais, 2011, p. 129)

Depth: 2 – 5 m

SPECIES	COMMON NAME	Transects 1	2	3	4	5
		Individuals/30m^2				
Thalassoma bifasciatum	Bluehead wrasse	14	2	10	44	0
Stegastes partitus	Bicolor Damselfish	7	2	14	17	4
Stegastes adustus	Dusky Damselfish	6	5	5	10	16
Microspathodon chrysurus	Yellowtail damselfish	5	5	2	7	14
Haemulon flavolineatum	French Grunt	0	3	1	0	22
Ophioblennius atlanticus	Redlip blenny	4	1	7	8	4
Abudefduf sexatilis	Sargent Major	6	0	0	0	14
Chromis multilineata	Brown Chromis	0	0	0	13	0
Chaetodon capistratus	Four-eye Butterflyfish	3	1	2	0	3
Sargocentron vexillarium	Dusky Squirrelfish	0	0	0	0	6
Acanthurus chirurgus	Doctorfish	0	0	2	3	0
Sparisoma aurofrenatum	Redband Parrotfish	1	1	1	1	1
Scarus iserti	Striped Parrotfish	0	0	2	2	0
Sparisoma radians	Bucktooth parrotfish	3	1	0	0	0
Aulostomus maculatus	Trumpetfish	0	1	1	0	1
Acanthurus coeruleus	Blue tang	0	0	1	2	0
Halichoeres maculipinna	Clown wrasse	0	1	1	1	0
Halichoeres radiates	Pudding wife	0	1	1	1	0
Epinephelus cruentatus	Graysby	0	0	0	1	1
Heteropricantus cruentatus	Bigeye	0	1	0	0	1
Anisotremus virginicus	Porkfish	0	0	1	0	0
Canthigaster rostrata	Caribbean puffer	0	0	0	1	0
Caranx ruber	Bar jack	0	0	0	0	1
Haemulon melanorum	Cottonwick	0	0	0	1	0
Halichoeres garnoti	Yellowhead Wrasse	1	0	0	0	0
Haemulon carbonarium	Cesar Grunt	1	0	0	0	0
Halichoeres bivittatus	Slippery dick	1	0	0	0	0
Holocentrus adcensionis	Longjaw squirrelfish	0	1	0	0	0
Holocentrus rufus	Squirrelfish	0	0	0	0	1
Lutjanus mahogany	Mahogany Snapper	0	0	1	0	0
Malacoctenus triangulates	Saddled blenny	0	0	1	0	0
Neoniphon marianus	Longspine Squirrelfish	0	0	1	0	0
Sparisoma rubripinne	Yellowtail parrotfish	0	0	0	0	1
Sparisoma viride	Stoplight parrotfish	0	1	0	0	0
Stegastes planifrons	Three-spot Damselfish	0	0	0	0	1
	TOTAL INDIVIDUALS	52	27	54	112	91
	TOTAL SPECIES	12	15	18	15	16

Appendix G: Reef by Reef Analysis

The goal of our project was to identify the trends behind non-environmental and climate-related stressors on Puerto Rico's coral reefs by developing a comprehensive set of Geographic Informational System (GIS) maps. We compiled various map layers created by the DRNA into more organized GIS maps, which allowed us to determine problems and their potential cause at each of the specific nine coral reef monitoring sites. These GIS maps permitted us to determine possible solutions to protect the damaged reefs by identifying trends and patterns of coral degradation. In addition to this, archival research of past reports and interviews with experts from the University of Puerto Rico and the DRNA were conducted to provide us with further insights.

Coral Reef Characteristics

Although every one of Puerto Rico's coral reefs has seen some form of degradation in the past decade, there have been some reefs that have specifically been more significantly damaged. The DRNA's 2011 Coral Reef Monitoring Report and the Caribbean Coral Reef Institutes 2010 reports provide the data we were able to analyze (see Appendix F for a more complete data set). The Marine Reserves that were analyzed in the 2008 report were Isla Desecheo, Isla de Mona, Rincon, Guanica, Ponce, Caja de Muerto and Mayaguez Bay. For this section we discussed the trends found in the coral reefs that lead to recommendations found in section 5.2.

Tres Palmas Reef – Rincon

The Tres Palmas Reef system has recorded data from three different reef depths, which are 5 meters (m), 10m and 20m. At the 5m depth there has been a slight decline in the amount of live coral, along with a slight increase in the amount of algae and abiotic coverage. This leads us to believe that in the shallow depths of 5m, the coral has been negatively affected by the sediment that has been kicked up. The decline seen in figure 129, started in 2008, the same year there were abnormally large waves during Holy Week. Also, this fringing reef is particularly susceptible to rainfall runoff from the main island. In the past this runoff has deposited large amounts of terrestrial sediment into the ocean. This should be closely monitored, as it is a serious threat to this delicate reef. Also, Professor Garcia-Sais in his 2011-2012 Report states that the fringing reef at 5m is suffering from the white pox disease, also known as "patchy necrosis." This disease is evidence of a very delicate and fragile reef, whose conditions must be closely monitored to ensure the entire reef does not fall victim to this disease.

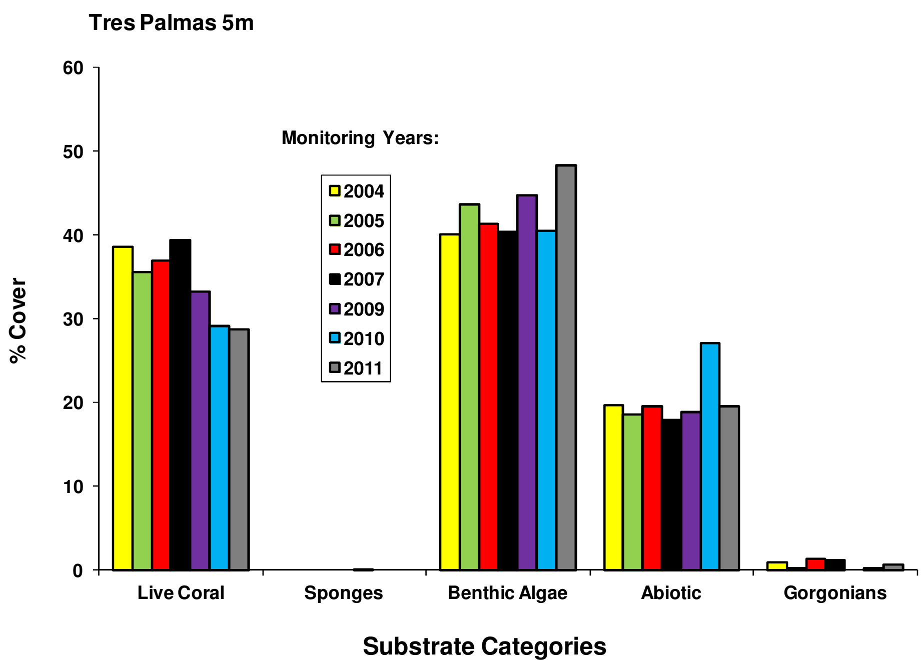

Figure 128:Percent Cover vs Substrate Categories, Tres Palmas, 5m (García-Sais, 2011, p. 11)

In terms of other factors associated with coral degradation such as fish species richness and abundance, fish species went down as well as fish species abundance. This means the fish populations are declining across the majority of species as seen in figures 130 and 131.

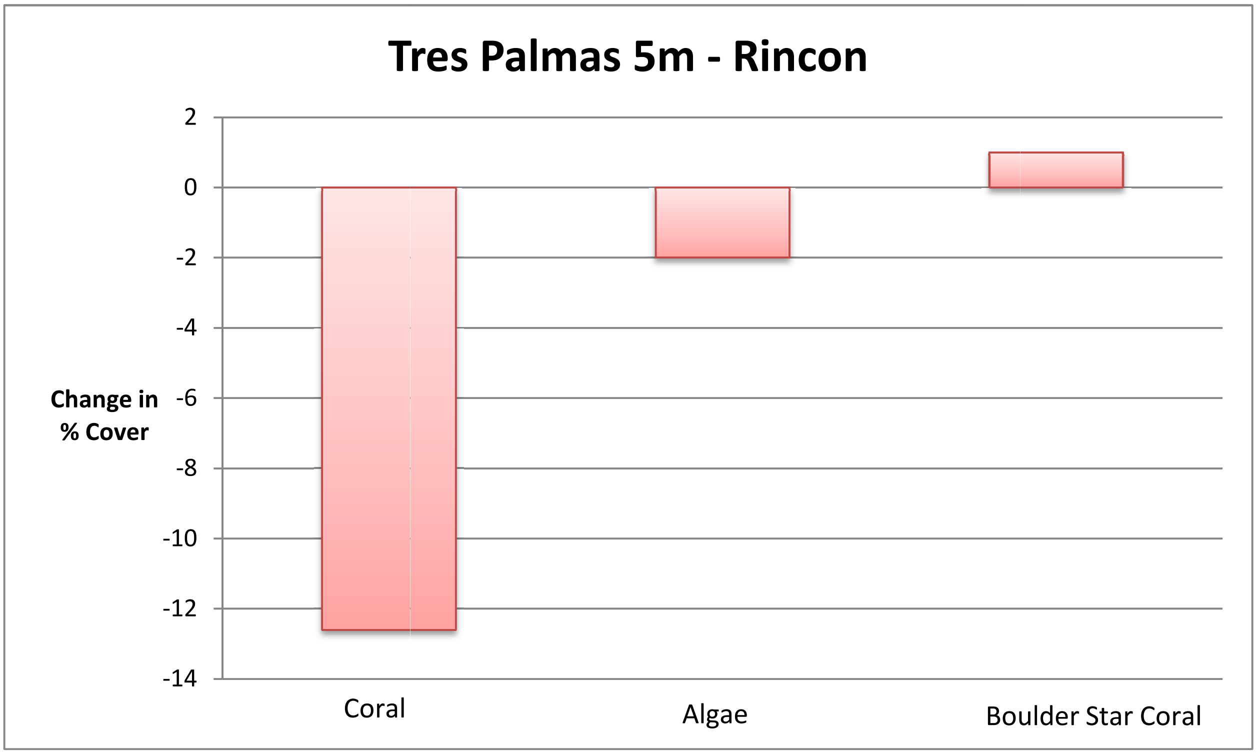

Figure 129: Change in Percent Cover for Tres Palmas, Reef 5m

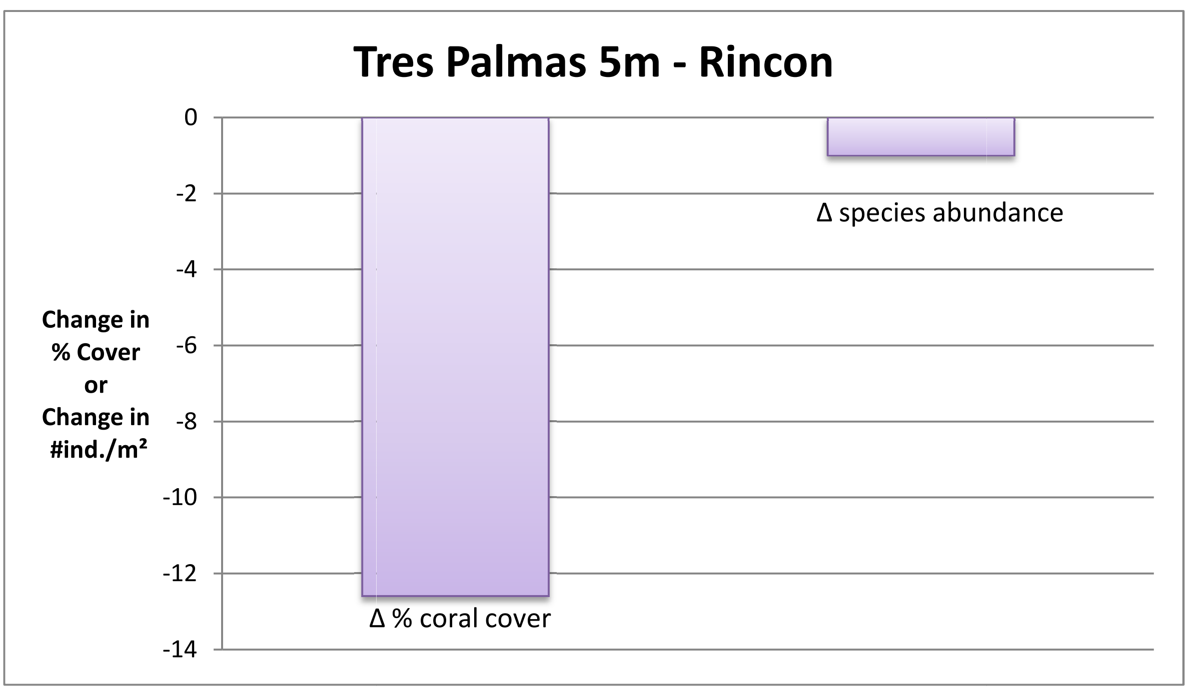

Figure 130: Change in Percent Cover vs Change in Species Abundance, Tres Palmas, 5m

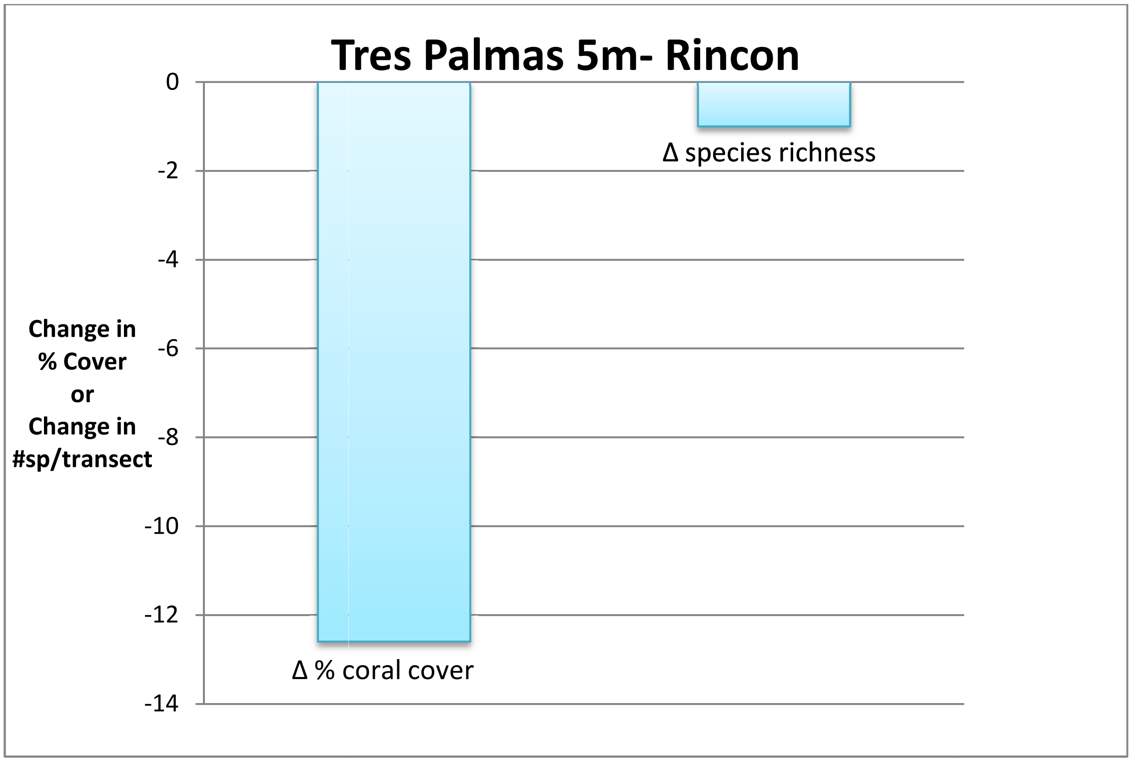

Figure 131: Change in Percent Cover vs Change in Species Richness, Tres Palmas, 5m

At the Tres Palmas 10m depth there was a small actually increase in the percent coral cover, despite a decrease in percent cover of the boulder star coral, *M. annularis*, the main reef building coral species. According to the 2011 DRNA Report there was also a modest reduction in the percent algae cover, as can be seen in Figure 133. This reef exhibits all the qualities of being a very healthy and stable reef system. It would be advantageous for the DRNA to use these reef conditions as a baseline to compare with other reefs' data.

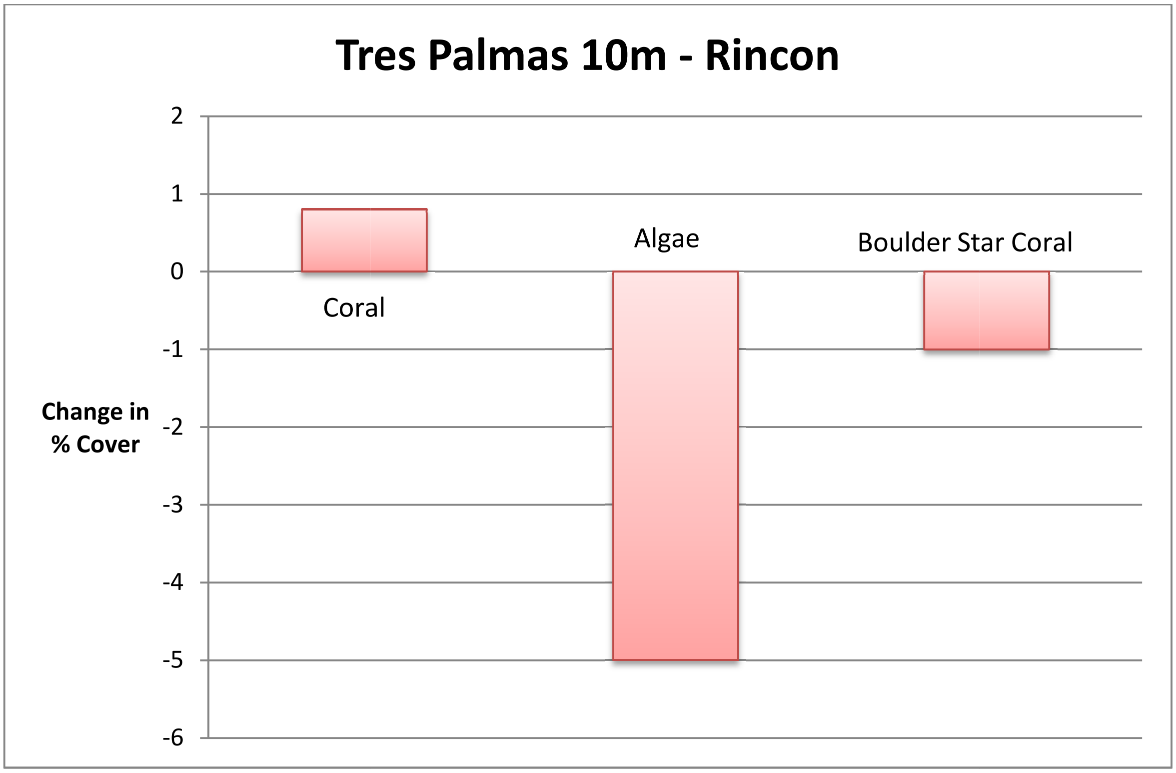

Figure 132: Change in Percent Cover for Tres Palmas Reef, 10m

There was little correlation between the fish species richness and abundance in comparison to the percent change of coral cover. However, both the richness and abundance for this Tres Palmas Reef at 10m depth declined, even though there was an increase in the amount of coral, which can be seen in Figures 134 and 135. This possibly suggests that the quality of fish populations around reefs remains somewhat independent of the coral's condition.

