Assessment and Catalogue of Puerto Rican Mooring Buoys

WORCESTER POLYTECHNIC INSTITUTE

May 5, 2009

By

Greg Coffey
Eric Greer
Ryan LaSante
Brittany McNally

Project Liaison: Dr. Craig Lilyestrom, Mr. Carlos Matos

Project Advisors: Professor Karen Lemone and Professor Ingrid Shockey

ABSTRACT

The Department of Natural and Environmental Resources of Puerto Rico has installed over 270 mooring buoys in seagrass, coral, and mangrove regions with the anticipation that they will curb boating damage and allow these natural environments to recover. To streamline buoy management, our group constructed a Geographic Information System database. This contains data we gathered at each buoy concerning its exact GPS location, condition, the recovery of the environment it is protecting, and observations of boating trends within the region.

ACKNOWLEDGEMENTS

Throughout the course of this project there have been many helpful individuals who have taken time from their busy lives to contribute to the success of this project. We would like to thank them for their contributions.

To Craig Lilyestrom for his wealth of information and coordination of our entire project.

To Carlos Matos for his exceptional aid with fieldwork, and continuous support with all aspects of our project.

To Edwin and Maribel Rodriguez for the sharing of their photography, and help throughout our project.

To the Oficina de Informática: Nora Alvarez, Victor Cuadrado Landrau, and Alberto Colón for their help with developing the GIS Database.

To the Coral Rangers for their assistance with aquatic transportation.

To our fellow colleagues from WPI: Kevin Vayda, Dan Cafferty, and Jason Carmichael for their willingness to share their survey results.

AUTHORSHIP

We, as a group, have researched and written this report. All sections of this paper were written through our combined efforts. We have all agreed upon this.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

In 1990, the Department of Natural and Environmental Resources (DNER) of Puerto Rico began the Marine Buoy Program in an effort to protect the offshore ecosystems that are constantly being damaged by harmful boating practices. The Marine Resources Division of the DNER installs and maintains the mooring buoys, which are permanently anchored buoys that allow boaters to moor without damaging the seafloor. Prior to our project, there were 270 mooring buoys off the coast of Puerto Rico whose exact location, current condition, and extent of use were relatively unknown. The DNER was unsure of the effectiveness of their program; to remedy this we created a Geographic Information System (GIS) database. The database contains a catalogue of the buoys' exact GPS coordinates in addition to information regarding the buoys' current conditions, states of the surrounding environments, and observations of the boating activities and traffic in the area.

We traveled to different areas around Puerto Rico so that we could collect a representative sample of the buoys surrounding the island. We recorded our data using a Trimble GPS transponder, which is a handheld GPS unit with the ability to store locations and record our observations in editable datasheets. When we traveled to the mooring fields, we catalogued each buoy's location and discovered that the buoys were all installed on the lee side of the islands and cays. The lee side corresponds to the Puerto Rican side of the surrounding islands, and contains delicate coral and seagrass ecosystems. Interviews conducted in situ provided another reason as to why the buoys were placed on the Puerto Rican side of the islands: boaters would rather anchor closer to the Puerto Rican mainland than waste time and gasoline to circumnavigate the islands. The sheltered waters also offer a safer environment for other aquatic recreational activities, especially for children.

In addition to recording the locations, we analyzed the conditions of the buoys to discern their maintenance needs. Using the Trimble, we recorded the level of damage for each of the buoy's components. We found that the conditions of the buoys were generally a good indicator of the popularity of the site: the more visited locations had a greater number of buoys with deteriorating components. However, at more remote locations, the most prevalent damage that needed to be addressed was the accumulation of excessive marine flora and fauna on the lines and buoy. The buoy's downline, which attaches the buoy to the anchor, serves as a beneficial microenvironment where many species flourish without competition from other seafloor inhabitants. However, when this environment ascends to the buoy and the pickup line, these components become weighed down, and sit lower in the

water. This leads to an increase in damage, especially to the pickup line, as boaters will frequently run over these components.

To determine whether the Marine Buoy Program alleviates damage to the environment, we assessed the surrounding marine ecosystems: coral, seagrass, and mangroves. With one exception, the areas that harbored coral showed no signs of recent damage. However, due to coral's long recovery time (25-100 years), we were unable to observe much growth in hard coral environments. Although we have not seen hard coral recover, we have seen that seagrass recovery times vary drastically with depth. There is more damage in shallow water than deep water; yet damage to seagrass in deeper water takes longer to recover –nine years. Unlike the other environments, mangroves showed no obvious damage in the areas inspected; however our schedule did not allow us to return after a major holiday weekend to examine the damage accrued from boaters. Aerial photographs taken during the holiday depict a large number of crafts tying to the mangrove roots, which could cause damage to their root systems.

We identified activities boaters conducted at the mooring buoys to the primary buoy uses. From our observations, we discovered the majority of buoy users were fishing, swimming, snorkeling, sunbathing, or socializing. Unfortunately, most of our fieldwork took place during normal business hours, so aerial surveys were used to reveal the weekend popularity of the sites we visited. Through these we found that many of the boaters who tied up to the buoys were using the system incorrectly. These boaters were acting in a way that could damage the mooring buoy, as well as the surrounding ecosystems, by not tying their own line to the pickup line, connecting to other boats, or dropping anchor in addition to being moored at the buoy. From the surveys, we discovered that only a small percentage of the boats were actually using the buoys properly, if at all. This is because most boaters are drawn to the near-shore areas of shallow calm water. Here, they can anchor in the sand of the beach, avoiding the fines for dropping anchor on reefs or seagrass, while still remaining close to shore.

Our analysis of boat traffic around the buoys took into account all the boats in the general vicinity. These data came from a combination of our observations and the DNER's aerial surveys. During the week, we found the dominant boat type to be commercial ferries. Aside from these crafts transporting people back and forth between islands, there were only a few small to medium-sized recreational boats on the water. The aerial surveys show that, unlike weekdays, the holiday weekend brought many recreational crafts to areas supported by mooring buoys. The sheer number of boats indicates that the influx on weekends is too great for the current number of mooring buoys to handle. Although there are not a sufficient number of buoys to handle the holiday traffic, enough buoys should be installed to accommodate the average weekend influx. With protection against average weekend boating traffic, the surrounding ecosystems would be able to recover more fully between holidays. A problem that we have noticed, though, is that sometimes the mooring buoy cannot provide adequate protection because the boats are too large to use the buoy and are forced to drop anchor, damaging the ecosystem.