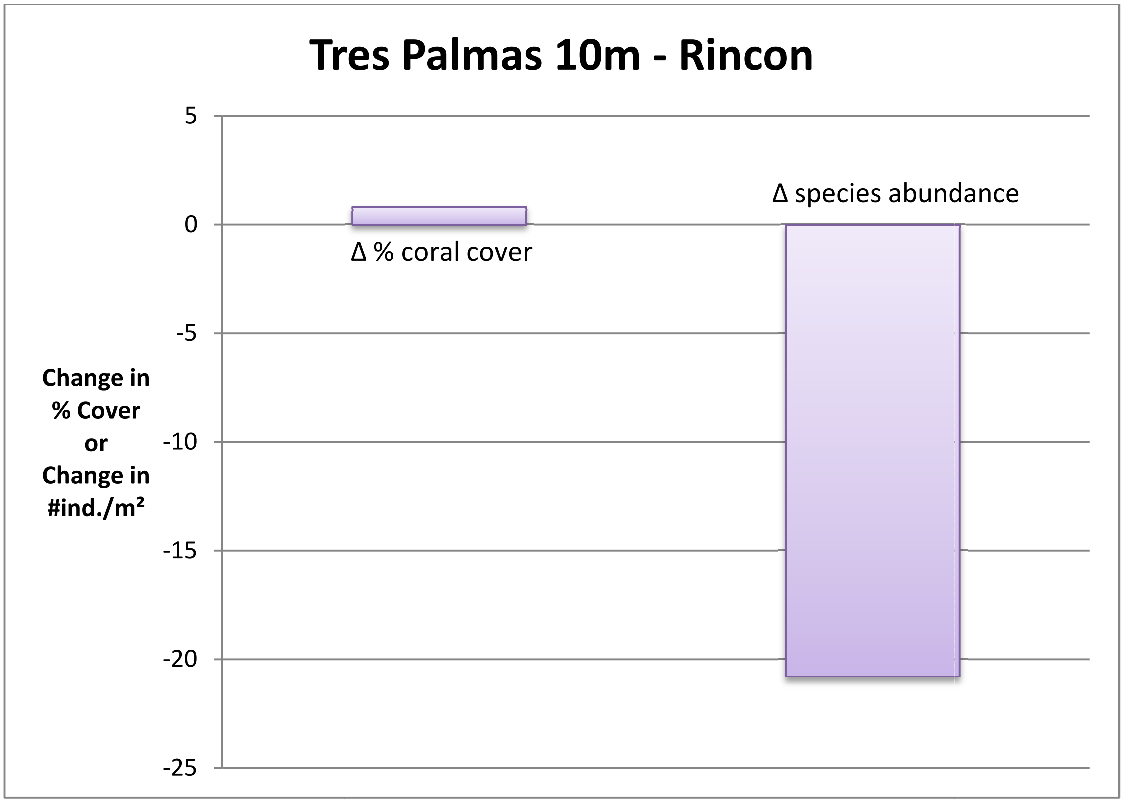

Figure 133: Change in Percent Cover vs Change in Species Abundance, Tres Palmas, 10m

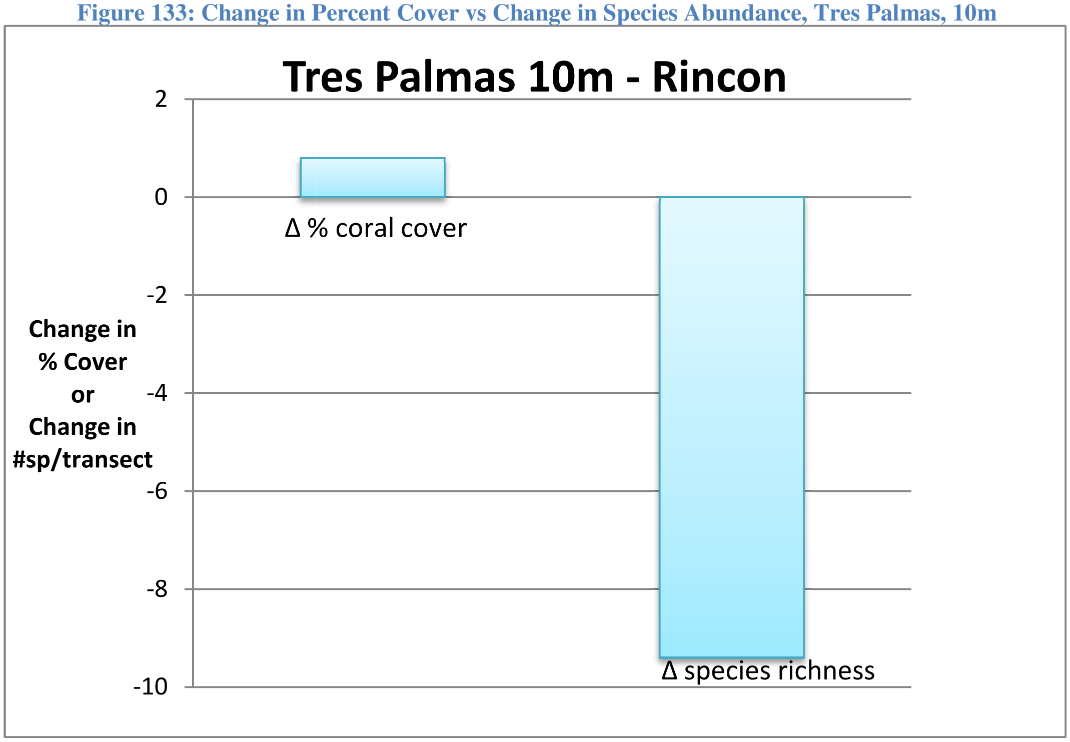

Figure 134: Change in Percent Cover vs Change in Species Richness, Tres Palmas, 10m

At the depth of 20 meters there was a slight decline in the amount of coral coverage (4%) and also a slight decline in the amount of Boulder Star Coral (*M. annularis*). This is coupled with a 4% increase in the amount of algae cover present at the reef. These results are shown in Figure 136. Despite this small decline in the amount of coral coverage up until 2008, recent unreleased reports have shown that the reef is rebounding. Its percent coral coverage is increasing, while the benthic algae is on the decline. This is a sign that the reef is recovering and healthy.

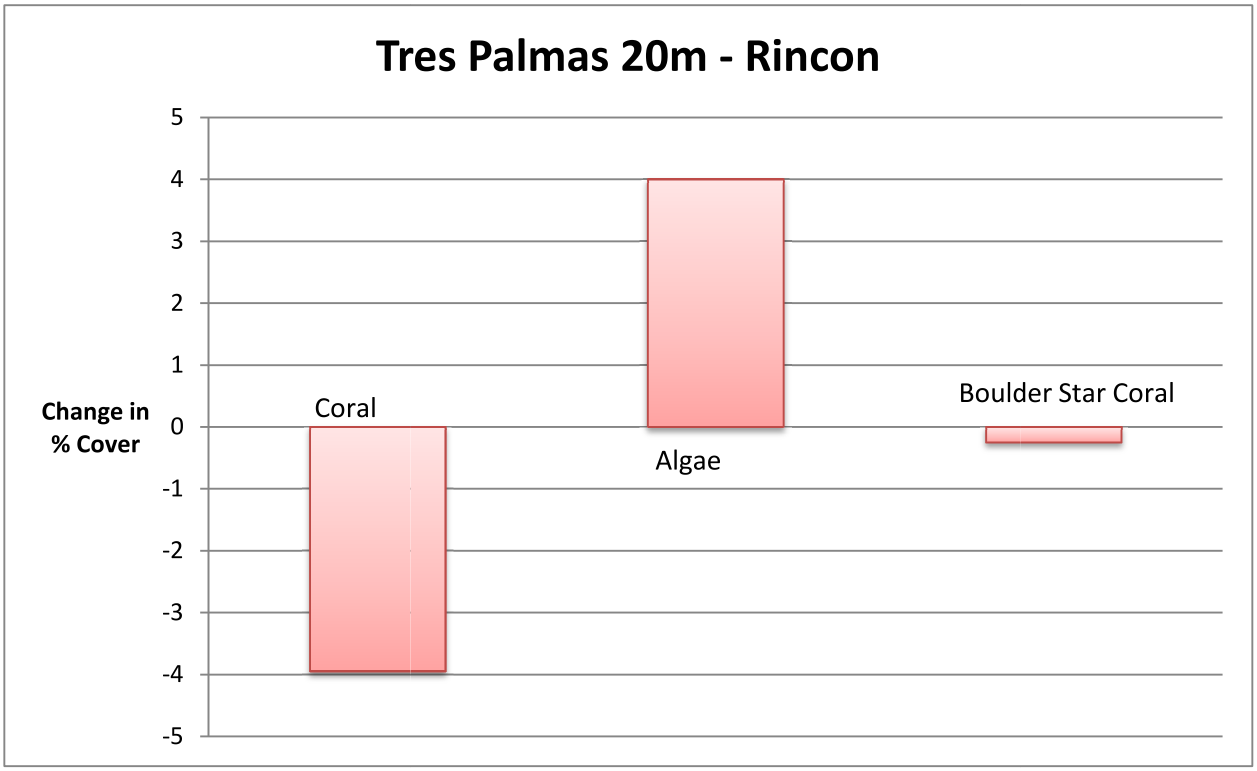

Figure 135: Change in Percent Cover for Tres Palmas Reef, 20m

There was a sharp decline in the species abundance at the 20m depth even though the coral amount stayed relatively stable. Much like the coral cover, the species richness also stayed relatively constant, as it only dropped by 4 species per transect. These results little correlation between the coral degradation and the health of the fish species surrounding the reefs.

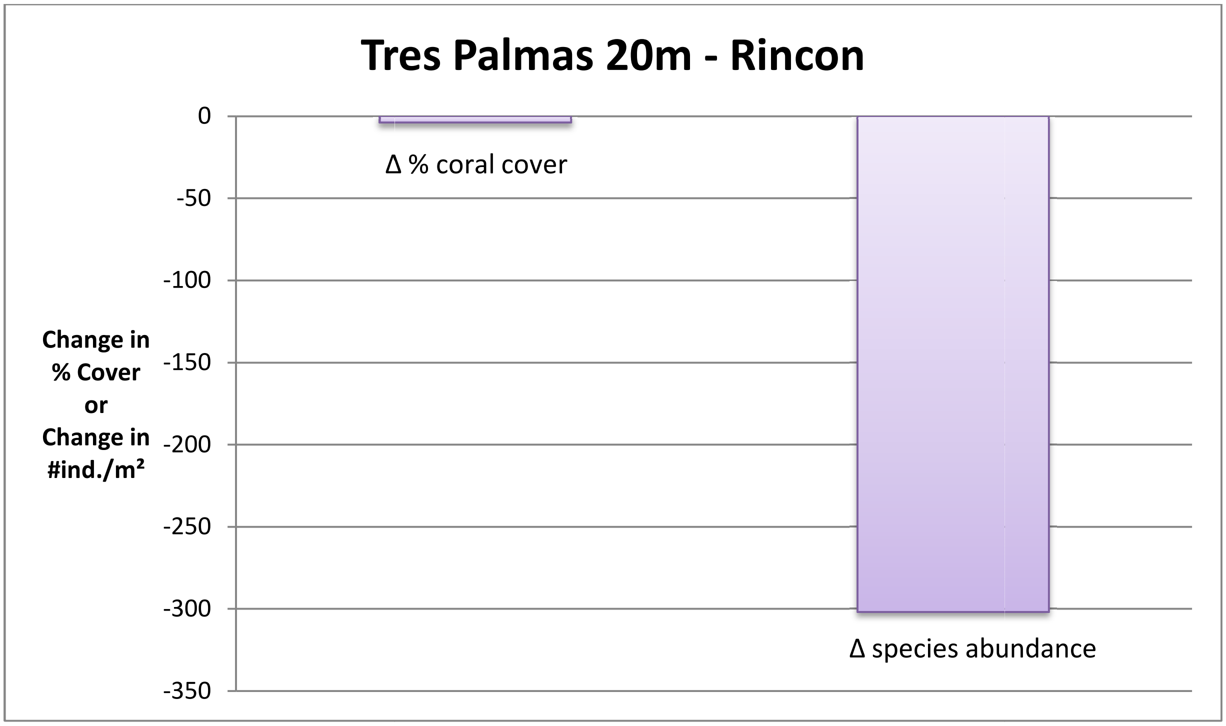

Figure 136: Change in Percent Cover vs Change in Species Abundance, Tres Palmas, 20m

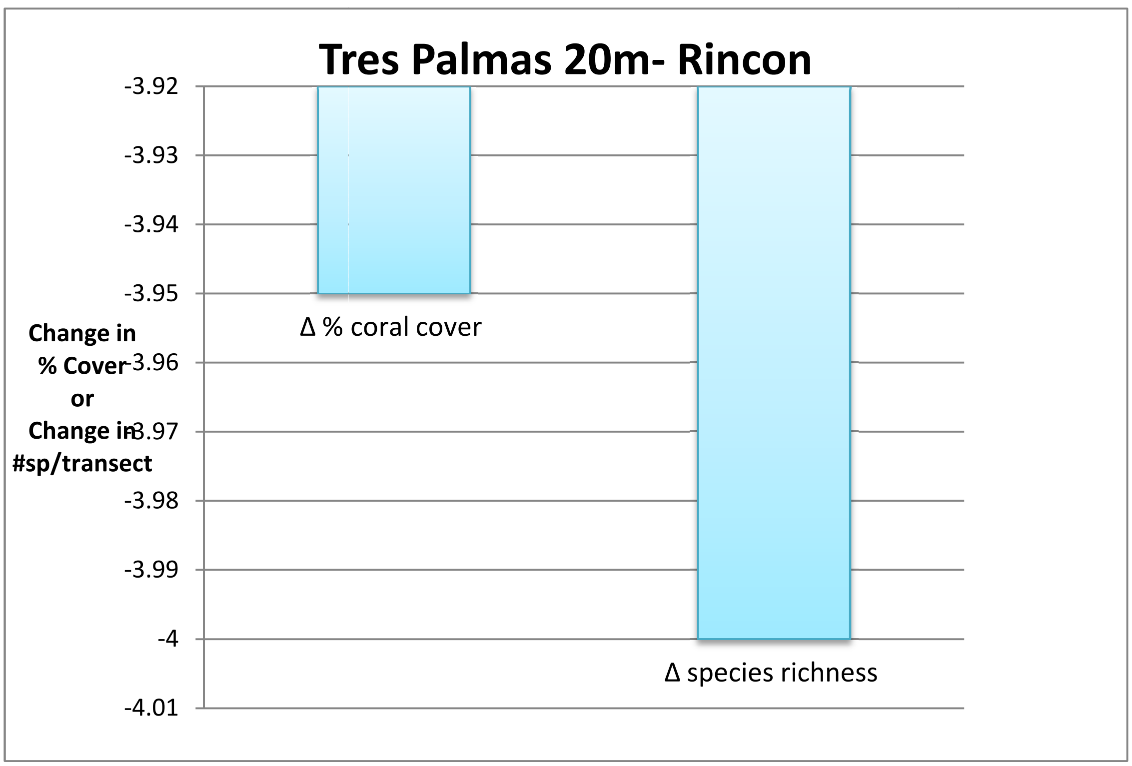

Figure 137: Change in Percent Cover vs Change in Species Richness, Tres Palmas, 20m

Further information regarding land-based sources of pollution was discovered through the use of the DRNA's GIS information. The Tres Palmas monitoring sites are located within a Natural Reserve and a nationally protected area; however, there were no buoys identified within the DRNA GIS layers for boats visiting the reef to moor at. There was a marina located 1 kilometer away from the reef so the potential for boat traffic is present. Also located within 3 kilometers of the monitoring sites were potential pollution hazards such as hotels, industrial zones, a public beach, gas stations, and water tanks. This information can be found within the GIS analysis spreadsheet in Appendix D and within the GIS screenshots in Appendix E.

Tourmaline Reef – Mayaguez Bay

The Tourmaline system has recorded data for three different reef depths, which are 10 meters (m), 20m and 30m. According to the 2008 Report, there have been fluctuations in the percent cover of live coral at the 10 and 20 meter depths. At a depth of 10 meters the coral was adversely affected by the 2005 bleaching event. The loss of live coral cover was associated with a dramatic rise in benthic algae along with fluctuations in abiotic levels. At 20 meters there is a linear trend instead of fluctuations. A loss in coral cover after 2005 is in conjunction with a rise in abiotic levels and benthic algae, which can be seen in Figure 140.

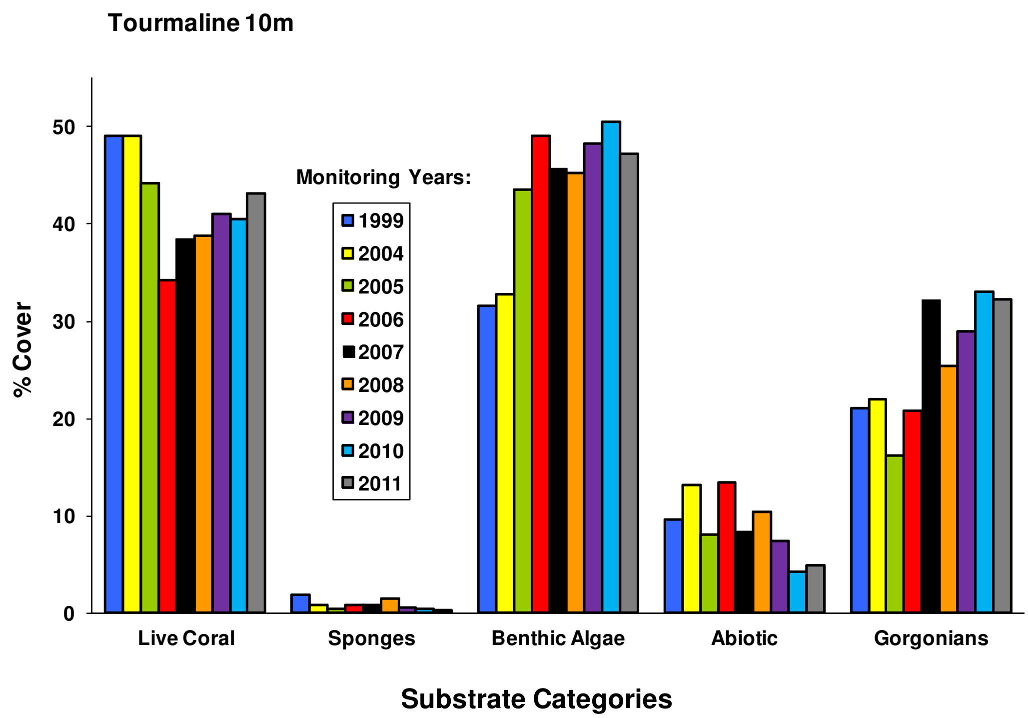

Figure 138: Percent Cover vs Substrate Categories, Tourmaline, 10m (García-Sais, 2011, p. 105)

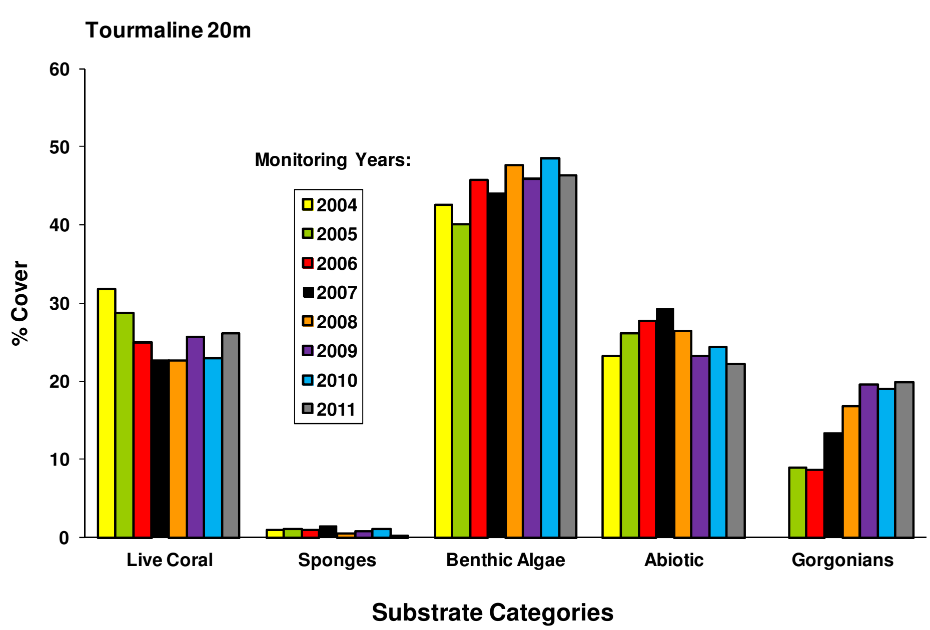

Figure 139: Percent Cover vs Substrate Categories, Tourmaline 20m (García-Sais, 2011, p. 93)

According to the 2008 DRNA report the Tourmaline 30m monitoring station has experienced no degradation. As can be seen in Figures 141, 142 and 143 the percent coral cover has remained almost unchanged, but the species abundance has dramatically increased as has the Boulder Star Coral, and the algae levels have dropped. All of these factors show positive health trends for the reef's sustainability. We have found so far that the deep reefs have typically been thriving. In fact, recent reports have shown that the reef has continued to grow and develop. Perhaps this is because the deeper water acts as a buffer against any possible threats to the coral. Also species richenss has declined, while species abundance has increase as can be seen in figures 142 and 143. This could result in an imbalance in the reef, and cause more problems

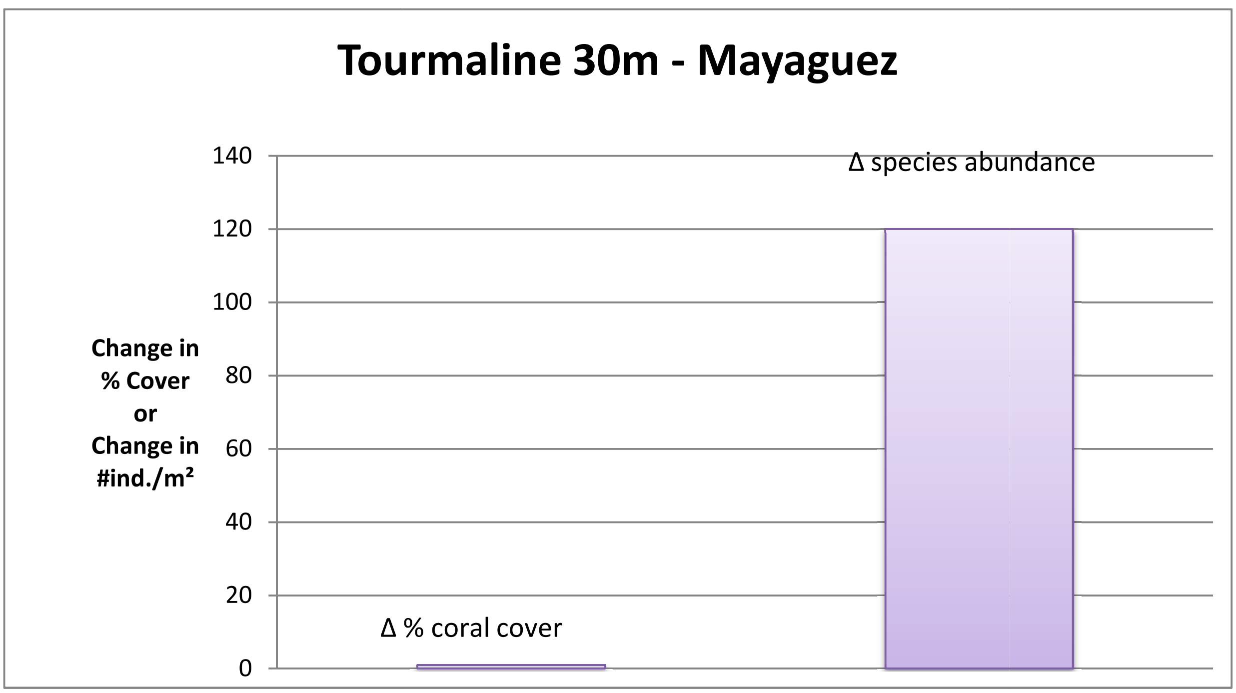

Figure 140: Change in Percent Cover vs Change in Species Abundance, Tourmaline, 30m

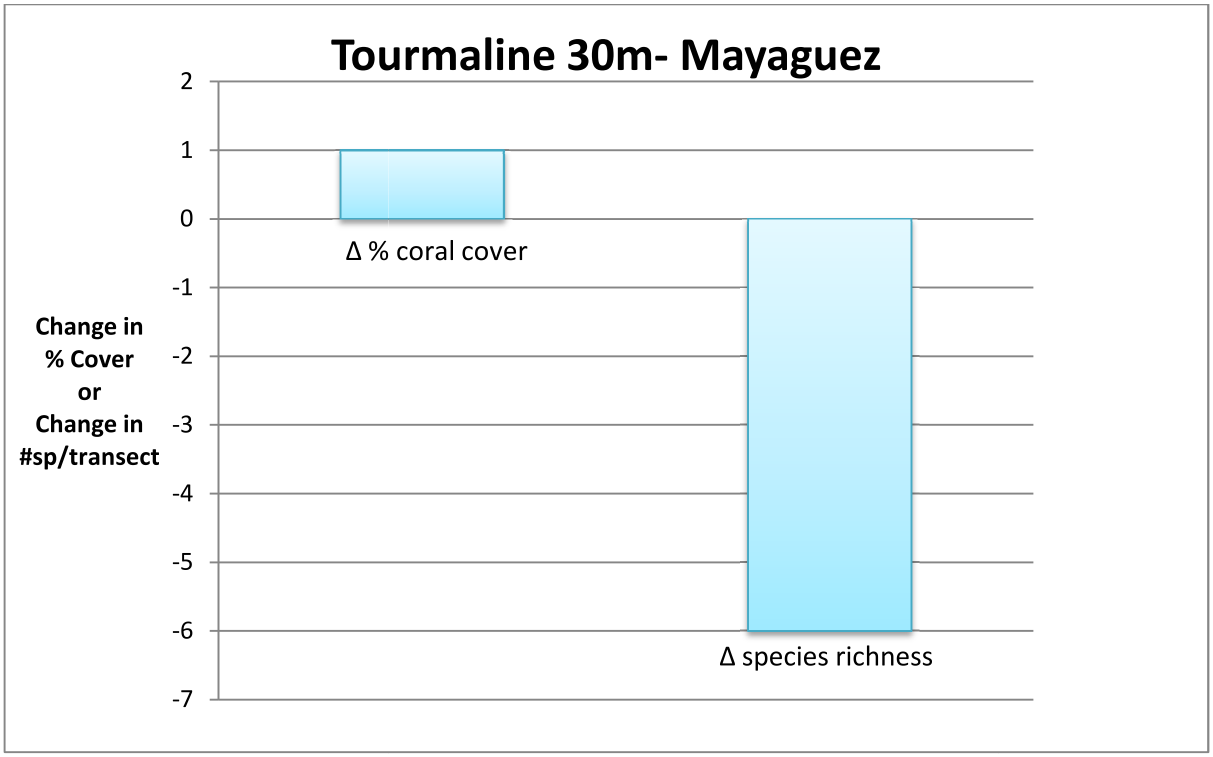

Figure 141: Change in Percent Cover vs Change in Species Abundance, Tourmaline, 30m

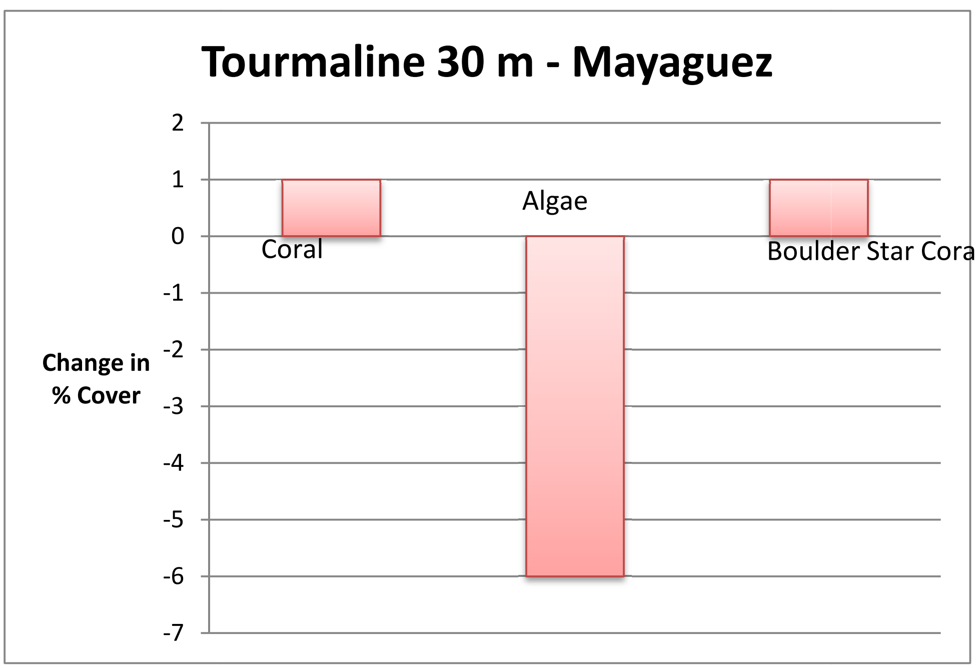

Figure 142: Change in Percent Cover of Coral & Algae, Tourmaline, 30m

The data from the 20m section of the Tourmaline Reef in Mayaguez Bay differs greatly from the 30m depth area. The graph in Figure 144 shows that there was a significant decline in the percent coral coverage, particularly the Boulder Star Coral species. This decline is coupled with an increase in benthic algae, such as the species *Lobophora variegata,* as depicted in Figure 20. The percent coral cover has since been fairly stable, but it seems as though the DRNA would benefit from looking into the correlation between algae growth and coral death at this reef site.

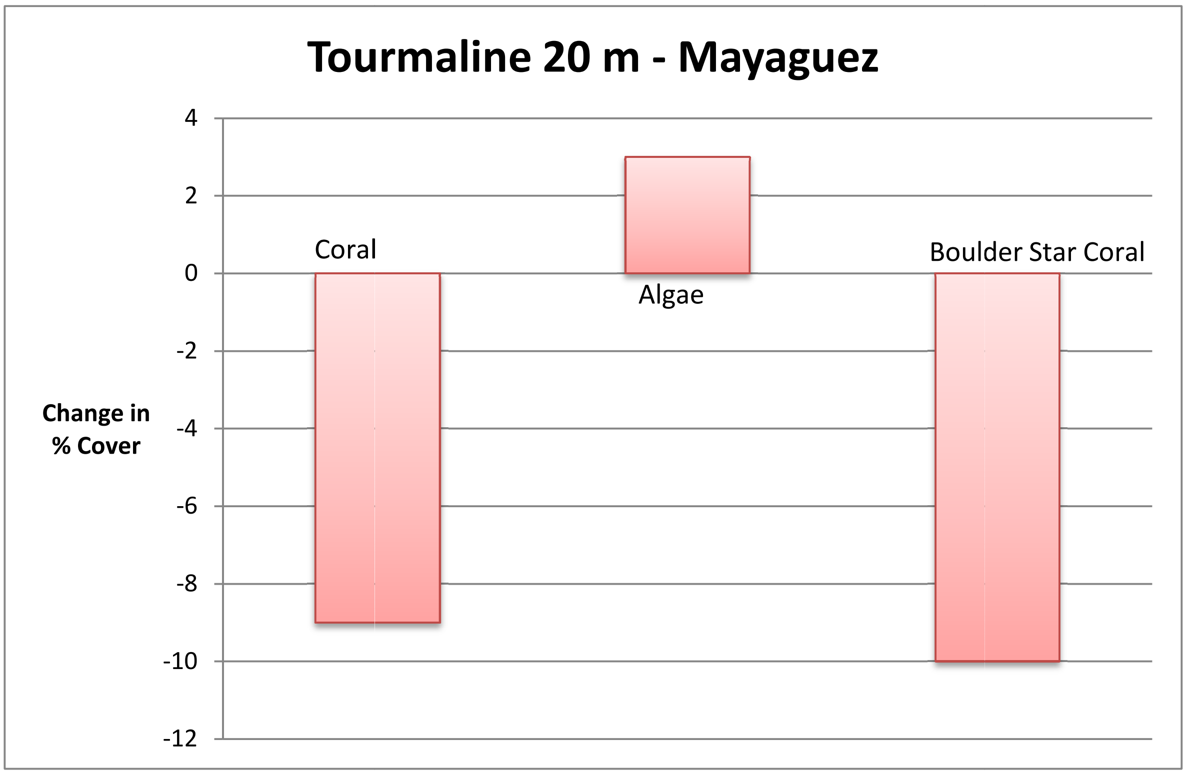

Figure 143: Change in Percent Cover, Tourmaline, 20m

The data for species richness at the 20m depth shows that the richness also declines in the same fashion that the percent coral coverage declined. However, this is not the case with the species abundance. The number of individuals per square meter increased by 80 individuals in the same four years that the coral coverage went down 9%. This discrepancy makes it difficult to determine any connection between the fish populations and coral degradation. These data can be seen in Figures 145 and 146. However as fish species richness went down, species adundace went up, meaning there could be an inbalence in the environment.

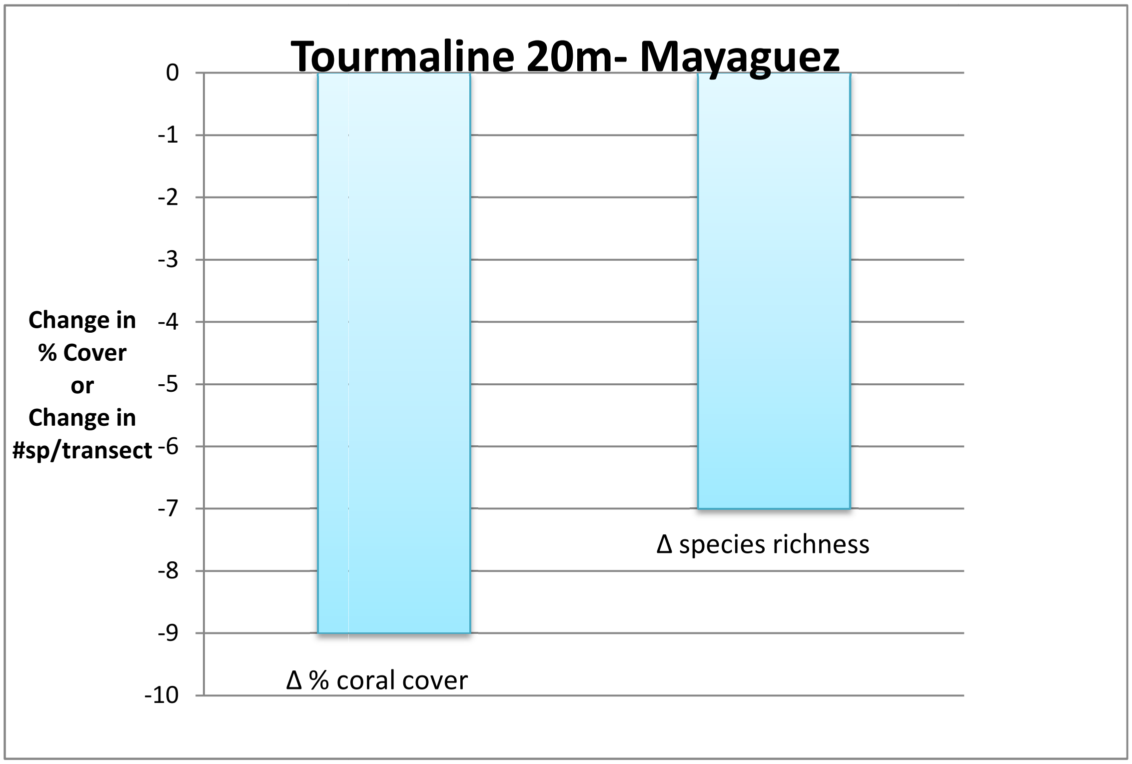

Figure 144: Change in Percent Cover vs Change in Species Richness, Tourmaline, 20m

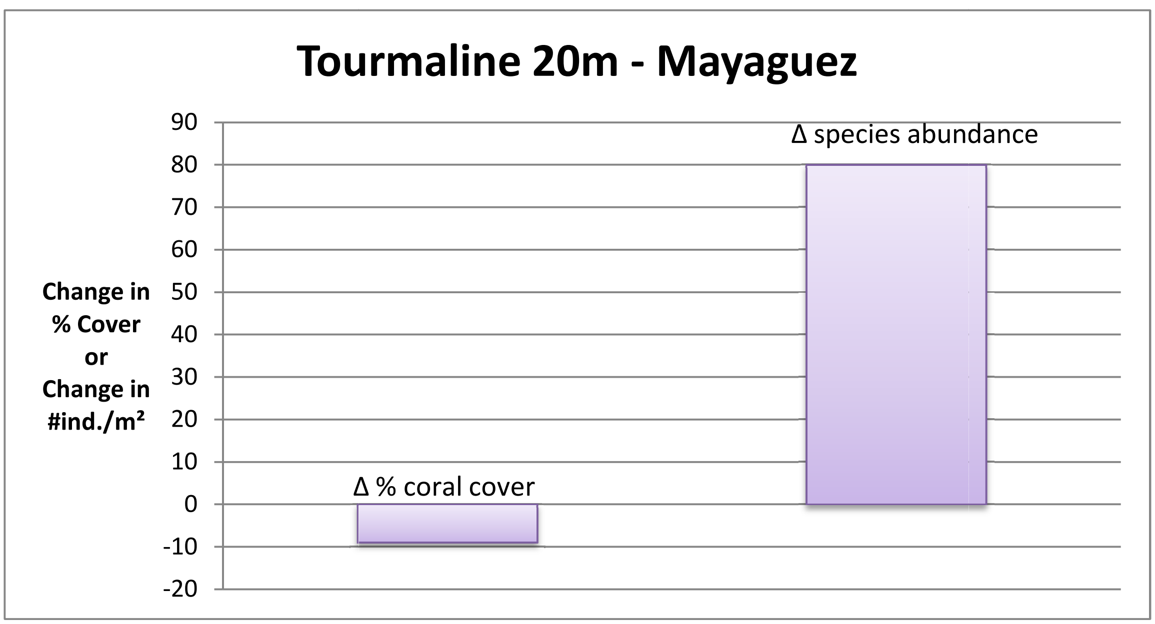

Figure 145: Change in Percent Cover vs Change in Species Abundance, Tourmaline, 20m

The Tourmaline Reef at 10m experienced the typical pattern of coral degradation and algal bloom that we've seen at various other reef sites. The coral coverage declined by 10% and the Boulder Star Coral decreased by 7%. This decrease was accompanied by a 12% increase in benthic algae cover. This fairly common trend can be seen in Figure 147. However, this reef site has experienced some regrowth in its amount of coral since its decline in 2006. This is extremely important because our research has shown that shallow reefs are typically more degraded. To see the Tourmaline Reef at 10m improving is a good sign for the reef conditions around Puerto Rico.

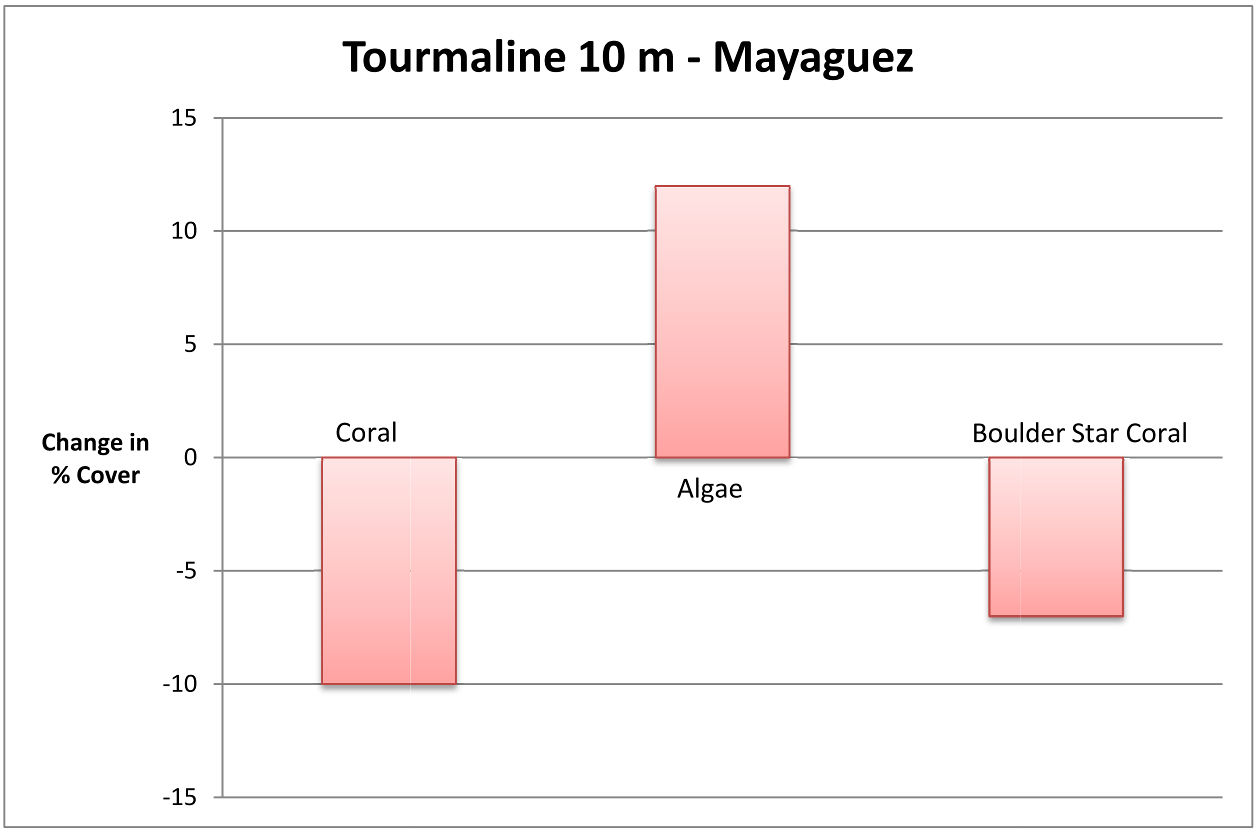

Figure 146: Change in Percent Cover, Tourmaline, 10m

The species richness and abundance follow similar trends at 10m as they did at the 20m section of the reef. Again the species abundance spiked up while the coral coverage went down.

And contrary to that the species richness declined much like the percent coral coverage did. Once again, this means the environment could be becoming inbalanced, which can be seen in Figures 148 and 149.