The GIS database that we constructed contains the information collected regarding the Marine Buoy Program, and will aid the DNER in protecting the marine environments around Puerto Rico. With this database, the DNER will be able to better organize and plan maintenance schedules for the buoys that manage the surrounding environments. Because of the buoys, damage to the seagrass, soft coral, and mangroves is greatly decreased, and, even if there are not sufficient mooring buoys for all the boaters on weekends, there are enough during the week to allow these ecosystems to begin to recover. Another pattern we discovered is that areas subject to heavy traffic sustain a significant amount of damage to ecosystems and mooring buoys alike. Additionally, because there has not been significant evidence of hard coral recovery, the effectiveness of the mooring buoys pertaining to hard coral is unknown.

Based upon our findings, we recommend that buoys in popular locations be reexamined following major weekends. This will allow the DNER to simultaneously check the conditions of the buoys and the environmental impact of the large influx of boaters. The GIS database should also be regularly updated with the current conditions of both the buoys and the surrounding ecosystems, along with any additional information. We also believe that a limited view of the database should be published on the DNER's website, to be available for public access. Another idea is to use our database to expand the "Adopt-A-Buoy" program, which allows the public to "adopt" buoys, but could see the sponsors performing a more active role in the cleaning and maintenance of their buoys. In following these recommendations, and with continued attention to habitat restoration, maintenance of the buoys, and regulations of boating practices, the marine environments around Puerto Rico should see a full recovery.

CHAPTER 1: INTRODUCTION

As global awareness shifts toward the reality that humans are causing major environmental impacts, many corporations and governments are turning some of their funding to address these issues (National Wildlife Federation, 2007). Some private companies, in an effort to preserve the environment have given money to endangered terrestrial zones and in some instances use these areas for their mutual gain as nature tourism sites (Moreno, 2005). On an island such as Puerto Rico aquatic tourism can be a strong source of revenue, making the benefits of preserving marine ecosystems both environmentally and economically sound.

An example of an environment providing both ecological and economic gain is the coral reef. The collective coral reef systems of the world provide a home for over half a million different species and have more biodiversity than the summation of the rest of the oceans (Spalding, Ravilious, & Green, 2001). These ecosystems, among the most productive on the planet, can provide valuable resources to mankind when properly maintained. If gathered in a responsible manner, the fauna in one square kilometer of a reef ecosystem can supply all of the protein 300 people need for day-to-day living (Jennings & Polunin, 1996). Reefs can also be a valuable asset for the tourism industry. Activities such as scuba diving, snorkeling, and boating can all bring revenue to local businesses. Other environments, such as seagrass and mangroves, function symbiotically with coral reefs and can provide similar benefits for the community.

Seagrass enriches the biodiversity of the waters and provides a unique commercial venue. Within this habitat there exist numerous creatures that use the vegetation for shelter and sustenance. Marine grass ecosystems reduce current speeds and wave intensity, which creates a more hospitable environment for its inhabitants. This reduction of current velocity by the flora, in combination with a complex root system, reduces aquatic erosion. The roots also redistribute nutrients, which allows for certain fish and shellfish to flourish (Gullström et al., 2002).

Due to the large number of boats registered in Puerto Rico, anchor damage has become one of the major causes of devastation to seagrass and coral; however it can be successfully abated with the use of mooring buoys (U.S. Dept of Homeland Security & United States Coast Guard, 2008). Surrounding the island of Puerto Rico, the Department of Natural and Environmental Resources (DNER) has installed over 270 mooring buoys in sensitive marine floor environments to combat the damage done by boating anchors.

At the commencement of our project, the exact location, condition, and extent of use of these buoys were unknown. The exact GPS coordinates of the anchor pin are needed to facilitate reinstallation of a buoy, since the pin is hard to locate even when given a general position. Following installation, conditions will often vary between buoys, making it important to know the current levels of damage so that the DNER can perform maintenance in a timely manner. Additionally, knowledge of the distribution and concentration of marine traffic is required for the DNER to provide convenient mooring sites.

The goal of our project was to create a Geographic Information System (GIS) database containing clear and updatable data regarding the mooring buoys surrounding Puerto Rico. This database was completed by addressing the following objectives: obtaining complete information on the locations and conditions of the mooring buoys, assessing the surrounding ecosystems, identifying boating activities that are conducted at the buoys, and analyzing boat traffic. This GIS database will provide the basis for future projects of the DNER as well as a valuable reference regarding the mooring buoys.

CHAPTER 2: BACKGROUND

In constructing a GIS database of the mooring buoys around Puerto Rico, a number of elements are needed to understand the methods employed. These elements also offer an insight to the importance to our project. Coral reefs and seagrass are the primary environments that the DNER is trying to protect from marine damage. While most damage cannot be controlled, mooring buoys may be a solution to helping coral and seagrass to recover by lessening the negative impact of humans. It is important to know who advocates for the protection of the ecosystems with mooring buoys and who uses the ecosystems for their benefit.

2.1 Coral Reefs

The coral reef is a very important ecosystem that is made up of a plethora of organisms, each doing a different job to help the coral reef operate. Reefs are one of the "most productive and biologically diverse ecosystems on earth" (Moberg & Folke, 1999).

2.1.1 Location and Extent

A coral reef is a collection of coral organisms that have come together to live in a large colony. The coral polyps that do not live in these colonies can be found all over the world. Aside from the coral, many other organisms live in the reef because of the shelter and food it provides (Spalding et al., 2001).

Figure 1: Hard and Soft Coral

One might think that due to the sheer magnitude of species that live in the coral reef that reefs occupy a large ocean area, but they only represent 1.2% of the continental shelf and 0.09% of all the oceans (Spalding et al., 2001). Coral can be found all over the ocean at any depth, but coral reefs are almost exclusively found in warm shallow coastal waters. The coral reefs located in the Caribbean and Atlantic make up less than 8% of the world's entire reef population (Spalding et al., 2001).

2.1.2 Importance

Despite the small amount of ocean floor covered by coral, there have been more than sixty thousand species classified. However, it is estimated that there are about a half million to two million plant and animal species living in coral reefs (Moberg & Folke, 1999; Spalding et al., 2001). Reefs provide a safe place and sustenance for their inhabitants to spawn, mature, and breed.

Besides being a home to many different species, coral reefs have other attributes as well, such as providing various resources for a large community (Spalding et al., 2001). This community includes pharmaceutical companies, tourists, commercial fishermen, and aquariums (Moberg & Folke, 1999). Pharmaceutical companies have researched the use of seaweeds, sponges, and other life forms located on the reef to produce useful substances that can be used in anticancer or AIDS-inhibiting drugs (Moberg & Folke, 1999; Spalding et al., 2001). A few examples of recreational activities that tourists and locals participate in and around the reef include scuba diving, snorkeling, and swimming. Another use of the reefs, commercial fishing, provides ten percent of all fish that are consumed by humans. Coral reefs also fuel the marine aquarium industry; the coral and many of the species that inhabit the reef are caught and sold to many aquarium enthusiasts (Moberg & Folke, 1999).

2.1.3 Interactions with Surrounding Ecosystems

Besides providing these resources, coral reefs also protect the coasts that they surround. The islands in the Caribbean are constantly hit by hurricanes and tropical storms (Spalding et al., 2001). The coral reefs bear the full brunt of these attacks. They also protect the islands from waves and currents. Without this protection, much of the land would erode into the ocean (Moberg & Folke, 1999). Even the beaches receive their sand from the coral reefs, through the process of erosion (Spalding et al., 2001). Furthermore, the mangrove ecosystem in Puerto Rico tends to grow in coral cays. These cays protect the mangroves and the seagrass, thus protecting valuable juvenile habitat of many of the reef's fauna (García-Sais et al., 2008). In return, mangroves trap unwanted runoff, which left unhindered, would devastate both seagrasses and coral reefs in the area by blocking sunlight to the marine ecosystems (Moberg & Folke, 1999).

Ultimately, coral reefs are part of a delicate balance between many other ecosystems. Humans use the reef for its many resources, while marine life relies on it for its shelter and abundance in sustenance. Without coral reefs, islands in the Caribbean would be left defenseless from the brute force of Mother Nature. While these ecosystems are very small and confined to very specific locations in the context of the world's oceans, they are still extremely important.

2.2 Seagrass

Seagrass beds are another ecosystem that can be found off the coast of Puerto Rico. Seagrass is a group of flowering underwater plants that have evolved to the point where they can now live fully submerged in seas across the world (Orth et al., 2006). They are considered to be "ecological engineers," and provide numerous important services to marine life and its dependants (Orth et al., 2006).

2.2.1 Location and Extent

Seagrass is estimated to cover 10% of coastal ocean floor, or about 0.15% of the global ocean, making its total area comparable to other important ecosystems such as coral reefs, macroalgae, and mangroves (Hemminga & Duarte, 2000). Different varieties of seagrass are located all around the world, living in all but the most polar waters and can be found off the shores of every continent except Antarctica (Orth et al., 2006, Hemminga & Duarte, 2000). Even with the beds covering such a small portion of the ocean floor, it still makes up 1% of the total biomass of marine plants (Hemminga & Duarte, 2000).

While seagrass is found in many different parts of the world, most species live in similar environments. This is because they all share the need to have an abundant supply of sunlight, meaning that the depth of water in which seagrass can live is limited by the amount of sunlight available. Seagrass also requires a good substrate into which it can extend its roots, such as sandy or muddy sediment, although a few species of seagrass can grow on rocks. Along with needing to be able to penetrate the substrate, seagrass requires the toxicity of the area it is growing in to be reasonable. Not all seagrass is created equal though. Some species can actually grow in intertidal areas where they are exposed to both air and excessive amounts of sunlight. This type of seagrass can grow much closer to shore than some of its cousins. Because it is not always submerged, fauna can only forage during high tides (Hemminga & Duarte, 2000).

2.2.2 Importance

Seagrass is important to all varieties of marine life, both big and small. Fish and invertebrates find food and shelter in seagrass meadows. They are found in much larger numbers because this area allows for improved chances of maturing when compared to areas without vegetation (Larkum, Orth, & Duarte, 2006). However, this does not mean that seagrass is a safe haven. In fact, seagrass provides an important foraging habitat for mobile predators such as sharks, various fish, and rays. It also can provide for more docile creatures such as sea turtles, dugongs, manatees, and many different kinds of fish and invertebrates (Jackson et al., 2001). Seagrass is so important to its inhabitants that in 1930 when there was a large-scale loss of seagrass to disease in the North Atlantic, it resulted in the only known extinction of a marine gastropod (Orth et al., 2006). Along with the extinction, there was also a collapse of scallop fisheries and a decrease in waterfowl numbers (Orth et al., 2006). It is the richness of seagrass that allows such diverse marine life to flourish, and when it is absent from the marine environment the effects are felt all over.

Figure 2: Peacock Flounder Swimming in Seagrass

While seagrass is important to marine life, one should not forget that it is also a vital part of the global community. It provides resources that help both local populations near the seagrass but also the overall well being of the planet (Gullström et al., 2002). Seagrass produces an impressive amount of resources for its relatively small biomass. In terms of size versus primary production, seagrass is much higher than many terrestrial forests and grasslands, and more than 10 times greater than coral reefs (Hemminga & Duarte, 2000).

Most of the carbon produced by seagrass is deposited in the surrounding sediment, making marine meadows carbon sinkholes that contain about 15% of the total carbon stored in marine ecosystems (Hemminga & Duarte, 2000). Seagrass actually traps nutrients and carbon, some of which gets picked up in currents and carried to deep sea environments where there are fewer nutrients (Orth et al., 2006). While storing carbon is important to the environment, seagrass also plays an important part for fishing, both commercial and recreational. Many recreationally and commercially important fish and invertebrates spend at least part of their life in a seagrass habitat (Larkum et al., 2006). Because certain types of fish and invertebrates flourish in seagrass, commercial fishing has become an extremely large venture for the surrounding communities (Gullström et al., 2002).

2.2.3 Interactions with Surrounding Ecosystems

Seagrass has positive impacts on the surrounding ecosystems, such as mangroves and coral reefs, due to its ability to act as a buffer zone and a habitat for fish. In some parts of the world, seagrass acts as a nursery for many fish, which can only be found in other ecosystems as adults (Larkum et al., 2006). Thus seagrass helps populate the surrounding habitats by providing a safe and nutrient-rich habitat in which marine life can grow. Many organisms travel between the coral reef and seagrass ecosystems. These organisms are important because they provide nourishment for predators and also control populations. For example, herbivores such as sea urchins travel to seagrass beds to feed on sun-blocking weeds, allowing the seagrass to flourish (Moberg & Folke, 1999). The reduction in current speed and wave intensity are two more ways that seagrass helps out neighboring ecosystems (Gullström et al., 2002). With lower currents and smaller waves, erosion is less of a problem along the coast (Larsen & Webb, 2009).