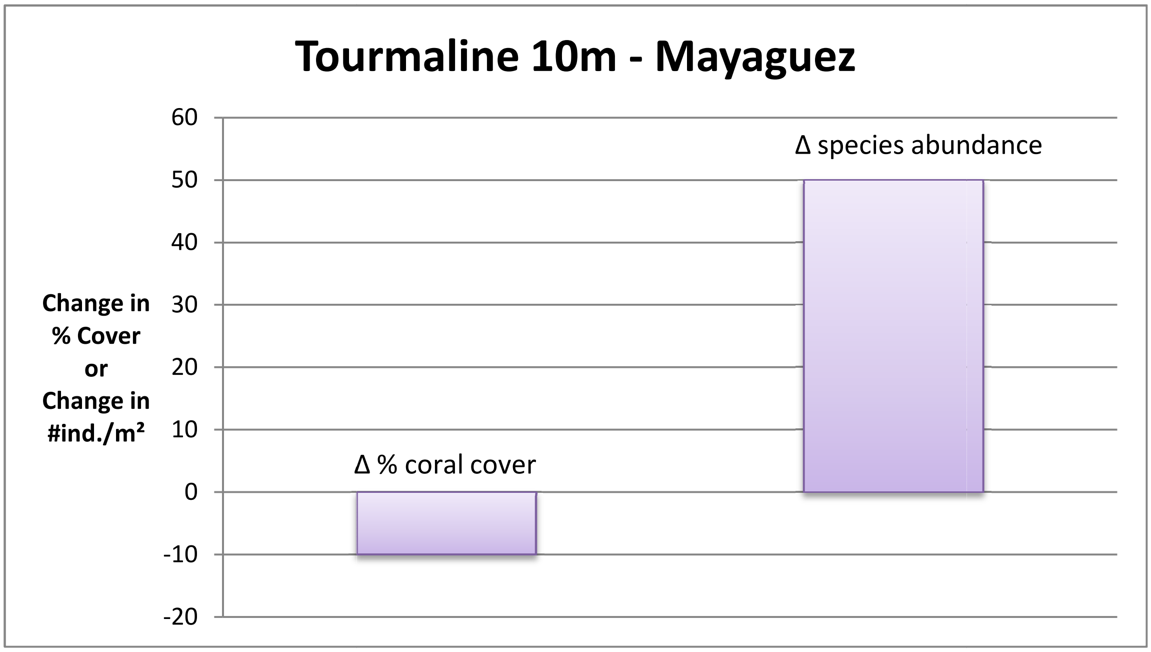

Figure 147: Change in Percent Cover vs Change in Species Abundance, Tourmaline, 10m

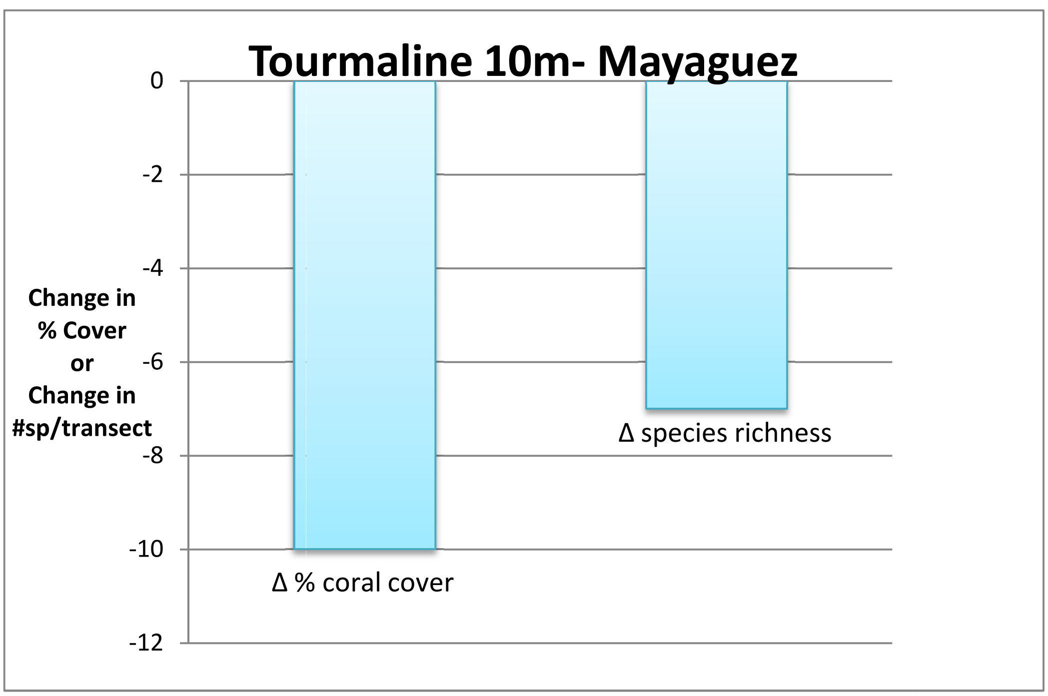

Figure 148: Change in Percent Cover vs Change in Species Richness, Tourmaline, 10m

Information regarding land-based sources of pollution was discovered through the use of the DRNA's GIS information. The Tourmaline Mayaguez Bay monitoring sites are located just outside of a Natural Reserve and a nationally protected area with buoys four kilometers away. The coast of Mayaguez Bay is ten kilometers away; however, there are serious causes for concern on the coast for potential chemical pollution. Due east from the monitoring sites was a river that goes straight through an agricultural valley. Also thirteen kilometers away are two EPA superfund sites on properties that abut the ocean. Further pollution comes from general city sources such as gas stations, hotels, faulty septic tanks, ports, and sewage treatment plants. This information can be found within the GIS analysis spreadsheet in Appendix D and within the GIS screenshots in Appendix E.

Isla Desecheo

Isla Desecheo, which is an island off the west coast of Puerto Rico, has two different reef systems within it. There is the Puerto Canoas Reef at the depth of 30m and the Puerto Botes Reef, which is measured at depths of 20m and 15m. These reefs felt the harsh negative effects of the 2005 bleaching event. This resulted in one of the most massive coral degradation episodes around Puerto Rico. At the 30m depth the percent coral cover dropped by 23%, and the Boulder Star Coral species dropped by 18%. This significant drop in coral coverage was accompanied by a 20% increase in the amount of algae coverage around these coral reefs, which can be seen in Figure 150. This pattern is extremely common among the reefs that succumbed to the worst coral degradation. In fact, recent reports show that the 30m reef still is feeling the effects of the 2005 5leaching event, and has not rebounded yet. This is particularly alarming for such a deep reef system, as these are typically protected by the deeper water.

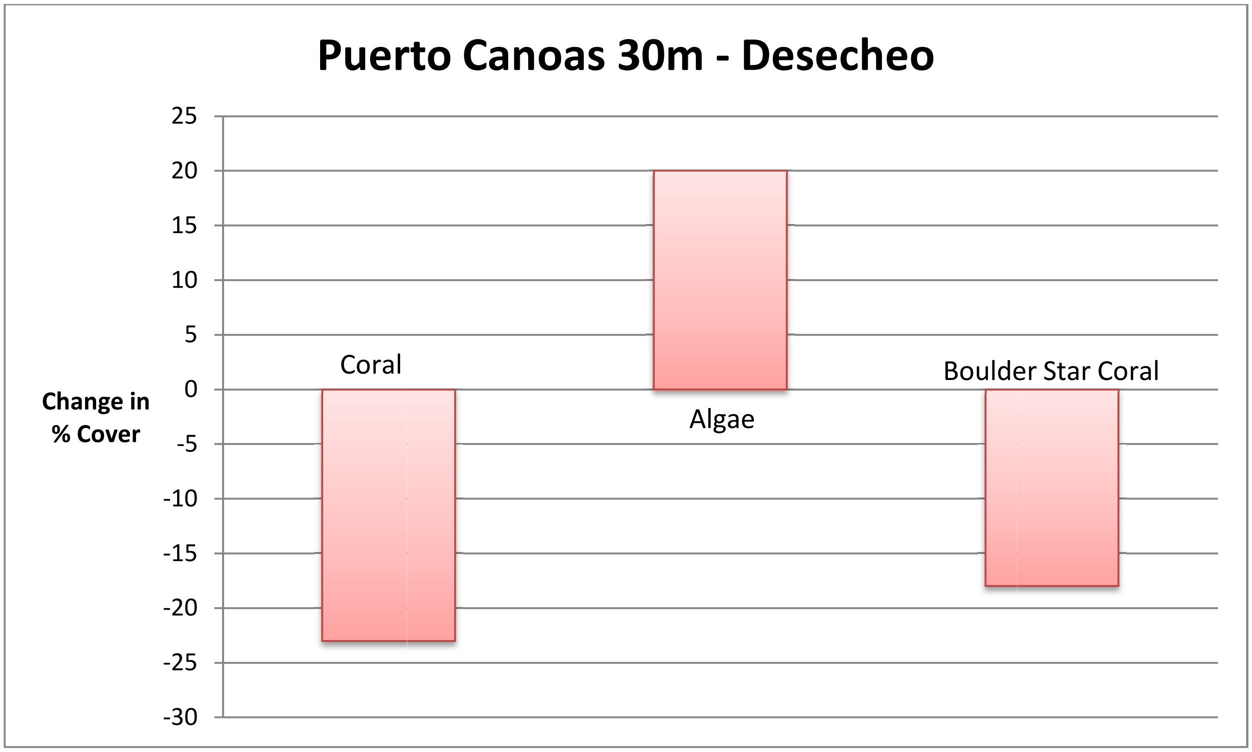

Figure 149: Change in Percent Cover, Puerto Canoas, 30m

Also, at the 30m depth there was a decrease in fish species abundance and richness. As seen below in Figures 151 and 152, the richness at the reef declined by 6 species per transect, while the abundance decreased by 10 individuals per square meter. This decline somewhat parallels the drop in percent coral cover, which may be an indication of a severely weakened ecosystem in the Isla Desecheo area. These numbers have also continued to decline in recent years, which means this specific marine ecosystem could die off completely in the near future if it is not dealt with and managed better. More careful and thorough analysis of what is affecting these reefs, like toxic chemicals or other water quality conditions, should be carried out.

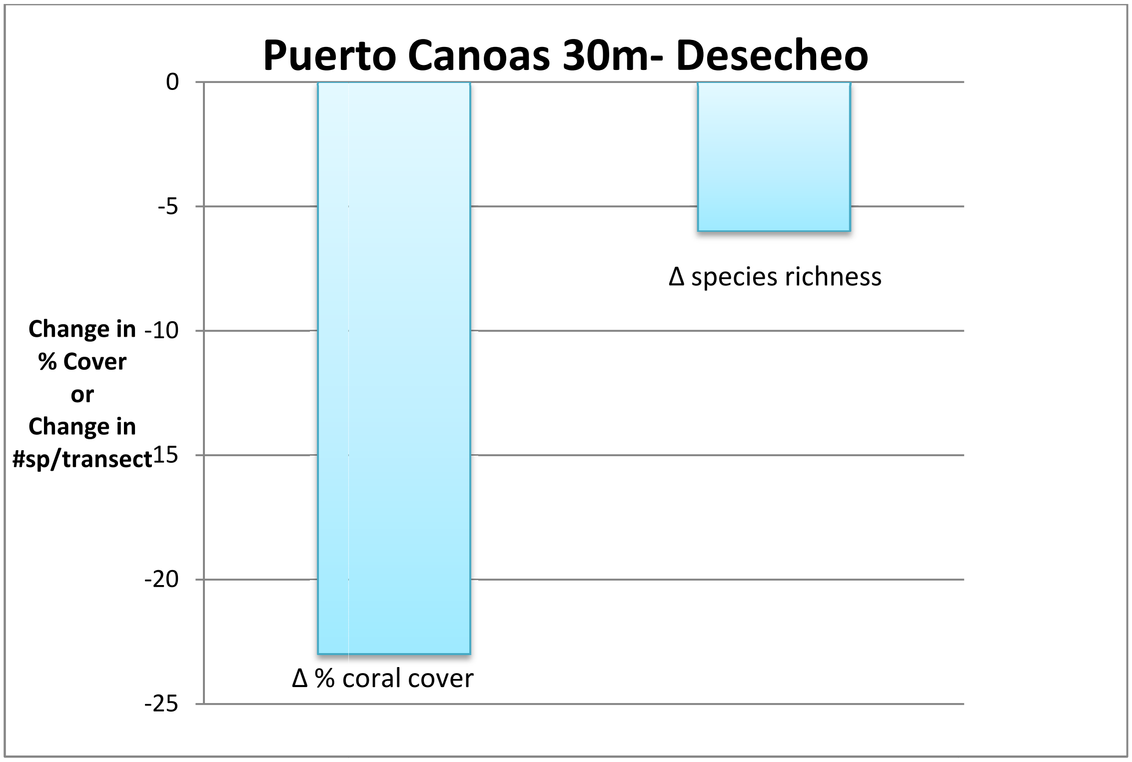

Figure 150: Change in Percent Cover vs Change in Species Richness, Puerto Canoas, 30m

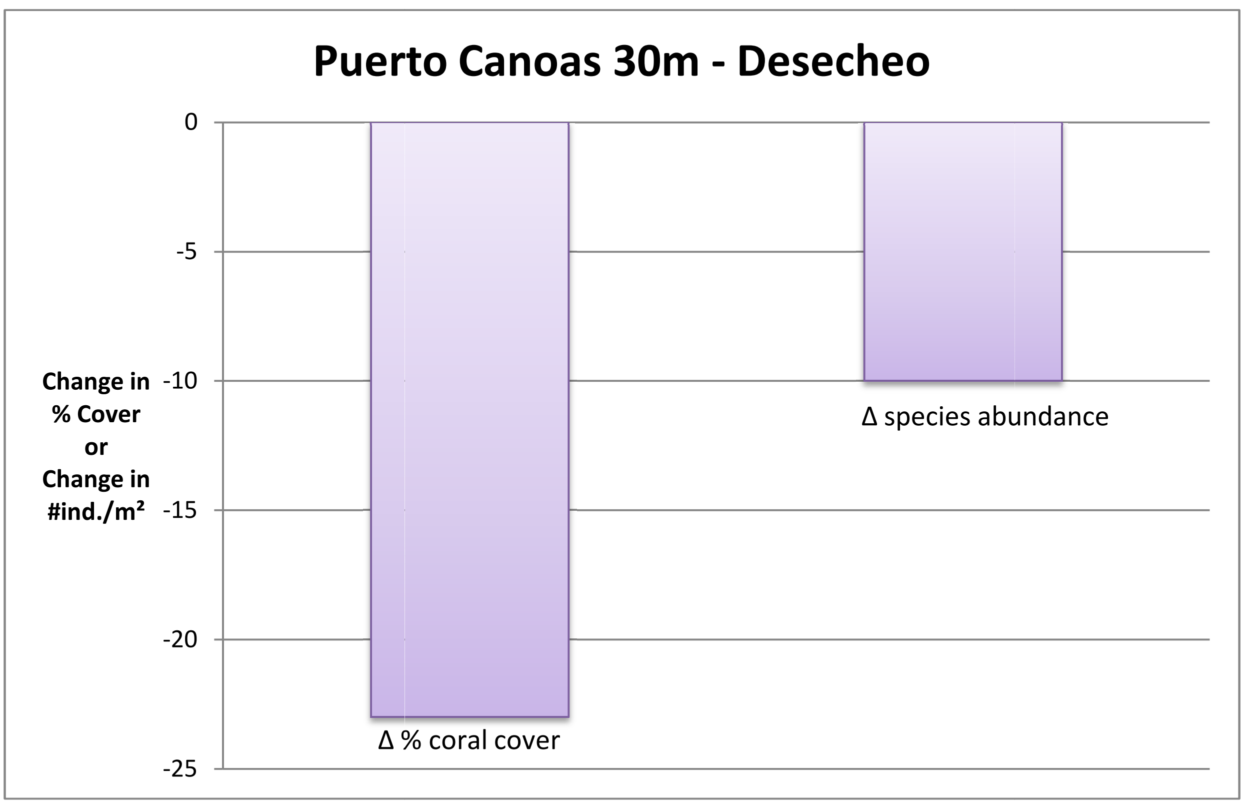

Figure 151: Change in Percent Cover vs Change in Species Abundance, Puerto Canoas, 30m

The Puerto Botes Reef at 20m experienced coral degradation in a similar way the Puerto Canoas Reef did. As Figure 153 depicts, the reef lost 30% of its coral coverage and 24% of its Boulder Star Coral coverage. These are extremely significant amounts of coral damage, while the algae coverage jumped up by 30%. This is the most severe example of coral degradation with a spike in algae coverage. Unfortunately, this pattern has resulted in the remaining coral coverage plummeting to around 10%, with no end in sight. The Puerto Botes Reef is in dire need of a full conditions inspection to determine what conditions are causing the continued coral death and algae blooms.

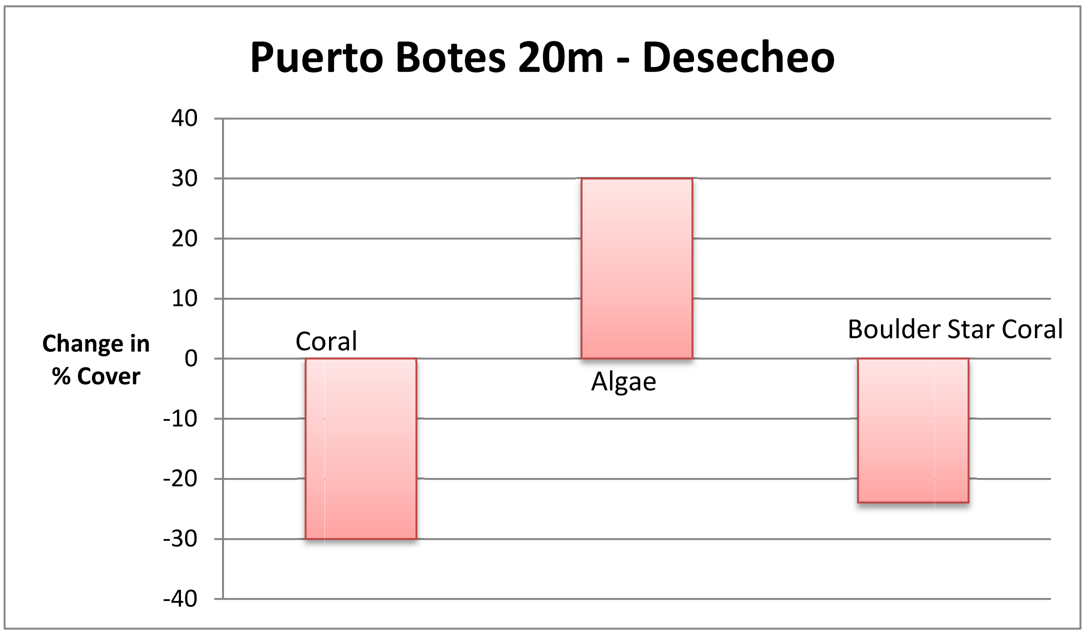

Figure 152: Change in Percent Cover Puerto, Botes, 20m

These reef were a little different from the Puerto Canoas Reef in terms of its fish species richness and abundance. The richness only declined by 2 species per transect, which is not too drastic of a change. The species abundance actually increased slightly by 5 individuals per square meter. This alludes to the fact that there is not too much correlation between coral health and fish health, which can be seen in Figures 154 and 155.

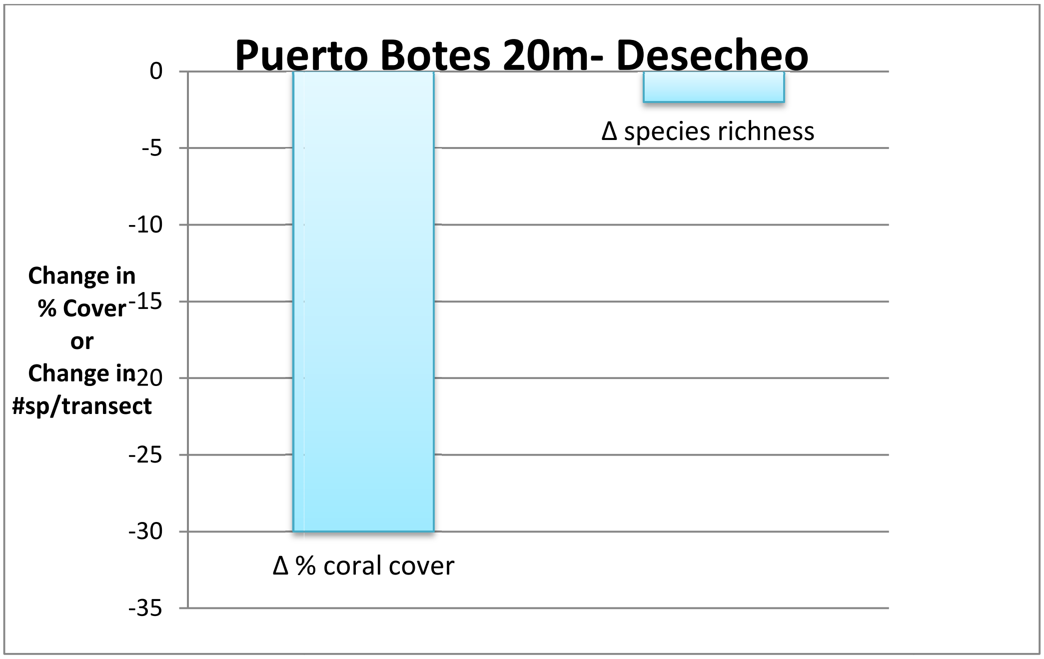

Figure 153: Change in Percent Cover vs Change in Species Richness, Puerto Canoas, 20m

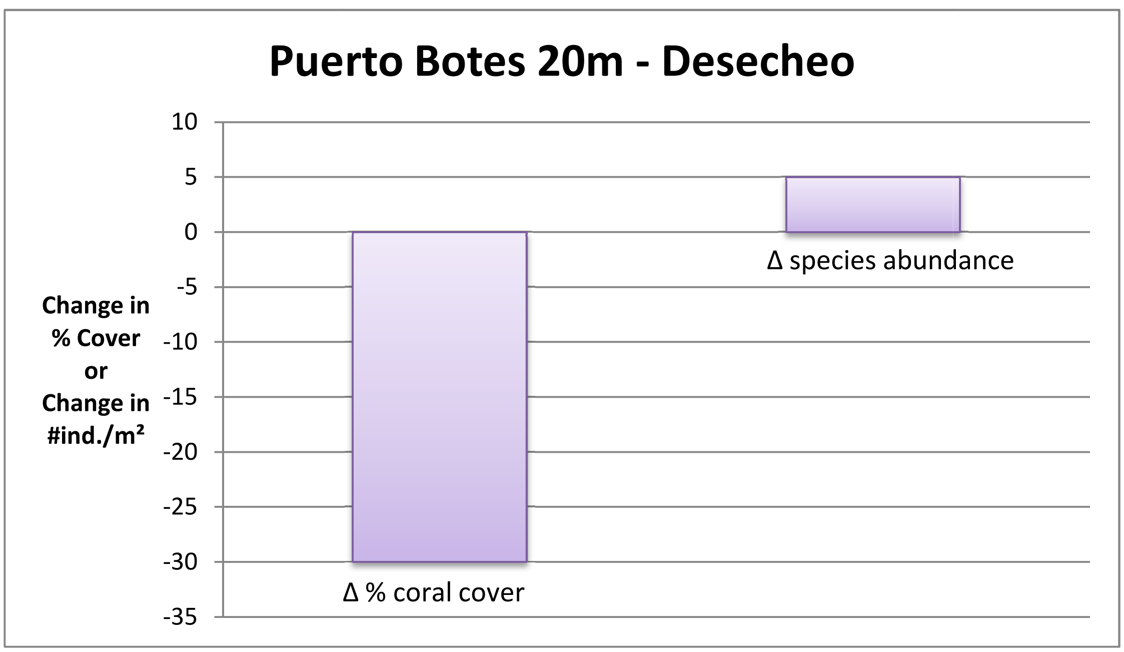

Figure 154: Change in Percent Cover vs Change in Species Abundance, Puerto Botes, 20m

The 15m section of the Puerto Botes Reef off the coast of Isla Desecheo also experienced large drops in the amount of coral coverage and a sharp rise in the amount of algae coverage.