Seagrass is located off of coasts all over the world, in different shapes and forms. In all forms, however, they are important both to the species that live and rely upon seagrass and for the resources to humans that it provides. Seagrass is also important to surrounding ecosystems and has even been considered by some as "biological sentinels, or 'coastal canaries'" (Orth et al., 2006). Changes in seagrass are early indicators of environmental shifts and are useful harbingers of challenges facing surrounding ecosystems. The importance of seagrass cannot be overstated in terms of both economic benefit and the marine life that depends upon it. From these observations, action must be taken to protect these important ecosystems from destruction.

2.3 Environmental Damage

There are three primary forms of damage to seagrass and coral environment: hurricane damage, disease, and boating damage. Of these three damages, our project is specifically focused on preventing boating damage. The other forms of damage are important to be aware of because they can exacerbate damage done by poor boating practices.

2.3.1 Hurricane Damage

In the Caribbean, hurricanes are the most prevalent natural disaster, and cause more devastation than all other sources of damage (García-Sais et al., 2008). Tropical storms create large fluctuations in waves, exposing shallow corals to intense stresses, such as being overturned and broken. In addition, the runoff from the rain causes an increase in sediment and terrestrial pollutants in the waters. All these factors lead to the destruction of the coral reef (García-Sais et al., 2008; Woodley et al., 1981).

Hurricanes can be just as deadly to seagrass environments as they are to coral. The strong waves disturb the beds and uproot the seagrass, which causes holes to appear that can last for many years. These holes travel around the beds with the ebb and flow of the tide, impairing the ability for the marine grass to mend and allowing for further damage. However, the primary species of seagrass found in the Caribbean is *Thalassia testudinum*, a robust species that has shown only modest damage from hurricanes in the past (Green & Short, 2003).

Damage done by hurricanes is impossible to control, but diseases that exist in these marine ecosystems often have causes that can be linked to human activities. Coral bleaching and eutrophication of seagrass are some such diseases.

2.3.2 Disease

Coral bleaching is a disease that has many causes, and affects all coral reefs in the world. Bleaching occurs when the photosynthetic species, namely zooxanthaellae, that help the coral produce energy die off (Rosenberg & Loya, 2004). Coral bleaching is caused by many factors that work together: temperature changes, variance in salinity, and exposure to sunlight. Sedimentation from runoff and pollutants in the water also play a part in the coral bleaching process (Larsen & Webb, 2009). Bleaching devastates coral reefs by depriving them of energy and causing a loss of pigmentation. It can take up to fifty years for coral to recover from a bleaching event, during which its support of other marine species is limited and it is more susceptible to mechanical damage (Rosenberg & Loya, 2004).

Eutrophication is a condition where water quality is decreased by excessive amounts of nitrogen and phosphate (Hemminga & Duarte, 2000). Nitrogen and phosphate are two chemicals found in fertilizer, which can enter ocean water through runoff from land erosion. Nitrogen and phosphate in water promote the growth of algae, and this excess growth interferes with seagrass's ability to receive light from the sun and conduct photosynthesis. The lack of sun causes seagrass to produce less energy, and reduces the amount of nutrients it releases into the environment. Disruption of nutrients and large amounts of algae interfere with normal marine life and kill off many species of fish. The use of fertilizer near waterways is a human activity that is adversely affecting seagrass ecosystems (Hemminga & Duarte, 2000). Another human activity that harms marine environments is boating.

2.3.3 Boating Damage

Boating practices in marine habitats have a strong effect on coral and seagrass, and fortunately can be regulated easier than most other factors. Boats that frequent seagrass and coral habitats often set anchor to maintain their position. The use of anchors in these natural environments, as well as groundings on coral reefs and plowing through seagrass, all have a profound impact upon these ecosystems and cause significant damage.

Boats and ships that run aground upon coral reefs cause severe breakage and damage along large areas of the reef. Large ships colliding with the reef cause damage in a greater area than just the immediate vicinity of the strike. This can destabilize large sections of reef whereas small boat groundings tend to have a more localized effect. After an impact, if unaided, soft coral begins to grow back within two years, and hard coral begins to form after eight years. The soft coral of the reef will return to its prior state after about 10-15 years whereas the hard coral can take up to a century to return to its prior state (Jaap, 2000).

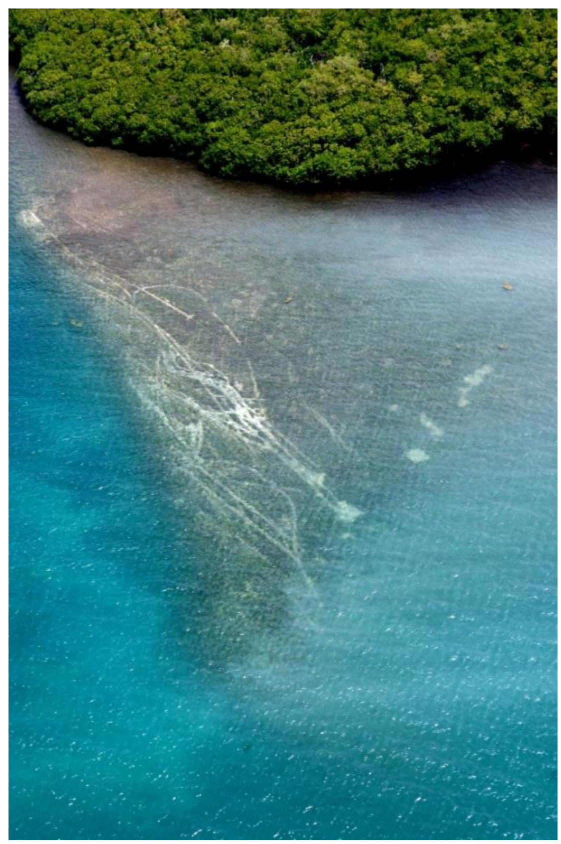


Figure 3: Scarring in a Seagrass Meadow

Seagrass beds are particularly susceptible to boating damages since they are often found in shallow coastal waters. People who use small boats often overestimate the depth of the water, or try to dock while in seagrass environments and run aground. The groundings carve long furrows into the seagrass, disrupting their root system, as shown in Figure 3. Even if the boat does not run aground, the propellers rip the seagrass up by their roots, and it can take 2-5 years to recover (Dawes, Andorfer, Rose, Uranowski, & Ehringer, 1997; Hemminga & Duarte, 2000).