The overall coral coverage fell by 12%, and its main coral species, the Boulder Star Coral decreased by 10%. Also, the algae coverage in the area increased by 6%. This reef is slightly different from the other two reefs at Isla Desecheo, as its levels of live coral have balanced out and stayed constant for about 5 years. However, this does not necessarily mean the reef is healthy and its environment should still be monitored by the DRNA, along with the other two reefs.

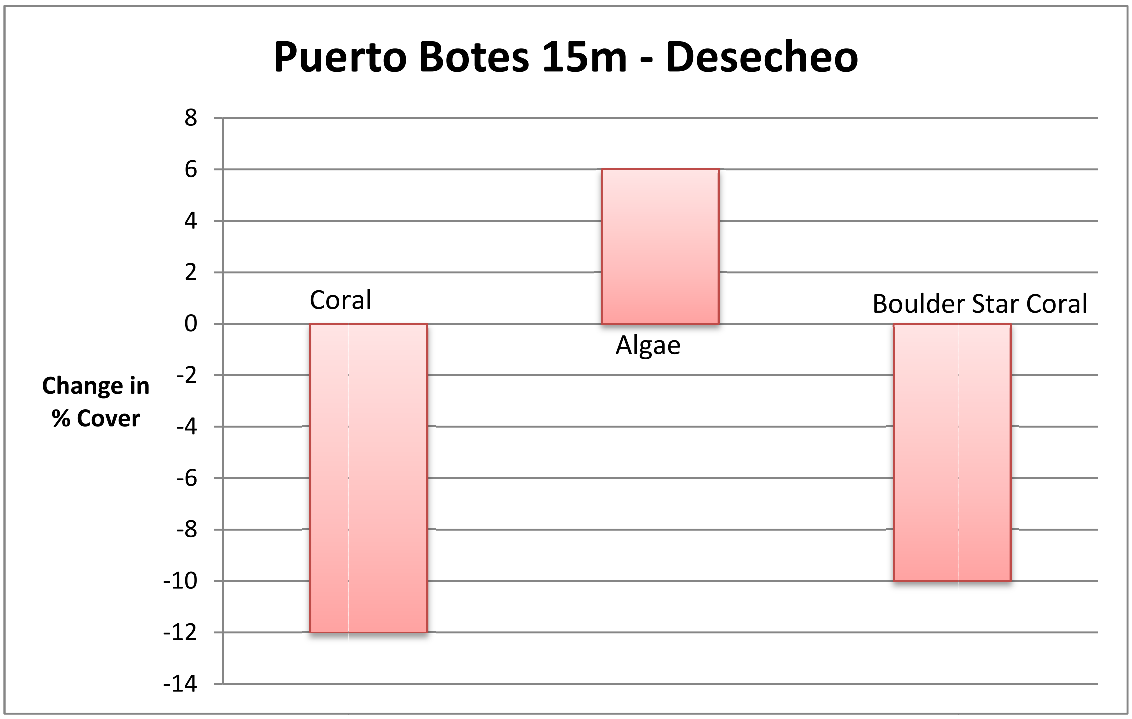

Figure 155: Change in Percent Cover, Puerto Botes, 15m

Much like most of the other reefs, the fish species richness and abundance show that the ecosystem at this depth might be becoming inbalance. The species richness is declining, but the abundance is going up. Figures 157 and 158 show the values for both richness and abundance.

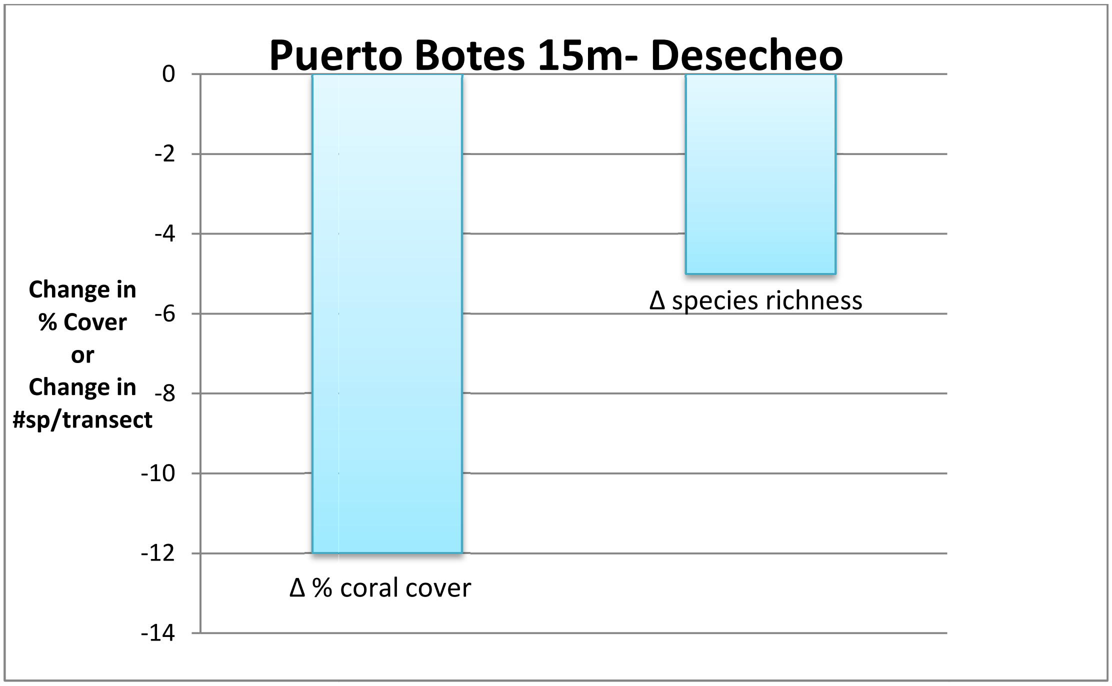

Figure 156: Change in Percent Cover vs Change in Species Richness, Puerto Canoas, 15m

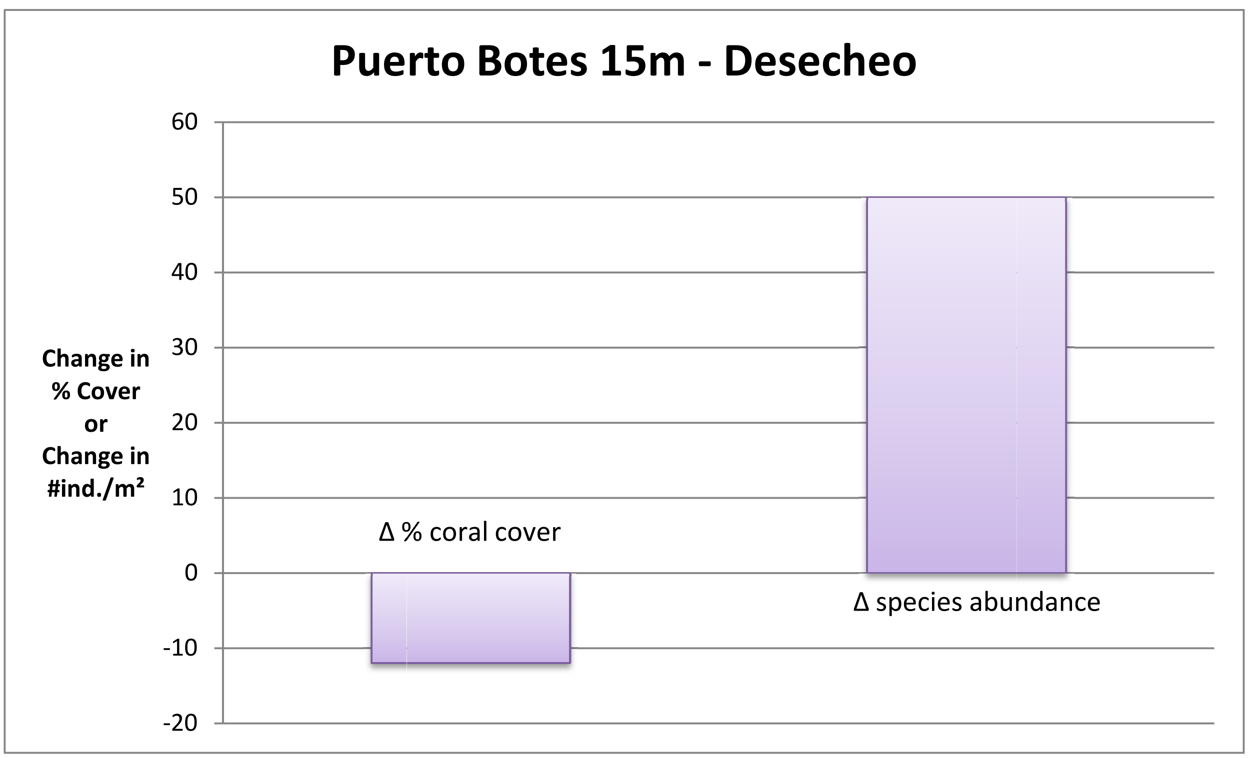

Figure 157: Change in Percent Cover vs Change in Species Abundance, Puerto Botes, 15m

From the GIS map layers it is hard to say how much of an affect land based pollution may be having on the health of the reefs. The monitoring sites are at least 27 km west of Rincon, with Rincon being the closest land mass besides the Island of Isla Desecheo. This island did not have any markers included within the GIS layers from the DRNA database. This monitoring site is within a natural reserve and has natural protection with buoys present. These buoys indicate that there could be boat traffic that could cause mechanical damage and pollution. The DRNA should observe water quality to ensure pollution is not an issue and look into the addition of more buoys in safe areas for the reefs to prevent mechanical damage from anchors and propellers. This information can be found within the GIS analysis spreadsheet in Appendix D and within the GIS screenshots in Appendix F.

Cayo Coral Guanica

The Cayo Coral system has recorded data for a single reef depth, which is at 10 meters (m). According to the 2008 Report, there has been a steady decline of live coral cover at this depth beginning in 2005. The loss of live coral cover was associated with a dramatic rise in benthic algae in 2005 along with fluctuations in abiotic levels. This can be seen in Figure 159 below. Despite this drop, since 2008 the amount of live coral has slowly started to increase to make it appear as if the coral is recovering. This indicates that although the reef was negatively affected by the 2005 bleaching event, its conditions are stabilizing. However, even with the improvement, more data on water quality should be collected along with the current set of data to see if conditions stay healthy enough for the reef to continue to regrow.

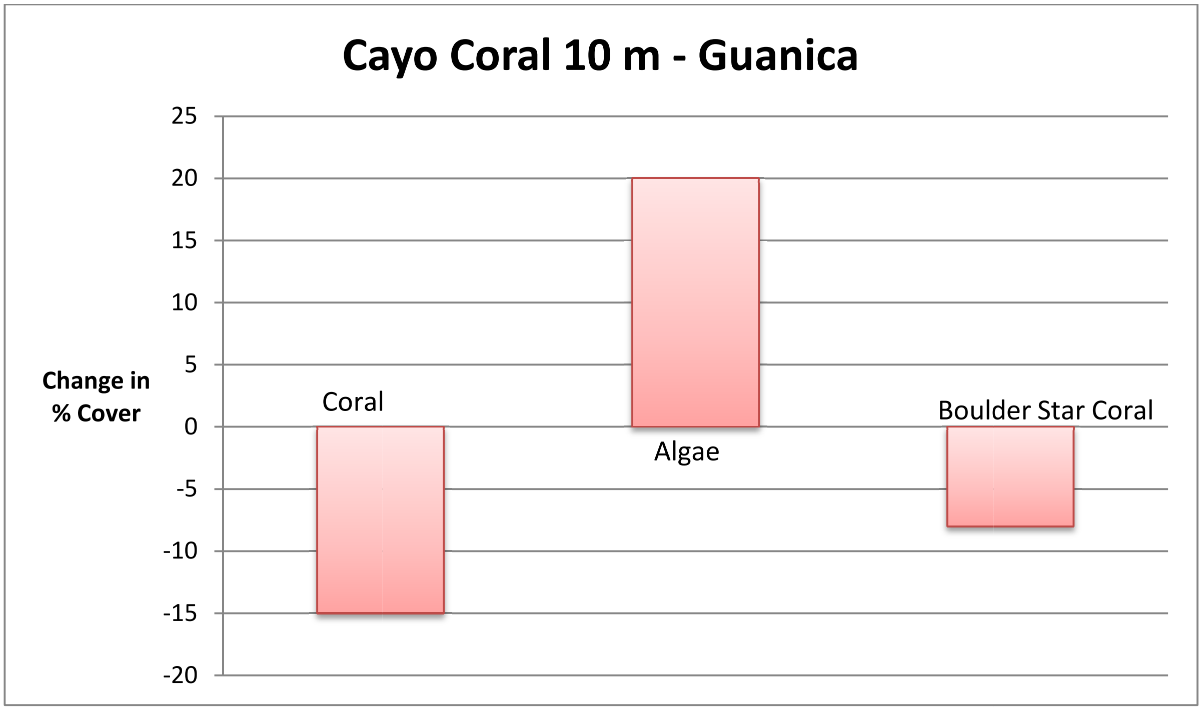

Figure 158: Change in Cover, Cayo Coral, 10m

The richness and abundance of fish species have both had a slight increase despite the significant decline in live coral cover. It is difficult to conclude if these two factors directly impact the percentage of live coral based on these statistics. However, it does mean the fish species are on the rise.

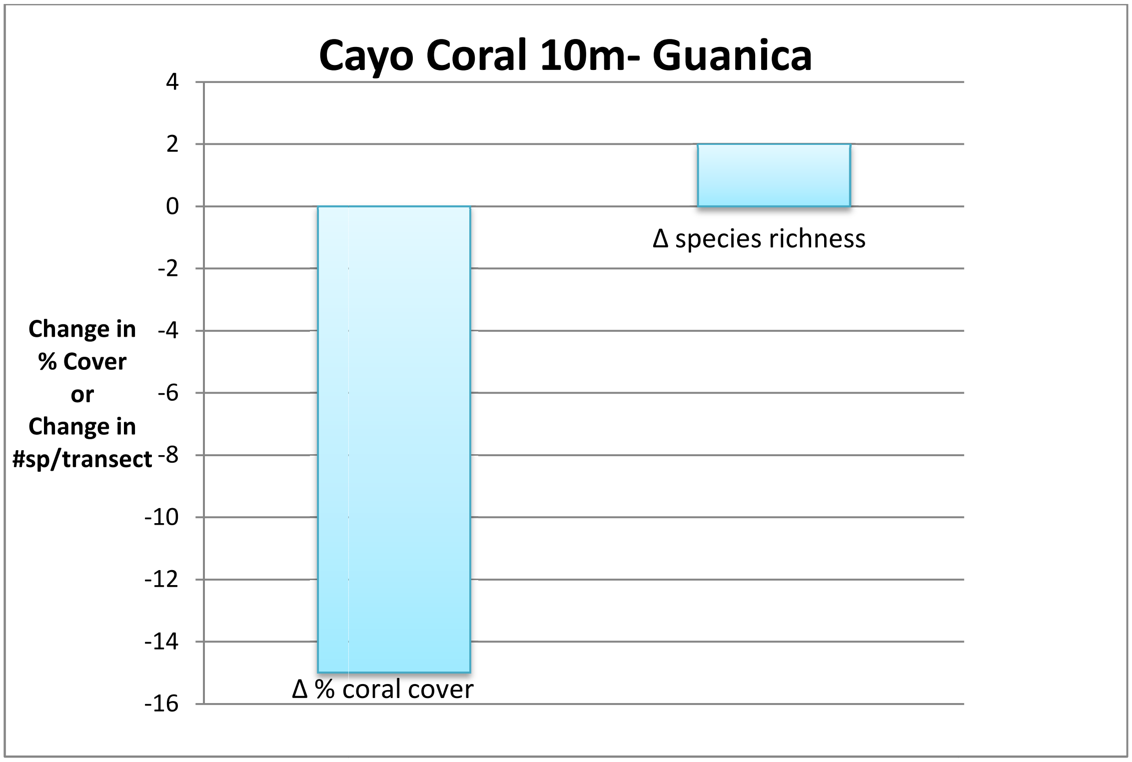

Figure 159: Change in Percent Cover vs Change in Species Richness, Cayo Coral, 10m

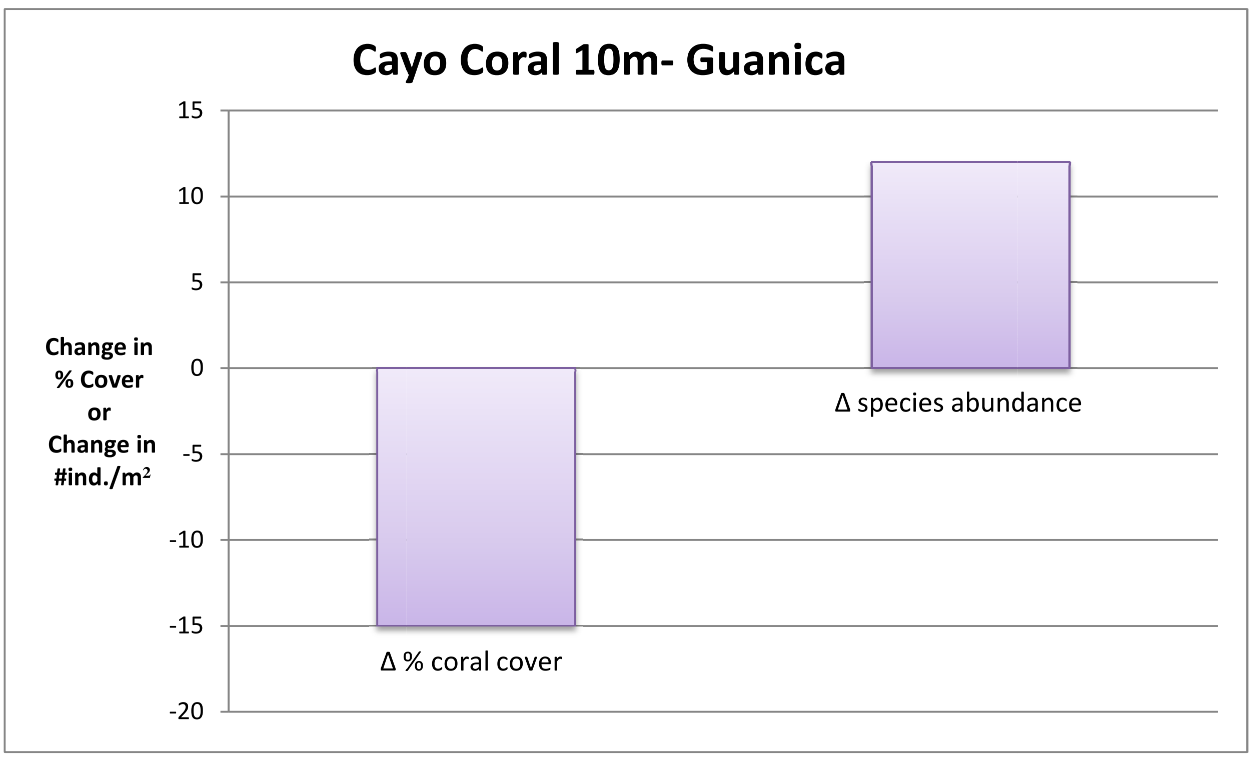

Figure 160: Change in Percent Cover vs Change in Species Abundance, Cayo Coral, 10m

From the GIS it is seen that water quality tests should be a priority. The monitoring site at Guanica sits at the mouth of a bay. There is a river present (Loco River) that dumps into the bay which runs through an agricultural valley for most of its length. This situation increases the likelihood that harmful chemicals could be present in the water leading to increases in algae or disease. Besides that, Guanica exhibits the same general pollution markers as the other reefs including beaches, gas stations, hotels, landfills, treatment plants, and superfund sites. This monitoring site is very close to the coast however, which would increase the pollutions ability to have an impact before dilution. Also as with the other sites there is the presence of buoys at the reef which means it should be researched if more buoys are needed and if there is public awareness about where the reef is and what stressors may cause harm.

West Reef Caja de Muertos

The West Reef system has recorded data for a single reef depth, which is at 10 meters (m). The loss of live coral cover at this depth was adversely affected by the 2005 bleaching event and also associated with a dramatic rise in benthic algae. The rise in benthic algae with the decrease in the percent of live coral coverage can be seen in Figure 162 below. The West Reef's Boulder Star Coral population suffered severely following the 2005 bleaching event, losing 58% of its original cover. The reef's conditions have somewhat stabilized, but are not showing the same improvement that other reefs have experienced. This means more data collection and analysis should be conducted to determine what is prohibiting the reef from rebuilding.

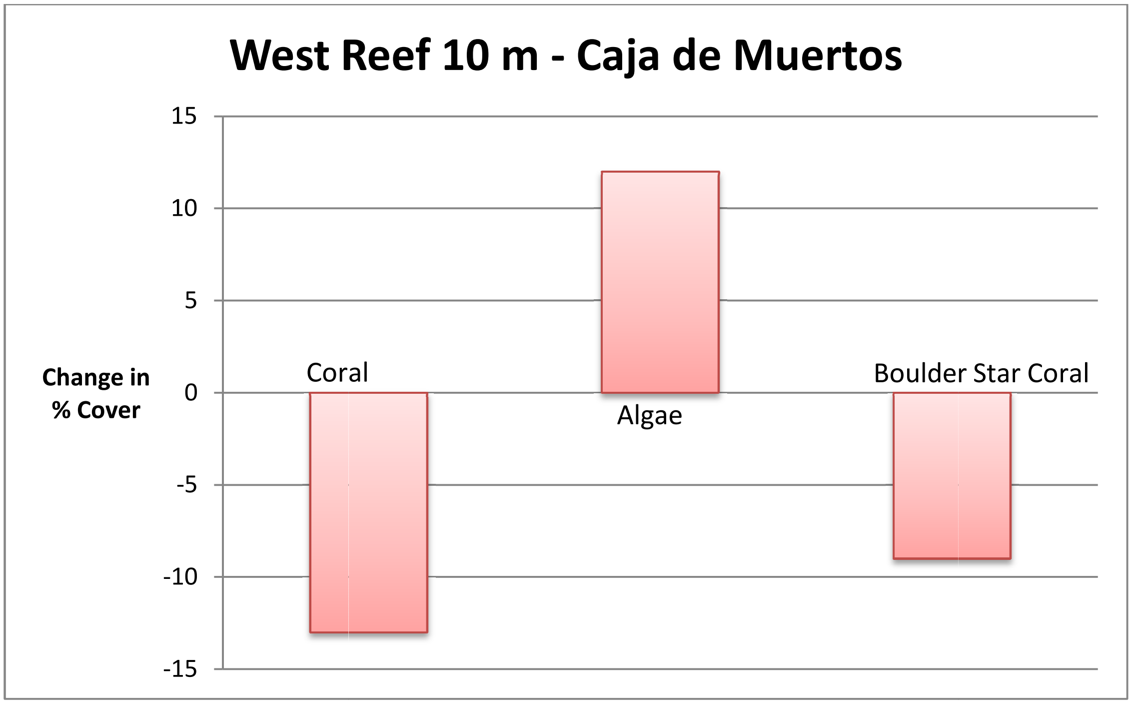

Figure 161: Change in Percent Cover, West Reef, 10m

The richness and abundance of fish species both slightly decreased as live coral cover was significantly decreasing. This can be shown below in Figures 163 and 164. Due to inconsistencies with results from other reef sites, it is unknown if richness and abundance of fish species correlate with the amount of live coral cover.

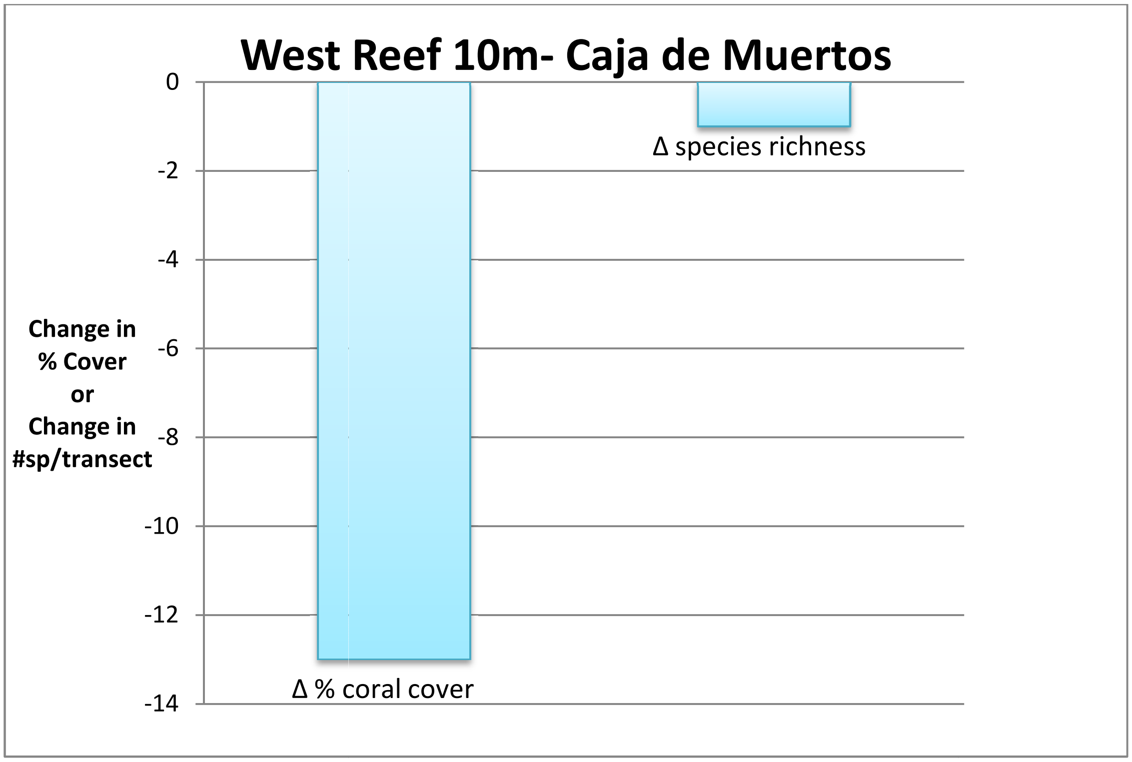

Figure 162: Change in Percent Cover vs Change in Species Richness, West Reef, 10m

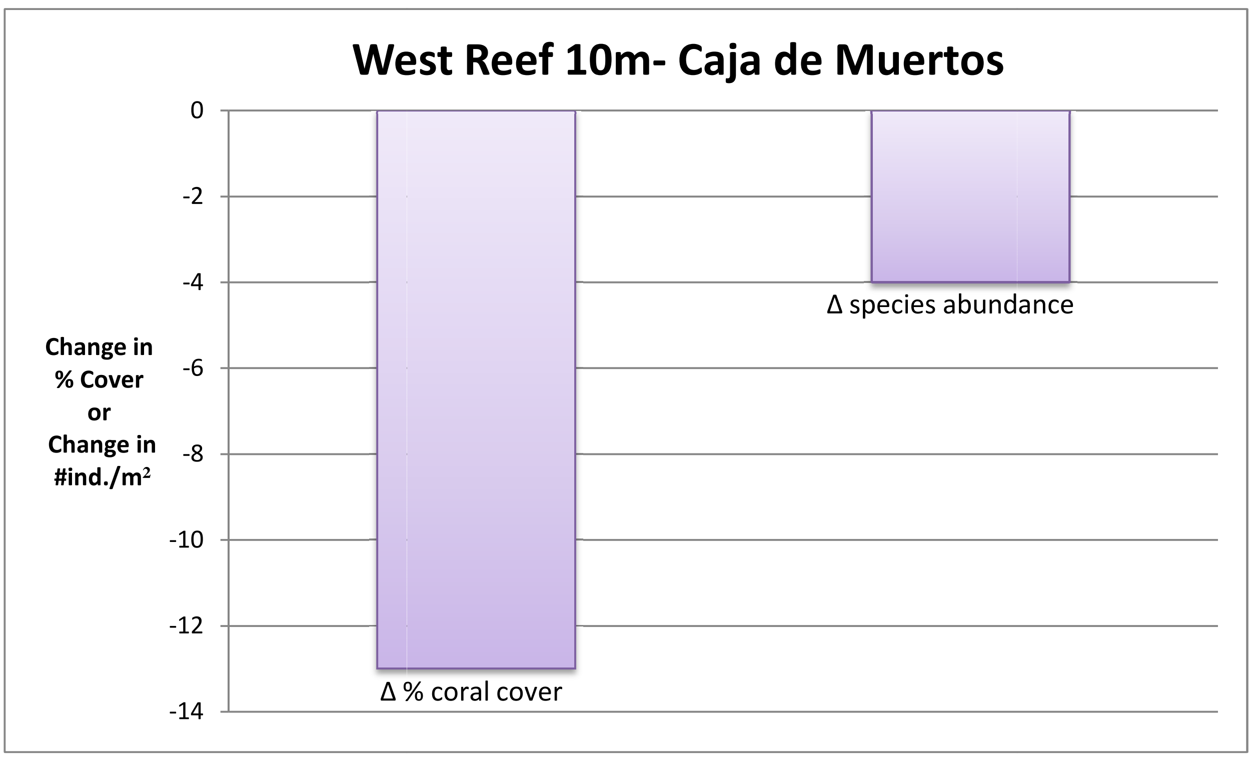

Figure 163: Change in Percent Cover vs Change in Species Abundance, West Reef, 10m

Caja de Muertos has some of the same potential stressors as will be discussed for the Derrumbadero Ponce monitoring site. The potential for land-based stressors due to its location near Ponce is there, however the major stressors are farther away. This includes general polluters such as hotels, gas stations, a marina, and industrial zones within 10 km. The bigger concerns are also farther away including landfills, EPA superfund sites, underground tanks, sewage treatment plants, filtration plants, and a river mouth within 15km. These are all major sources of pollution, so it is advisable for the DRNA to frequently test water quality levels for chemicals like phosphorus and nitrates along with determining if any runoff is going in the direction of the coral reef. This is particularly advisable since there is a landfill up river from the river mouth due north of the monitoring site. The Caja de Muertos site is a natural reserve and nationally protected area with buoys in place. Like the other sites mentioned before it is suggested that the number of mooring buoys be examined and potentially expended to reduce potential mechanical damage from anchors. This information can be found within the GIS analysis spreadsheet in Appendix D and within the GIS screenshots in Appendix E.

Derrumbadero Reef – Ponce

The Derrumbadero Reef is only monitored at the depth of 20m, but it has experienced some severe effects from the 2005 bleaching event. This reef experienced the characteristic drop in coral coverage while also having a massive algal bloom in the year 2006. Derrumbadero also has a predominant population of the main reef building species, *Montastraea annularis* which also felt the negative effects of the bleaching event. As Figure 165, shows there was a 31% decrease in the amount of coral, while the algae spiked up 22%. Also, Boulder Star Coral, the main reef building species, dropped 22% in its percent coverage. Since the event the coral coverage has remained fairly constant. This implies that the conditions at the reef are stable besides what happened in 2005. However, we recommend that in addition to the current data collected, the DRNA monitor for chemical pollutants, such as nitrates and phosphates, to try to maintain the reef's overall health.

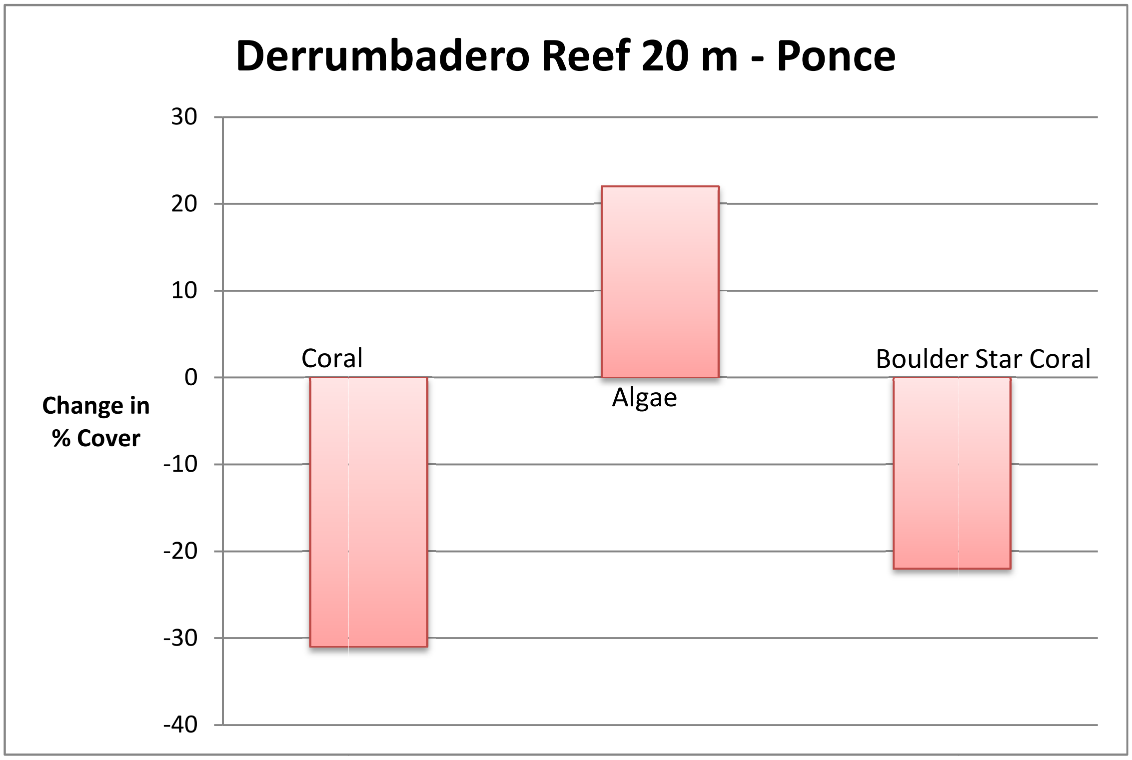

Figure 164: Change in Percent Cover, Derrumbadero, 20m

As can be seen in Figures 166 and 167 the fish species richness and abundance also suffered during the 2005 bleaching event. Both dropped immediately after the bleaching event, but since that time have recovered slowly. This gives the impression once again that the reef has stabilized since 2006. Although these numbers are improving, we still recommend that the DRNA monitors these populations to ensure nothing in the coral reef environment changes, and hinders the marine ecosystem's stability.

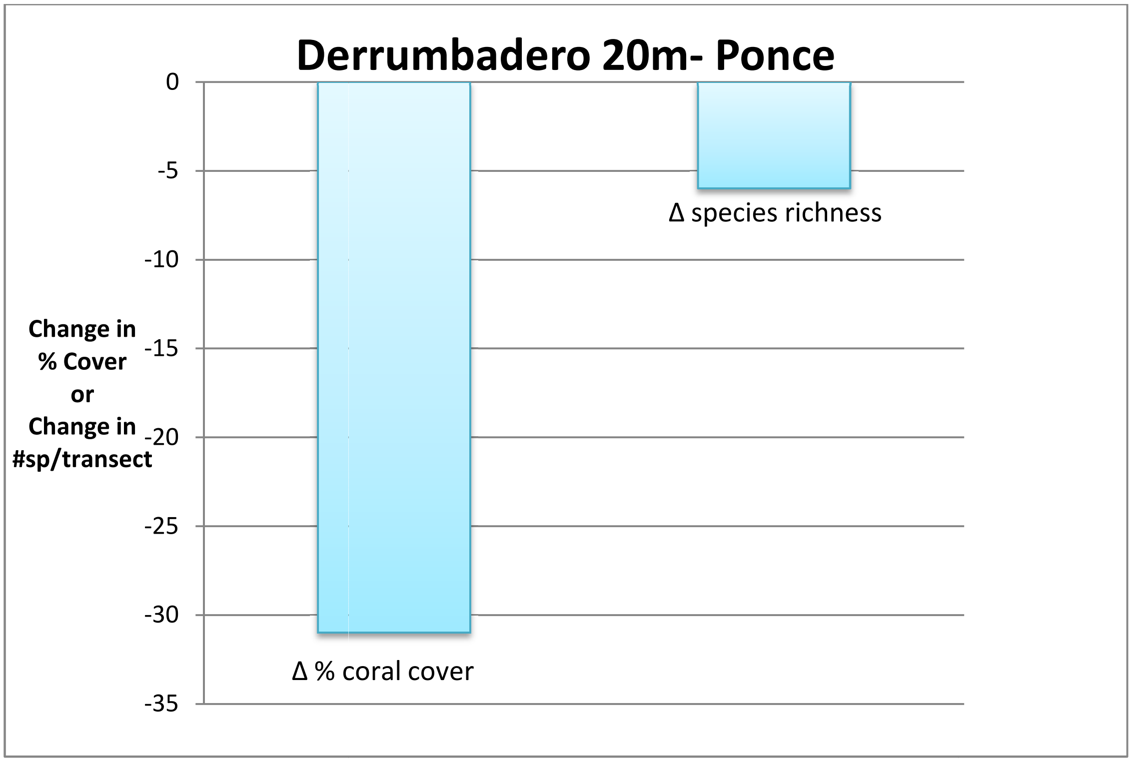

Figure 165: Change in Percent Cover vs Change in Species Richness, Derrumbadero, 20m

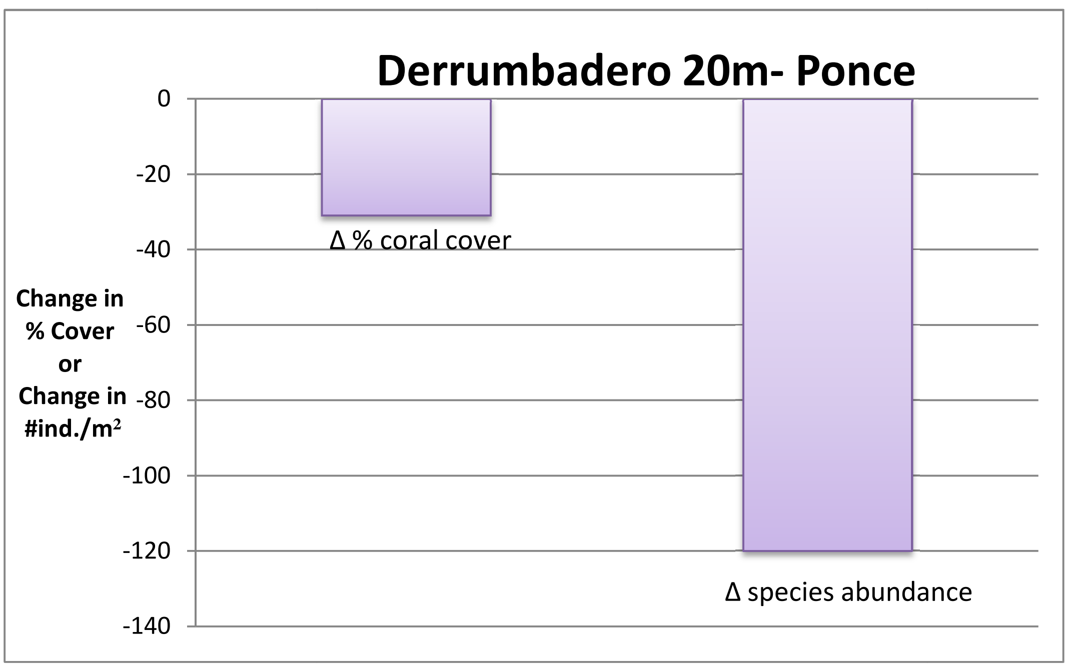

Figure 166: Change in Percent Cover vs Change in Species Abundance, Derrumbadero, 20m

The GIS layers for the Derrumbadero monitoring site reveal alarming possibilities for land-based stressors due to its location near Ponce. This includes general polluters such as hotels, gas stations, a marina, and industrial zones within 6km. More worrisome is the presence of landfills, EPA superfund sites, underground tanks, sewage treatment plants, filtration plants, and a river mouth all within 11km. These are potentially all major sources of pollution, so it is advisable for the DRNA to frequently test water quality levels for chemicals like phosphorus and nitrates along with determining if any runoff is going in the direction of the coral reef. It should also be noted that according to the DRNA GIS layer information, there is a lack of mooring buoys, and the monitoring site is not within a reserve or nationally protected area, so damage from boat anchors and propellers is a potential threat. This information can be found within the GIS analysis spreadsheet in Appendix D and within the GIS screenshots in Appendix E

Isla de Mona

Off the coast of the Isla de Mona there are two separate reefs that are monitored by the DRNA. The first is the Playa Mujeres Reef which is at a depth of 20m. As one can see from Figure 168 there has been significant coral degradation and algae growth in this particular reef. This again is a prime example of the correlation between coral death and algae growth. This pattern needs to be more thoroughly researched to find if the algae growth is what is hurting the reef. The Boulder Star Coral was degraded so badly that it dropped 19% in total live coverage. Since Mona is relatively free of human influence, one can assume the changing climate conditions played a large role in the coral death. However, to make sure this already delicate ecosystem does not collapse, the reef should be watched closely, and data should be collected for every monitoring report.