A study conducted in the Abrolhos Marine National Park in Brazil found that anchors damaged 0.5% of the park's meadow per year (Creed & Amado Filho, 1999). Although this percentage seems small, the amount of time it takes for the seagrass to recuperate makes the extent of damage very significant. Seagrass can recover from anchor damage within one year when in a sheltered environment, but if exposed to heavy surf or other forms of damage the grass can take up to nine years to repair (Dawes et al., 1997). The research conducted in Brazil has found that recovering seagrass in damaged areas had a lower concentration of plants than control areas did at the start of the experiment. The root system of the damaged grass is less dense, allowing more sediment to escape into the environment and erode the seafloor (Creed & Amado Filho, 1999). The time it takes for seagrass to recover, and the amount of damage that is done by an anchor, makes it important to protect the seagrass from boating damages.

Anchors cause extreme damage to coral reefs, especially when used improperly. When anchors are set from boats they cause crushing damage to polyps, which break off or die. Once the anchor is set the chain can drag across the reef, fracturing weaker soft coral, or can be wrapped around hard coral structures that protrude from the reef. The retrieval of the anchor can also sever, overturn, or crush the coral reef (Dinsdale & Harriott, 2004). Compared to other forms of damage, damage caused by anchors is preventable.

Hurricane damage, disease, and boating damage are all major sources of destruction to marine habitats surrounding Puerto Rico. Unfortunately, disease and hurricane damage cannot be easily controlled; however, boating damage can be lessened by human intervention. The use of public mooring buoys is one potential answer in the quest to reduce the amount of damage caused by anchors to these marine environments.

2.4 Mooring Buoys

To successfully stave off the anchor damage done by ships, the Department of Natural and Environmental Resources has installed mooring buoys all around the island in locations where diving and boating are most popular. Mooring buoys are small round floats that support a pickup line on the surface, are tied to a through-line that connects to a downline, which ties to a pin anchored deep in the substrate of the ocean floor (Figure 4). These are then placed where dropping anchor can lead to damage to a sensitive marine environment. The shackle connecting the downline and the anchor allows the buoy to twist and turn without becoming entangled. The purpose of the buoy is to float a pickup line on the surface of the water and mark its location. This pickup line allows for boats to tie up instead of dropping anchor (Boaters Land, 2009).

Mooring buoys are designed so that a boater can tie up their boat and leave it for periods of time without worrying about it. In a sense, it is a permanent fixture in the ocean, and can last several seasons. Unfortunately, mooring buoys do not last as long in salt water as they do with freshwater (Boaters Land, 2009).

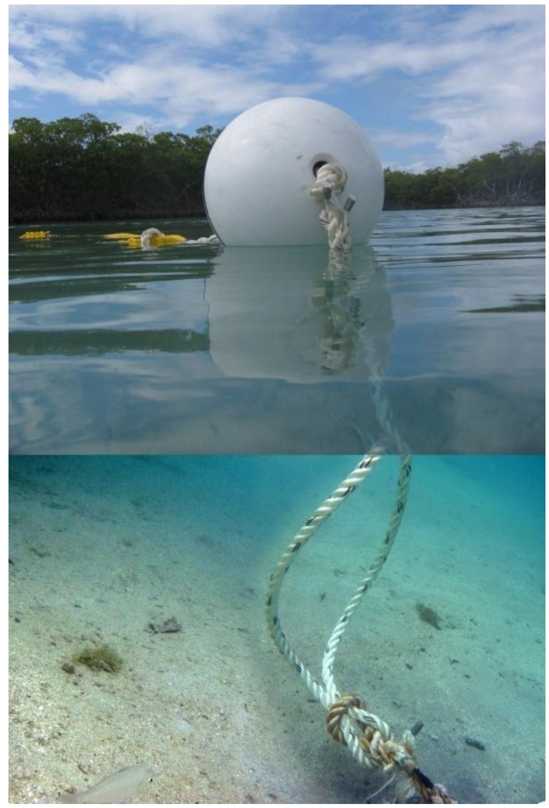


Figure 4: Mooring Buoy System

On the island of Puerto Rico, a plethora of people use and work on the coral reef every day. Diving and fishing charters, commercial fisherman, and recreational boaters work and play out on the water. With all of these people taking advantage of the natural wonders of the island, the coral reef is suffering. The reef appeals to recreational boaters because of the calmer waters it provides. Unfortunately, the reef cannot withstand so much boating traffic. Even so, Puerto Rican officials are not necessarily as concerned with the scuba diving charter boats because it is in the charters' best interest to preserve the reef as their livelihood depends on its continuing prosperity (García-Sais et al., 2008). Additionally, the majority of charter boats are up to date with all of the marine policies put in place by the DNER. Recreational boaters and the general public, however, are not as familiar with DNER regulations, and therefore can cause more damage by improperly anchoring (García-Sais et al., 2008). Although anchor damage is only a small part of the damages that are inflicted on seagrass and coral reefs every day, it can be controlled with the use of mooring buoys (García-Sais et al., 2008).

Mooring buoys can be an easy solution to the problem of anchor damage. Just maintaining and providing enough mooring buoys for the public will lower the damage greatly. Since the DNER first provided mooring buoys in the more popular areas of the reef, anchor damage has been reduced

(García-Sais et al., 2008). Unfortunately, detailed information regarding the location and the condition of the buoys is unknown. The mooring buoys are not continually monitored; therefore the DNER does not know what kind of shape the mooring buoys are in, or if they are being used by recreational boaters (García-Sais et al., 2008).

2.4.1 Red Sea Case Study

To better understand the relationship between anchor damage and mooring buoys, a case study that took place in the Red Sea was examined. Off the east coast of Egypt, tourism within the coral reef environment, especially in the Hurghada section, had exploded. Until 1997, nothing was organized to prevent damage done to the reef by the sheer number of tourists. To try to curtail the damage, 250 mooring buoys and reef top pins were placed all over the reef for the public to use. The Hurghada Environmental Protection and Conservation Association was formed to maintain these buoys and regulate not only who uses the reef, but how they use it as well. These regulations state that diving charters are only allowed to be in a location for a certain amount of time. There is also a mandate that states that only a certain amount of dives can be performed each year. Before 1997, diving charters performed as many dives as they wished without any thought to the damage that was being done on the reef. Without any mooring buoys, these boats anchored wherever they wanted. Too much diving was taking place at sites that were popular and the reef was severely damaged.

This environmental plan has taken off because of the success of installing these mooring buoys. Now more than 1000 buoys are located all over the reef and it is against the law to drop anchor. Egyptian Environmental Affairs Authority even has rangers that are assigned to the Hurghada section to regulate this law (Jameson, Ammar, Saadalla, Mostafa, & Riegl, 2007).

2.4.2 Great Barrier Reef Study

The negative impact of tourism has also affected the coral in the Great Barrier Reef. In the more popular areas of the Great Barrier Reef Marine Park, anchor damage is found to be the most detrimental. The officials that regulate the Marine Park have instituted many solutions to the anchor damage. They, like many other places in the world, have placed public mooring buoys all around the reef. As a major step in preserving the reef, they also have posted signs in certain areas where anchoring is not allowed at all. To help recreational boaters and tourists, a program was created to educate boaters on preservation policies regarding the reef (Harriott, 2002).

2.4.3 Potential Mooring Buoy Drawbacks

Even though mooring buoys can decrease the amount of anchor damage in seagrass and coral, the mooring anchors can cause damage themselves. In areas where mooring buoys are placed, damage caused by diving and snorkeling has increased, however anchor damage still far outweighs the damage done by divers (Harriott, 2002).

Seagrass can become very damaged by mooring anchors. When mooring anchors are not designed correctly, the surrounding habitat will be damaged by it. If a poor location is chosen, for example, sewage and sediment can build up around the anchor, which can block the seagrass from the sun (Creed & Amado Filho, 1999). A case study near Western Australia reported that permanent moorings were destroying the seagrass, particularly around Rottnest Island. This location has the most mooring installations in any area of the surrounding reef. To study the damage, aerial surveys were used to monitor the effect of the moorings on the seagrass. The team found that there were "bare patches" near the moorings where once there was seagrass (Hastings, Hesp, & Kendrick, 1995).

When it was found that the type of mooring that was implemented caused some damage to the seagrass, a new type of mooring anchor was chosen to lessen the impact. The first anchor, known as a one-chain system, was switched over to the "Cyclone" or three-chain system. The Australian study proved that the damage caused by the three-chain system is just as disastrous as caused by the one-chain system (Hastings et al., 1995). The problem that they did not realize is that the anchor is the cause of damage in seagrass, not the type of mooring. Because of this, the difference between the one chain and three chain systems is trivial, and the damage can only be avoided by using the anchor appropriate to the kind of seabed.

The types of anchors that are utilized by the DNER are Halas and Manta. Halas anchors, used in hard-bottom locations such as coral, are attached by being placed in a bored hole, which is then filled with hydraulic cement. The Manta anchors are used in seagrass locations with soft bottoms, and consist of a long rod drilled into the substrate, which is then pulled up slightly to engage two barb-like legs to hold it into the seafloor. These two systems do not damage the surrounding ecosystem beyond initial installation.

Mooring buoys can cause damage to the surrounding environment; however, the damage caused by boat anchors is more devastating to the marine environment. Further research is needed to determine if there is a better solution than mooring buoys. For the time being, mooring buoys are the solution practiced to prevent anchor damage problems. Other countries have seen success through the use of these buoys. Puerto Rico has started this endeavor and hopes to see success as well.

2.5 Stakeholders

Due to the lack of observations, interviews, surveys, and quantitative data that have been collected to date, it is difficult to determine the specific parties involved. At this time, the major stakeholders in the Marine Buoy Program are the DNER, the National Oceanographic and Atmospheric Association (NOAA), charter boat companies, eco-tourism agencies and recreational boaters.

NOAA is actively interested in preserving sensitive marine environments. Just like the DNER, NOAA is a trustee in the marine benthic habitat, and wishes to see the sites well maintained. They have provided funds for the DNER to install buoys off the south coast of the island, but their interest stems mostly from the surrounding environment. Recreational boaters solely care about the maintenance of the buoys so that they can moor without illegally dropping anchor. On the other hand, some charter companies and eco-tourism agencies care for the condition of both the seafloor and to a lesser extent the buoys. This is because they can moor without destroying the surrounding ecosystems, which act as their source of revenue.

2.6 Summary

Marine environments such as coral reefs and seagrass are important parts of the global ecosystem. These valuable habitats, however, are highly susceptible to damage from humans, and as such need to be protected. One such method of protection, which has been successfully employed, is the installation of mooring buoys in these fragile areas. While they are not perfect, mooring buoy benefits outweigh the costs and provide a better alternative to the haphazard anchor damage that can occur in their absence. Considering Puerto Rico's use of these marine environments, as well as the wealth of biodiversity they support, various stakeholders have a vested interest in the results of our project. After we collected this background information, we planned and undertook a thorough methodology resulting in the completion of the database by accomplishing our objectives.

CHAPTER 3: METHODOLOGY

As previously stated, there are 270 mooring buoys off the coast of Puerto Rico whose condition, exact location, and extent of use were unknown. This lack of information made it difficult for the Department of Natural and Environmental Resources (DNER) to properly allocate work and assets to maintain the buoys and the surrounding environments. A high priority of the DNER is to prevent marine damage, which mooring buoys help avert, making their maintenance a critical aspect of the coastal conservation efforts. Our goal was to remedy this situation by creating a GIS database that contains all the information in a clear and updatable way. To enable the completion of this goal, we met the following objectives:

- Catalogued the Buoys' Locations
- Evaluated the Conditions of the Buoys
- Assessed the Surrounding Ecosystem
- Identified Boating Activities
- Analyzed Boat Traffic

Data have been gathered from five key areas surrounding Puerto Rico: Guánica, Salinas, Fajardo, Parguera, and Culebra. These regions contain the highest number of buoys and are the areas most frequented by recreational boaters. These locales were chosen to obtain the maximum amount of data in the most critical regions. We begin with a description of the methods used to meet our objectives.

3.1 Catalogued the Buoys' Locations

One of the main concerns of the DNER was that the exact locations of the buoys were unknown, more specifically, the exact location of the buoys' anchors. Knowing the anchor's exact location is important because if a buoy becomes detached, the anchor pin can be easily found by divers to facilitate replacement. Using a Trimble GPS transponder, we established each anchor's precise

Figure 5: Mooring Buoys near Guánica

geographic coordinates, which have been imported into a GIS database.

3.2 Evaluated the Conditions of the Buoys

The Trimble software, called GPS Pathfinder Office, allowed for the creation of a digital evaluation form on the GPS unit. The Trimble also allowed for digital entry of our observations, which were directly imported into the GIS Database when back in the office. While in the field, we evaluated each buoy's condition by looking at its components: anchor, swivel, shaffing tube, downline, lead weight, thru-line, buoy, reflective tape and pickup line.