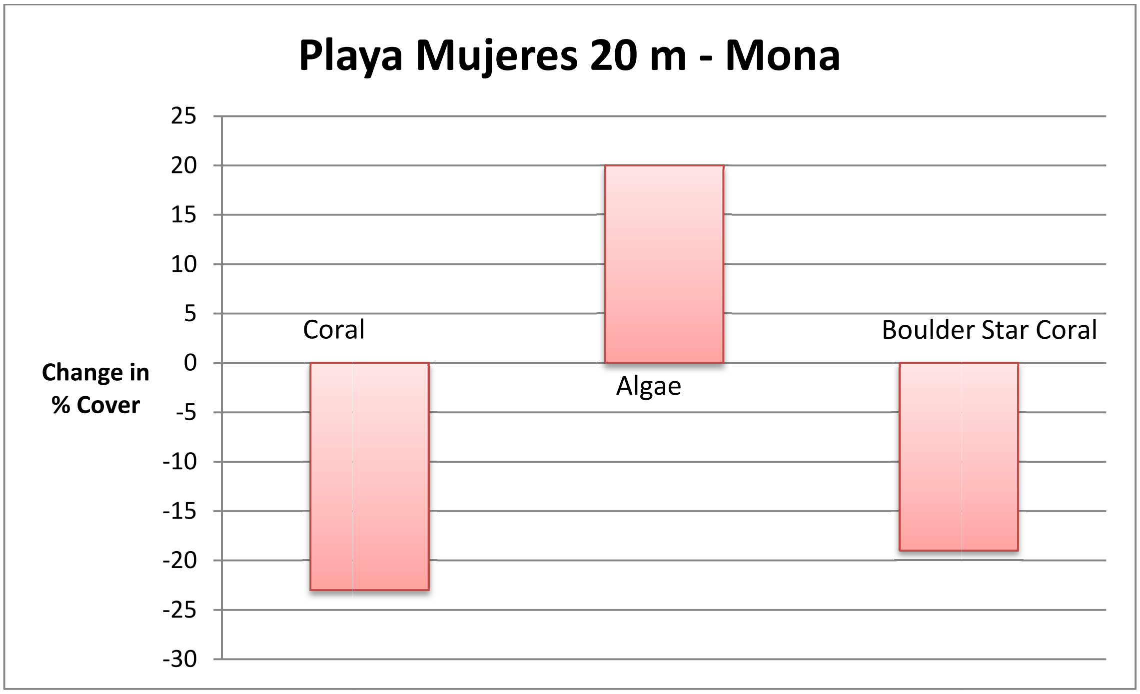

Figure 167: Change in Percent Cover, Playa Mujeres, 20m

The data for changes in species richness and abundance also show a slight drop as can be seen in Figures 169 and 170. This is a sign of a suffering ecosystem, and it needs to be monitored more closely. Mona does not have any data in the latest monitoring report, when it seems crucial now more than ever.

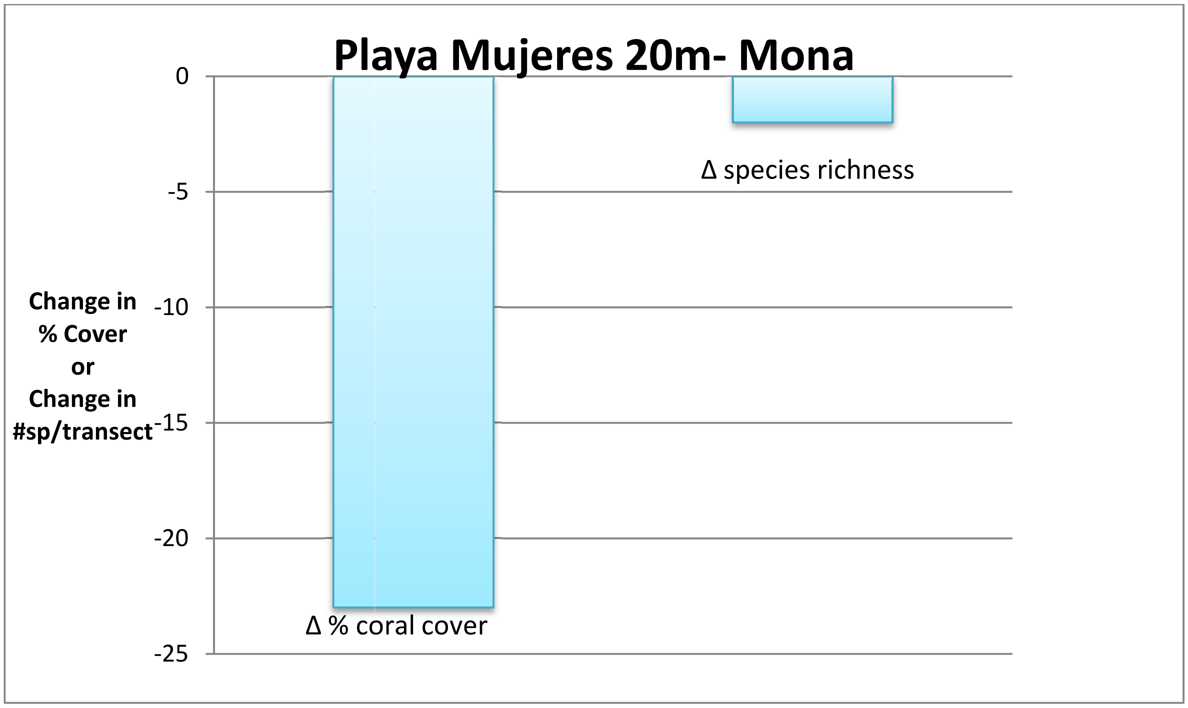

Figure 168: Change in Percent Cover vs Change in Species Richness, Playa Mujeres, 20m

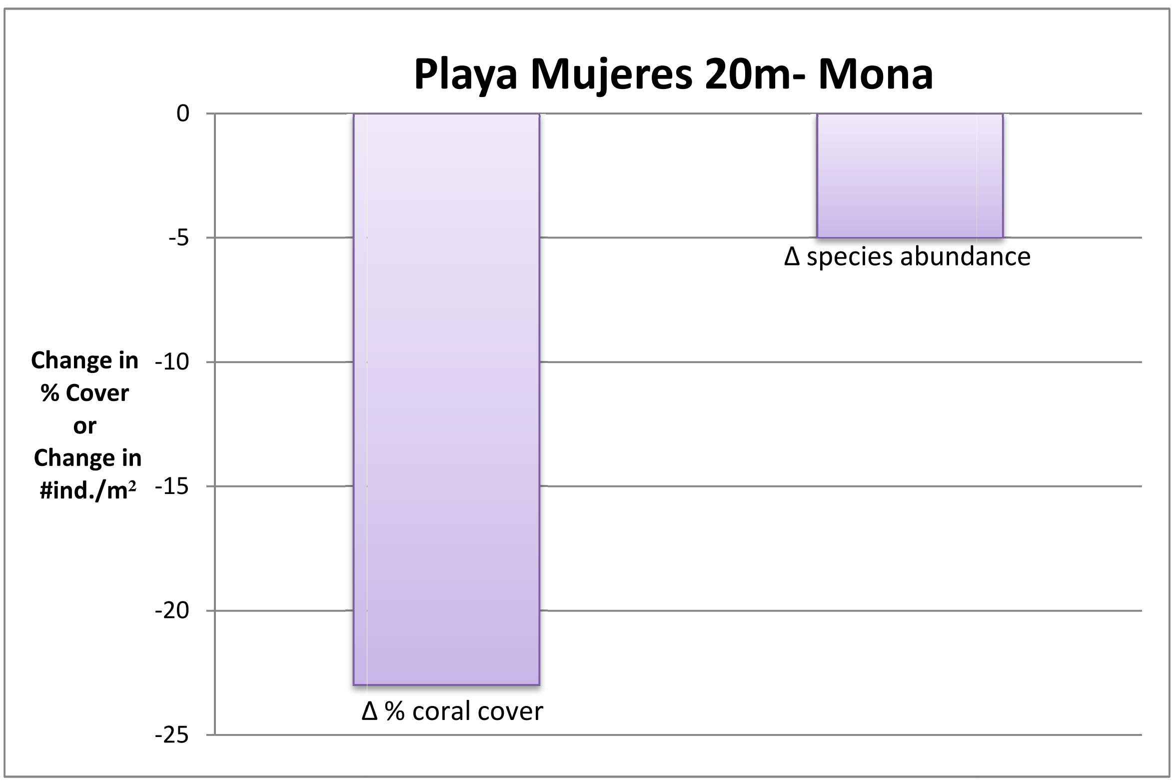

Figure 169: Change in Percent Cover vs Change in Species Abundance, Playa Mujeres, 20m

The second reef around Mona that is monitored by the DRNA is Las Carmalitas Reef at a depth of 10m. Much like Playa Mujeres, Las Carmalitas experienced major coral death and an algal bloom. Again this correlation between the algae growth and coral degradation needs to be looked into further. Also, data on water quality should be collected in order to monitor an already fragile reef system. This data should include content such as pH levels, nitrate and phosphate levels. This will give plenty of data that could be used to compare the conditions at each reef, and possibly determine any unknown factors associated with coral degradation.

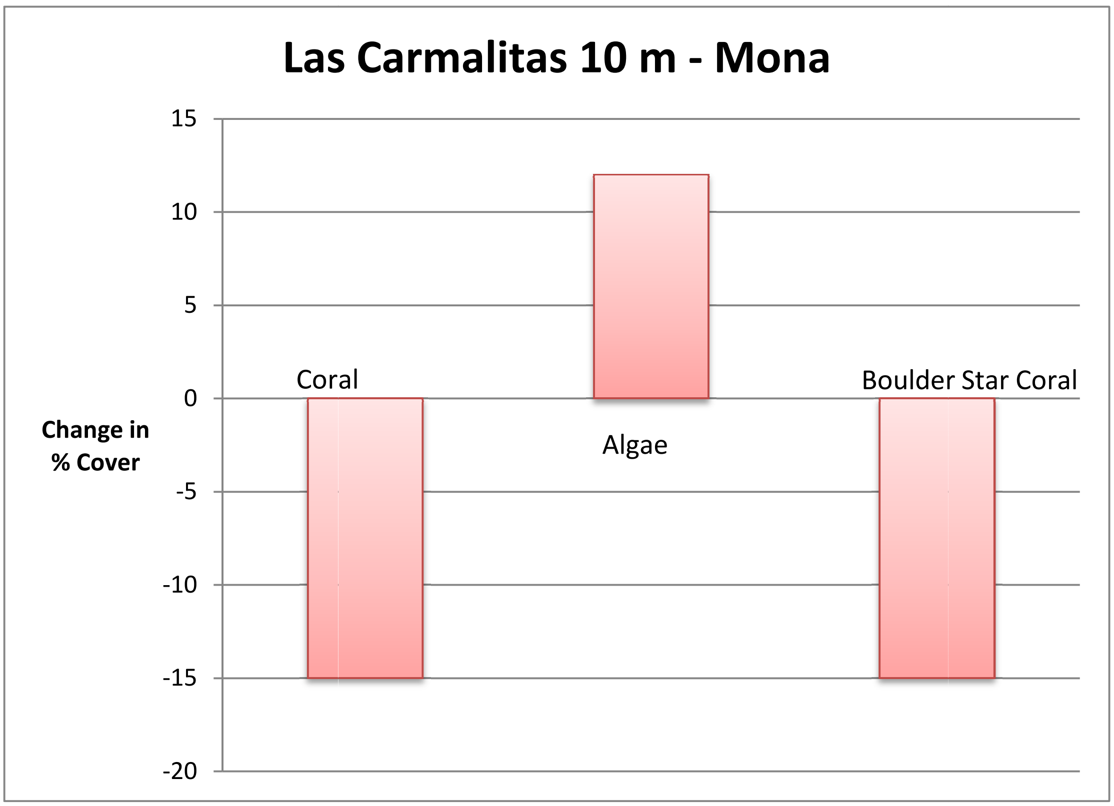

Figure 170: Change in Percent Cover, Las Carmalitas, 10m

As shown in Figures 172 and 173 the species richness and abundance for Las Carmalitas reef did not decline in the same way the coral coverage did. The species richness did fall slightly, but the species abundance actually increased by 50 individuals per square meter. So although the coral is dying off, the marine ecosystem is somewhat stable. This data should continue to be monitored to make sure the ecosystem is still able to support the fish population.This however also means that the ecosystem could be becoming in balanced. If the species richness is going down and abundance is going up, over time there will be a shift.

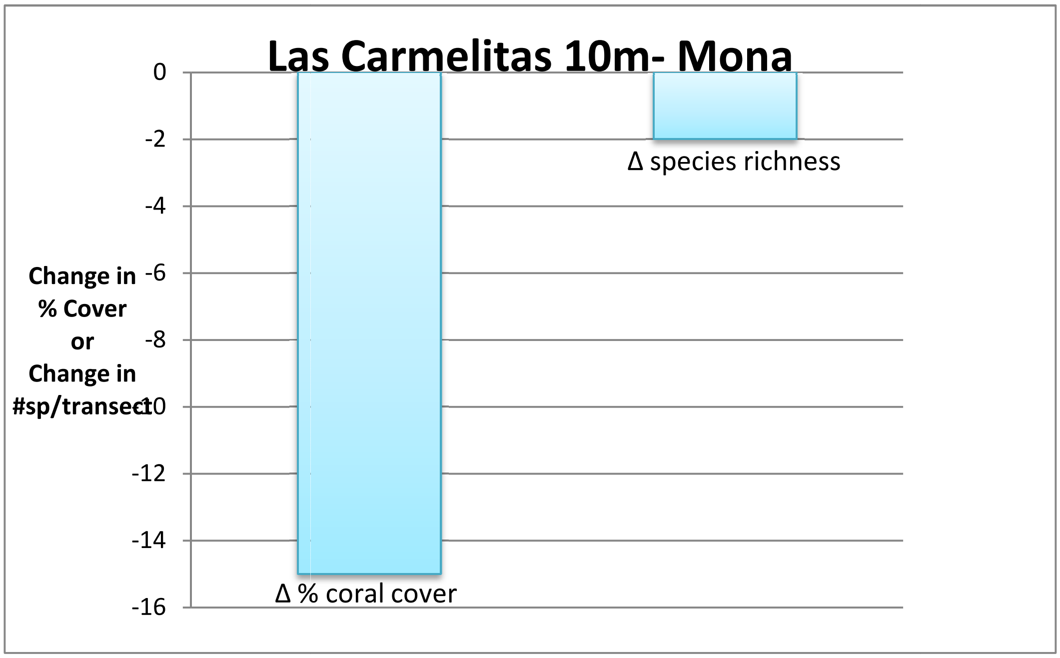

Figure 171: Change in Percent Cover vs Change in Species Richness, Las Carmelitas, 10m

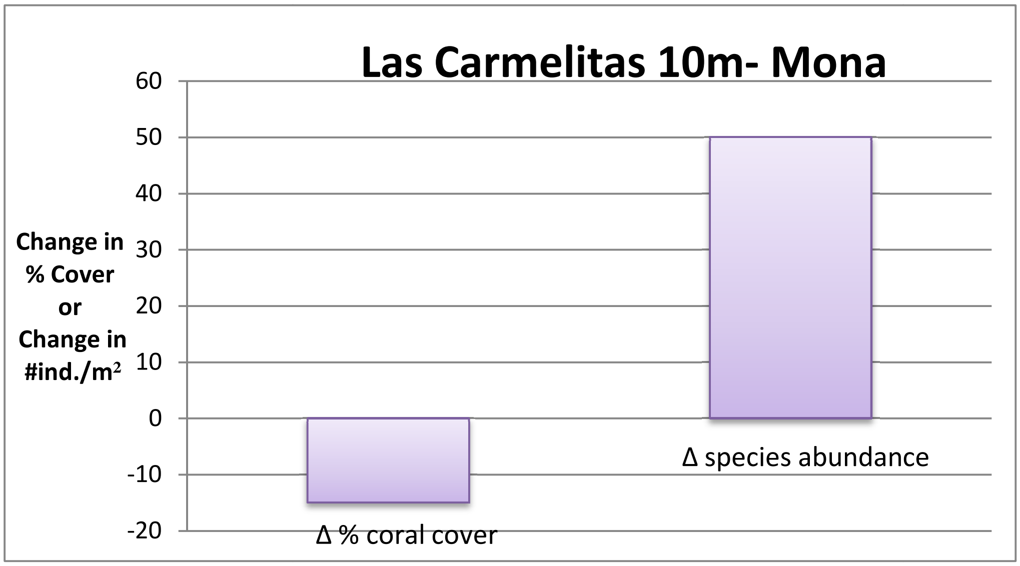

Figure 172: Change in Percent Cover vs Change in Species Abundance, Las Carmelitas, 10m

Similar to Isla Desecheo, it is difficult to draw analysis of what could be affecting the reef from the DRNA GIS layers. The two Mona monitoring sites are more than 80km away from the nearest shorelines of Puerto Rico, and the island is in fact closer to the Dominican Republic at a distance of less than 70km. There is no DRNA GIS information on the Dominican Republic to draw analysis from and at 80km away from the coast; it is hard to say if any main island pollution would be reaching the monitoring location. It is a natural reserve and nationally protected area with mooring buoys. The biggest conclusion to draw would be the risk of boater pollution and mechanical damage, so as at the other reefs it would be wise to research the potential need and feasibility of adding additionally buoys for boats to moor at.

Culebra

Three different locations off the Island of Culebra were monitored for coral reef fish species and abundance (See Figure 50).

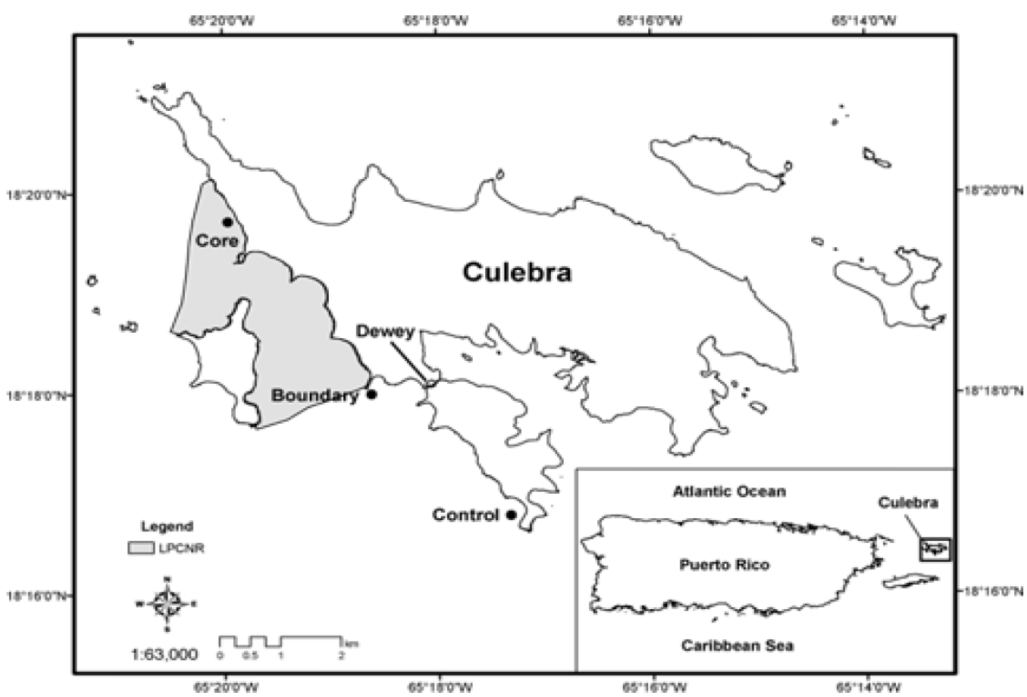

Figure 173: Playa Carlos Rosario (Core), Punta Melones (Boundary), and Punta Soldado (Control). (Hernández-Delgado, 2009, p. 6)

There is a core site at Playa Carlos Rosario, a control site at Punta Soldado, and a boundary Site at Punta Melones. The core and boundary sites are no take marine protected areas (MPA), whereas the control is outside the MPA. This area is called the Canal Luis Pena No-Take Natural Reserve (CLPNR). Since the boundary site is closer to the main population of Culebra, it has a lower water quality than the core and control sites. Prior to the installation of the MPAs, fishing was allowed at all three locations. In 1999, the MPA was installed, and there was a significant increase in species richness and abundance by the year 2002.