Figure 6: Growth on the Buoy and the Lines

We looked for evidence of corrosion, broken parts, fraying in the ropes, cleanliness, and propeller scars. Our group observed the submerged components by snorkeling. This information was included in the database so that the DNER is able to track maintenance needs, and update the condition as necessary for each buoy.

3.3 Assessed the Surrounding Ecosystems

An assessment of the surrounding ecosystems allows us to best evaluate the mooring buoy program. As with the evaluation of the buoys' conditions, snorkeling was used to examine these environments. Indicators of damage included overturned, bleached, or broken coral, and cuts or scarring in the seagrass bed. We used the Trimble to store information regarding the extent and type of damage to the ecosystems, which was uploaded to the GIS database for easy assessment. With this information in the database, updates can be made, and each individual buoy's effectiveness can be rated.

Figure 7: DNER Snorkeler Analyzing the Environment

3.4 Identified Boating Activities

We determined the use of the mooring buoys by a combination of methods, namely, in situ observations, aerial photography, and interviews with boaters encountered during fieldwork. Concurrently with cataloging the buoys, observations were recorded regarding how the mooring buoys were being used by boaters. Supplementing these data, short interviews were conducted with six boaters who were in the vicinity of mooring buoys. Here is a list of the questions we asked the subjects in English, which were translated into Spanish by our sponsor when needed:

1. Do you know about the mooring buoys provided by the DNER?
2. If yes, do you use the mooring buoys?
3. What is your favorite location to boat?
4. What is your favorite activity to do while boating?
5. How often do you go boating?
6. What type of boater do you think uses the mooring buoys the most? Commercial or recreational?
7. Are there enough mooring buoys for all the boaters?
8. Do you think the mooring buoys are placed in the proper locales?
9. Do you think the mooring buoys adequately prevent anchor damage to the reef and seabed? Please give your opinion.
10. How can this mooring buoy system be improved?

The responses to these interviews were compiled and analyzed to give us, and the DNER, a sense of the general opinions concerning buoy use.

Figure 8: Holiday Boat Traffic at Salinas

3.5 Analyzed Boat Traffic

The analysis of boat traffic will allow the DNER to develop a better perspective for placement of mooring buoys to best accommodate boating distribution and environmental protection. To accomplish this objective, we observed boats in the vicinity of mooring buoys. In order to get the most accurate data on boat traffic, we recorded these observations often and over a period of several weeks. To do this we created a form, located in Appendix H, to record our observations about the size and type of boat, their activity, type of marine environment, and their use of the buoy. Our group compiled this information into the database, providing the DNER with an idea of boating distributions around the buoys in Puerto Rico.

3.6 Developed Geographic Information System (GIS) Database

The GIS database provides the DNER with a tool to analyze and share current data concerning the mooring buoys. GIS is a system that combines the strengths of layered images with the power of a database by linking together maps and the information attributed to their features (Environmental Systems Research Institute, 1997).

Our team developed the GIS database using PostgreSQL in conjunction with the interfacing software, GPS Pathfinder Office and Quantum GIS. The database is structured to facilitate maintainability and updatability by the DNER, and is flexible enough to accommodate additional data sets. The transfer of data from the Trimble to the database has been automated as much as possible to reduce the complexity of the process while minimizing human error. This automated process is interfaced through a website on the DNER server.

We created the interface to the database with a specific focus directed toward its ease of use for DNER employees. The interface is an internal website hosted by the DNER and was developed using the web publishing technology, SIMILE Exhibit, which allowed us to display data directly from the DNER's Geo Server. Using this webpage, DNER employees will have access to all the information pertaining to mooring buoys.

3.7 Summary

By cataloging the buoys' locations, evaluating their conditions, assessing the surrounding ecosystems, identifying boating activities, and analyzing boat traffic, we obtained all the information needed for our database. This database represents the culmination of both our fieldwork and software development, which facilitated the creation of a clear and updatable web interface. Using this website and database, the DNER can make informed decisions regarding installation and maintenance of the mooring buoys, as well as monitor the surrounding ecosystems.

CHAPTER 4: RESULTS AND ANALYSIS

While conducting our fieldwork we visited many different locations around Puerto Rico where mooring buoys have been installed, including Guánica, Salinas, Fajardo, Parguera, and Culebra. These sites were chosen to maximize the effectiveness of the database by providing information regarding the locations most frequented by boaters that have delicate seafloor environments. While at these locales, we catalogued the buoys' locations, evaluated the conditions of the buoys, assessed the surrounding ecosystems, identified boating activities, and analyzed boat traffic. We took this information, which we stored in the Trimble GPS transponder, and transferred the data into a GIS database.

4.1 Catalogue of the Buoys' Locations

When we catalogued the buoys, we determined their exact geographical locations using the Trimble GPS Transponder. After downloading the data from the Trimble, we overlaid the locations on satellite imagery provided by Google Maps. On the maps below, each white circle represents a buoy (Figure 10-21).

Figure 9: Eric Greer Cataloguing Mooring Buoys with the Trimble

Figure 10 shows the 14 mooring buoys located off the coast of Guánica at the island of Cayo Aurora. These buoys were distributed in the area surrounding the island's sole pier, each approximately 54 feet from its closest neighbor. These relatively short distances are due to the shallow waters in which the buoys were installed. While at the site we discovered one buoy, not attached to an anchor, which the DNER brought back to the department for cleaning and reinstallation.

Figure 10: Map of Guánica Mooring Buoys

Figure 11 shows eight mooring buoys located off the coast of Salinas at Cayo Matias. These buoys were distributed very similarly to the buoys at Guánica, an average of 46 feet apart, and were located in the mangrove channels in the center of the island. While we were there, DNER divers reinstalled three mooring buoys in the western channel.

Figure 11: Map of Salinas Mooring Buoys

Off the coast of Fajardo, there are four small islands with mooring buoys: Palomino, Wolf's Den, Icacos, and Palominto. Figure 12 shows 22 mooring buoys off the coast of Palomino separated by an average of 150 feet. This distance is necessary due to the deep waters that require long downlines on the buoys. The longer downlines create a greater radius for the physical buoys to drift, and because they drift so far, the large distances between buoys prevent them from getting their lines tangled. With the deeper water, larger boats can also use these mooring buoys, which is another reason for the greater distance between them.