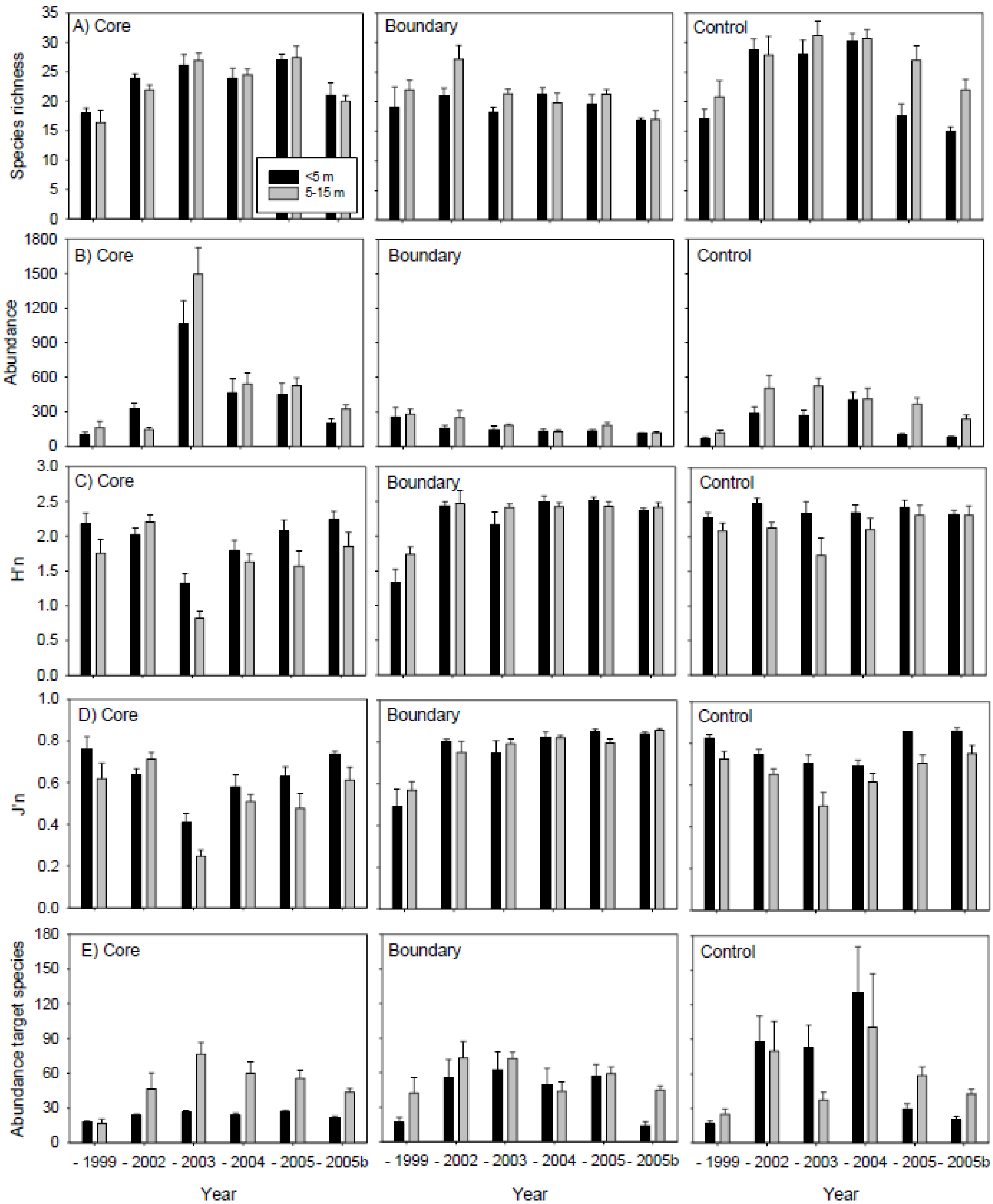

Figure 174: Spatio-temporal variation in fish community parameters A) Species Richness, B) Abundance, C) H'n (species diversity index), D) J'n (eveness), E) Abundance local fishery-targeted species (Hernández-Delgado, 2009, p. 12)

Fish abundance peaked in 2003 and steadily declined after that. The decline leading into

2005 is believed to be caused by fishing, especially poaching in the MPAs. The decline in abundance may also be linked to the pollution talked about in the following paragraphs. Then in 2005, a high sea surface temperature (SST) caused a widespread fish community collapse on Culebra and bleaching and disease outbreaks across the Caribbean, resulting in even more decline in the fish community.

What can be learned from this study is that MPA's are effective in protecting against local-scale anthropogenic effects such as fishing and trapping. However, if they are not enforced strongly, poaching and overfishing can still happen, as happened on Culebra. Also, they cannot protect against regional-scale impacts such as high SST events, which occurred in 2005. If the regulations are enforced strongly, however, the coral reef ecosystem may be stronger and able to withstand high SST events, and not experience the mortality rates as seen in 2005.

Also contributing to the decline of the reefs and fish species in Culebra is the pollution. Non-point source pollution from the island is a major problem. The island does not have enough sewage treatment plants which has resulted in most of the island utilizing septic tanks. However, many of the septic tanks are poorly constructed and leak. Many of the tanks are also constructed below the coastal water table, which means any leak will eventually lead to the ocean. In addition to the septic tank problem, there are Culebra has numerous illegal discharges from raw sewage into the storm drains that dump into the ocean. Due to the septic tank problems and illegal discharges, there are numerous fecal coliform violations and enterococci violations surrounding the Island. Figures 177 and 178 show May to November of 2008 levels of fecal coliforms and enterococci. Figure 176 shows the locations of each site (Ensenada Honda at Barriada Clark (CLA), Ensenada Honda at Municipal Pier (MPI), Lobina Channel (LOB), Bahía Sardinas (BSA), Punta Melones (PME), Punta Tamarindo Chico (PTC), Arrecife El Banderote (AEB), Punta Rompe Anzuelo (PRA), Cayo Luiz Peña-north (CLP), and Playa Carlos Rosario-south(PCR)). During the outgoing tide, the runoff and pollution from Ensenada Honda (CLA and MPI) flows through Lobina Channel (LOB) and eventually goes northwest through the other monitoring sites in Figure 176 and also into CLPNR.

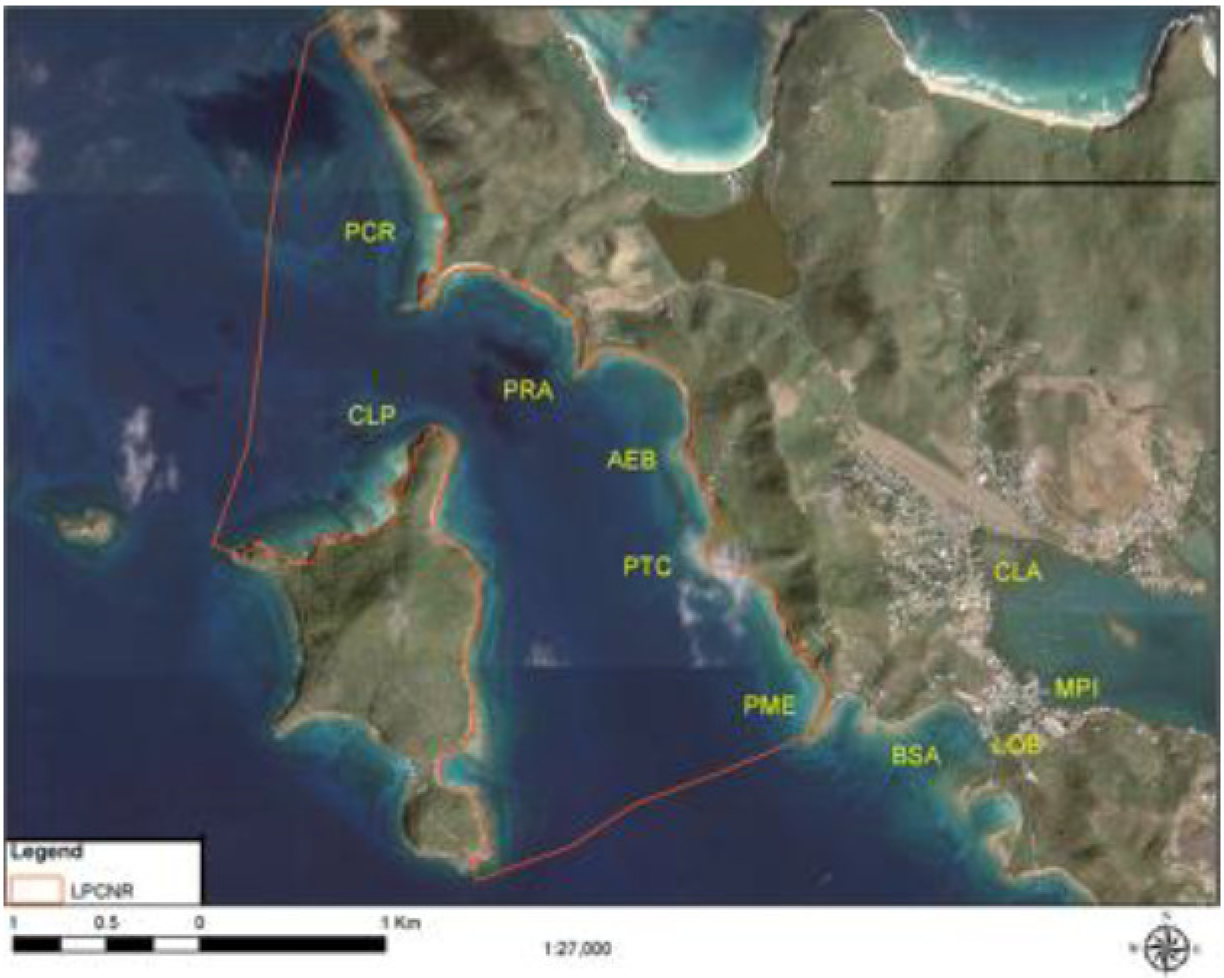

Figure 175: Map of Culebra Water Quality Monitoring Sites (Hernández-Delgado, 2010, p. 255)

Sample	May	Jun	Jun	Jun	Jul	Aug	Sep	Oct	Nov		Mean	Frq
CLA	15	119.5	190	19	1123	76	133	300	10		221	67%
MPI	NS	NS	25	134	125	5	157	100	20		80	57%
LOB	80	65	240	245	2095	1570	70	1150	45		590	100%
BSA	84	77	10	1	57	76	8126	30	0		948	56%
PME	0	0.5	10	1	2	3	239	0	0		26	11%
PTC	NS	NS	NS	NS	2	9	20	0	0		6	0%
AEB	NS	NS	NS	NS	0	6	833	10	0		88	20%
PRA	130	10	28	5	6	13	290	60	1		61	33%
CLP	NS	NS	54	0	0	3	77	0	2		19	29%
PCR	0	0.5	47	0.5	0.5	6	607	0	0		66	22%

NS= Site not sampled for that time period. Red color= violation to EQB class SB water quality classification enterococci standard (35 cfu/100 mL).

Figure 176: Microbiological water quality violations for enterococci across sites (Hernández-Delgado, 2010, p. 280)

As shown in Figure 177, Culebra has problems with enterococci, which is an indicator of sewage waste in the water. There seems to be a particular trend, that areas closest to the main population of Culebra have more enterococci in the water than the others. Even though there are no reefs there, the tides carry these bacteria over to the reefs and the MPAs discussed earlier. Another trend is the enterococci levels are much higher during the summer. In some cases, the levels are not even close to the Environmental Quality Board's water quality standard of 35 cfu/100 ml. In July 2008, Lobina Channel (LOB) was 60 times above the acceptable level and in September 2008, Bahía Sardinas (BSA) was 230 times over. These September data may be skewed because of Hurricane Kyle in September 2008, causing more runoff and more bacteria to enter the ocean. However, this should still be a concern because no matter what, this many bacteria should not runoff into the ocean. These bacteria are not healthy for the reefs, and when there are mass quantities of the bacteria, they can cause coral mortality.

Sample	May	Jun	Jun	Jun	Jul	Aug	Sep	Oct	Nov	Mean	Frq
CLA	40	168	23	26	1000	673	550	ND	ND	357	33%
MPI	NS	NS	ND	537	389	18	20	70	113	191	29%
LOB	95	194	39	850	1000	564.8	230	1975	228	555	67%
BSA	32	5.3	0	1	95	29	546	0	0	79	11%
PME	0	0	0	0	1	2	0	0	0	0.2	0%
PTC	NS	NS	NS	NS	0	0	0	0	0	0	0%
AEB	NS	NS	NS	NS	0	0	10	0	0	1	0%
PRA	350	3	0	102	3	1	2	0	2	51	11%
CLP	NS	NS	2	0	2	0	0	0	0	0.3	0%
PCR	0	0.5	0	0	2	0	5	0	0	0.7	0%

NS= Site not sampled for that time period. ND= Not detected due to interference overgrowth by other microbes. Red color= violation to EQB class SB water quality classification FC standard (200 cfu/100 mL).

Figure 177: Microbiological water quality violations for fecal coliforms across sites (Hernández-Delgado, 2010, p. 279)

As shown in Figure 178, Culebra also has problems not just with enterococci, but with fecal coliforms as well. The same two trends identified with enterococci happen with fecal coliforms. The areas closer to the main population of Culebra have the highest concentrations, and the violations happen mostly during the summer months. There are not as many violations as there were for enterococci, but there are still enough that there should be a concern. The fecal coliform levels are above the EQP water quality violation by a lot, in some cases close to ten times higher, but nowhere near the 230 times over like the enterococci. Fecal coliform, like enterococci, is also an indicator of sewage in the water and can also be fatal to the coral reefs and the fish species. If these trends continue, the damage could become permanent, and may even restrict activities such as swimming and fishing on Culebra. The chronic violations of enterococci and fecal coliform near the center of Culebra's population are proving that these waters are heavily polluted and the heavy rainfall is not helping the problem.

Another problem is the turbidity of the water. Due to all the runoff and erosion, Culebra is having problems with turbidity. Figure 179 is of May to November 2008 measuring turbidity.

Sample	May	Jun	Jun	Jun	Jul	Aug	Sep	Oct	Nov		Mean	% Frq
CLA	8.69	6.23	15.9	10.6	19.0	7.49	19.9	7.39	21.0		12.36	56%
MPI	NS	NS	4.43	1.64	1.30	1.25	9.99	1.59	2.78		3.28	0%
LOB	7.65	2.13	9.13	3.87	6.99	2.38	20.05	2.24	1.60		6.09	11%
BSA	1.27	1.59	5.68	1.28	1.02	0.58	3.16	0.89	0.49		1.74	0%
PME	1.61	0.75	1.25	1.37	0.48	0.51	1.39	0.52	0.28		0.93	0%
PTC	NS	NS	NS	NS	0.51	0.54	1.54	1.05	0.38		0.80	0%
AEB	NS	NS	NS	NS	0.98	1.00	1.71	1.01	0.38		1.02	0%
PRA	1.17	1.50	4.64	0.66	0.56	0.40	1.21	0.53	0.34		1.23	0%
CLP	NS	NS	1.13	0.37	0.53	0.45	0.88	0.67	0.29		0.61	0%
PCR	2.20	0.89	2.20	0.84	0.51	0.38	1.63	0.74	0.28		1.12	0%

NS= Site not sampled for that time period. Red color= violation to EQB class SB water quality classification turbidity standard (10 NTU).

Figure 178: Water Turbidity (NTU) standard violations across sites (Hernández-Delgado, 2010, p. 267)

As seen in Figure 179, Culebra has turbidity violations in addition to the sewage problems. The turbidity problem is not as prevalent as the sewage problem, but it is still there. All together, there were violations only 7.3% of the time in the coastal waters, but at CLA there were violations 56% of the time. The violations and other high levels of turbidity also mostly followed heavy rainfall.

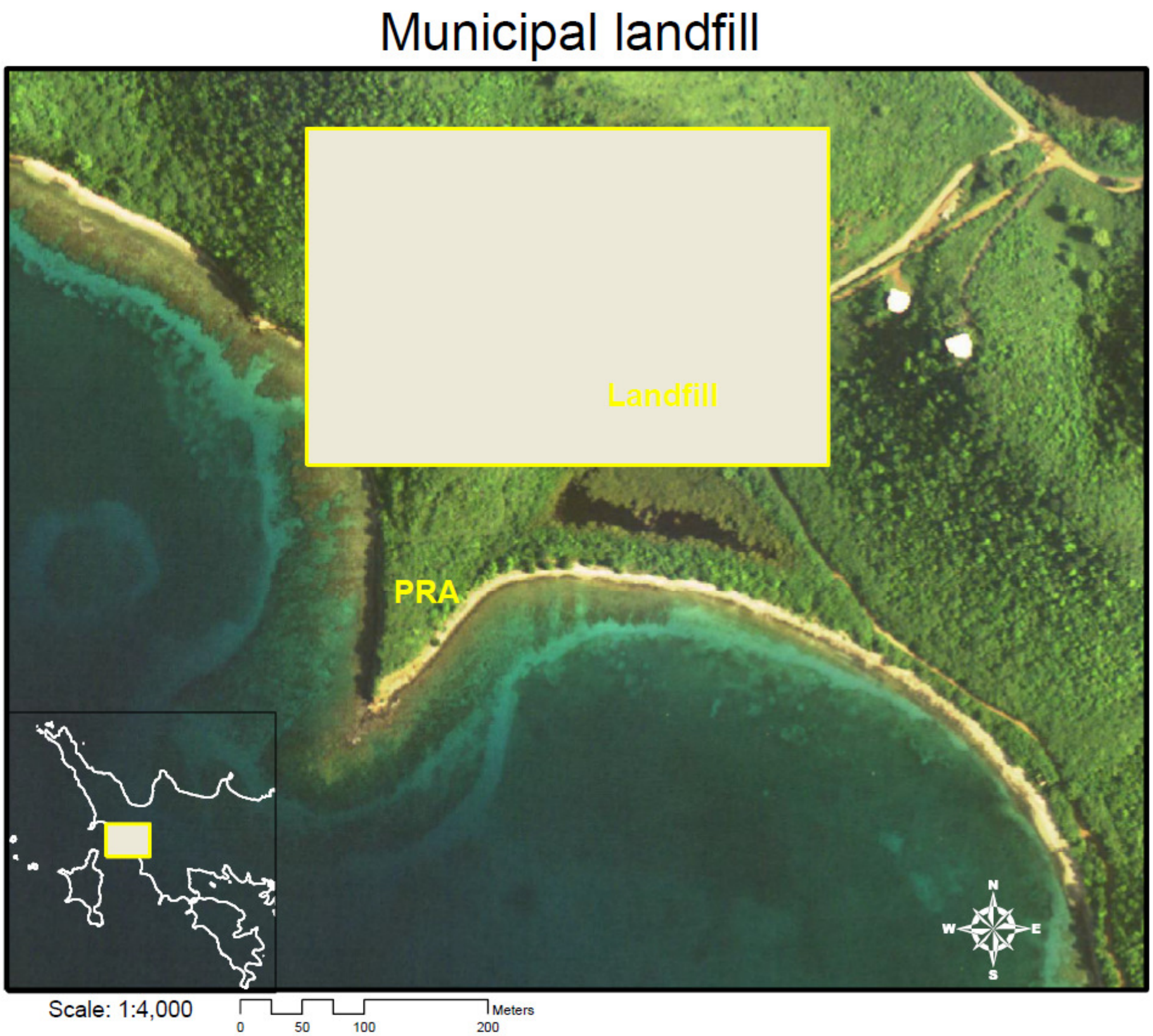

Figure 179: Culebra Island Municipal Landfill (Hernández-Delgado, 2010, p. 262)

Another problem Culebra is dealing with is the municipal landfill right in the middle of the MPA (Figure 180). During rain storms, sediment-laden runoff caused by be coming from the rainstorm may be pouring into the water and onto the reefs. There have yet to be tests to determine whether or not this is happening, but there generally is severe runoff on the island, and this problem should definitely be looked into by the DRNA. Also when there are strong easterly winds, garbage from the landfill, such as plastic bags, is blowing into the water and getting stuck on the reefs, suffocating them.

Vieques

For Vieques, the 2011-2012 Monitoring Report took data from El Seco Reef. This was the first time data was gathered at this reef, so it will be used as a baseline for comparison data gathered in future years. The reef overall shows signs of being a healthy reef. The percent live coral coverage is at 43.1%, with 85% of that coverage being from the *Montastraea* family. This family is the principle reef building species and is crucial for coral reef survival. The percent algae cover is 43.7%, with only 21.7% of that being from the *Lobophora* family. This is a decently low percentage, which means the reef has not been overtaken by algae growth yet. It will be important to monitor this reef for future years to identify any trends in the reef conditions.