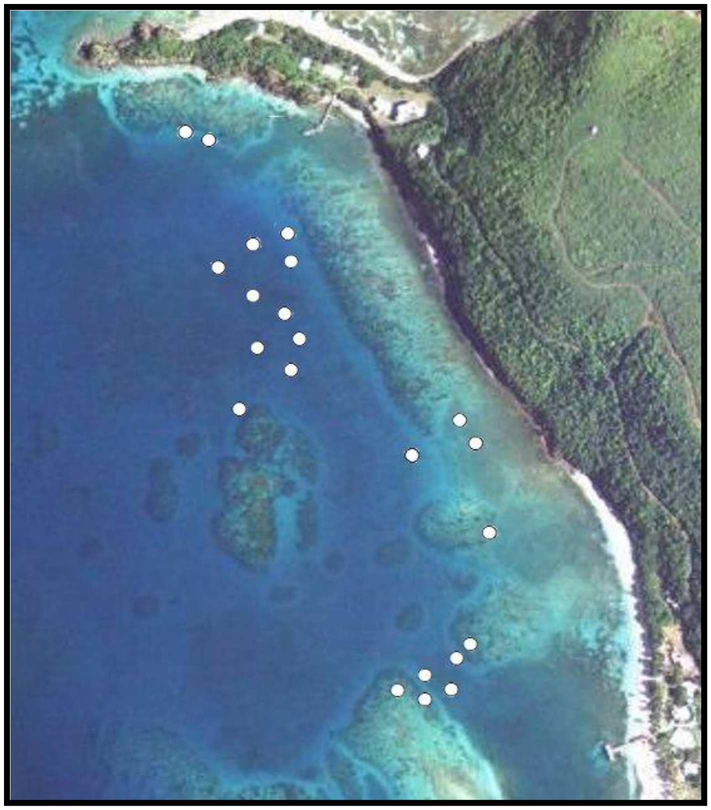


Figure 12: Map of Palomino Mooring Buoys

Figure 13 shows four mooring buoys located around Wolf's Den Island. Each buoy was spaced 150 ft apart, similarly to Palomino, in order to prevent collisions between moored boats in the deep water.

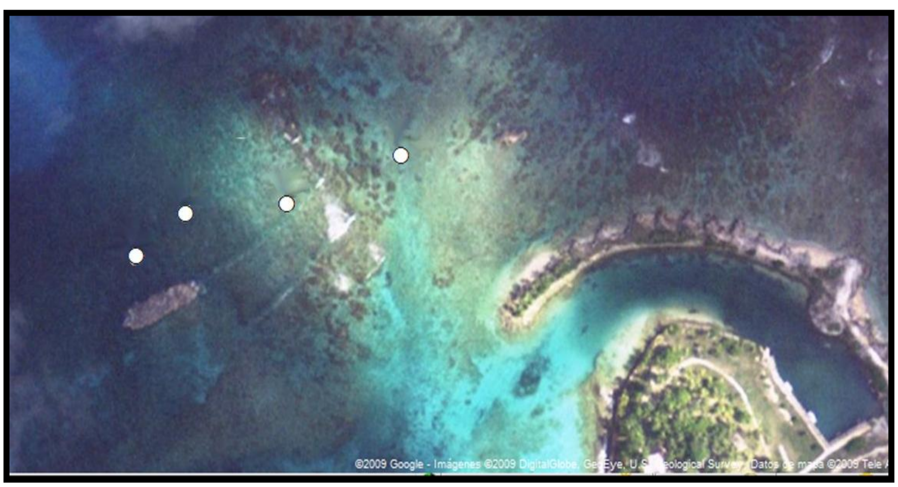


Figure 13: Map of Wolf's Den Mooring Buoys

Figure 14 shows only one buoy located off the island of Icacos. This is because two buoys were missing at the time of our cataloguing. However, there were other mooring buoys in the area that did not belong to the DNER, one of which appeared to be the same model as the DNER buoys. The other buoys are in place at Icacos probably due to the fact that charter boats that wish to keep the surrounding ecosystems intact while still being able to moor frequently in this area.

Figure 14: Map of Icacos Mooring Buoys

At the small island of Palominto, which is next to the island of Palomino, four buoys were catalogued (Figure 15). These buoys were anchored at a depth of approximately 15 feet and were about 300 feet apart from one another. There were supposed to be six buoys in this area, but two were missing.

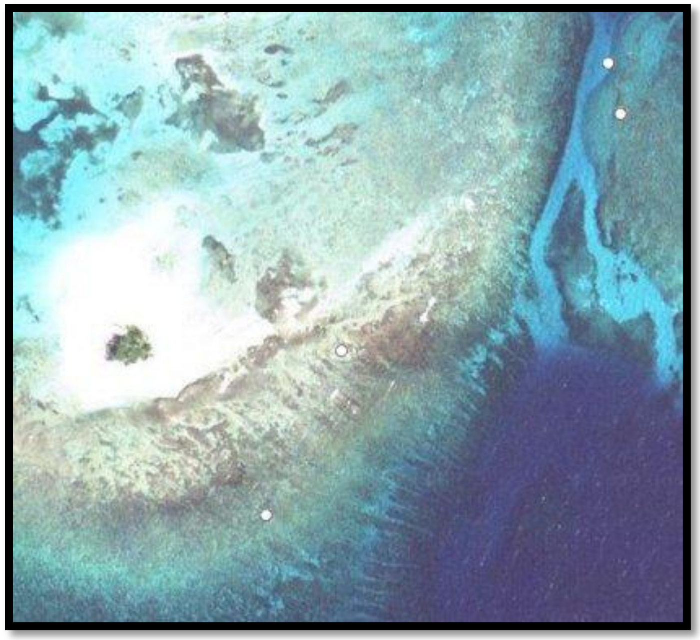


Figure 15: Mooring Buoys at Palominto

Figure 16 displays the mooring buoys off one of the coasts of Culebra. We catalogued only 15 mooring buoys, however, many more surround the island. There was not enough time during our fieldwork at Culebra to mark all of the buoys' locations. The depth of the water in this area ranged from 4-44 feet. These buoys had an average distance of 209 feet from each other; however we discovered an instance where two buoys were extremely close to one another. We only catalogued the buoy that was in better condition, and the other was marked for removal. The DNER will come back to this site to remove and relocate the second buoy at a later date.

Figure 16: Mooring Buoys at Culebra

Figure 17 shows Colloado, the first cay we visited off the coast of Parguera. With an average depth of three feet, and a range of depths from two to four feet, this area contained five mooring buoys that stood sentry over the seagrass below. The spacing between each buoy was common for shallow fields: approximately 75 feet.

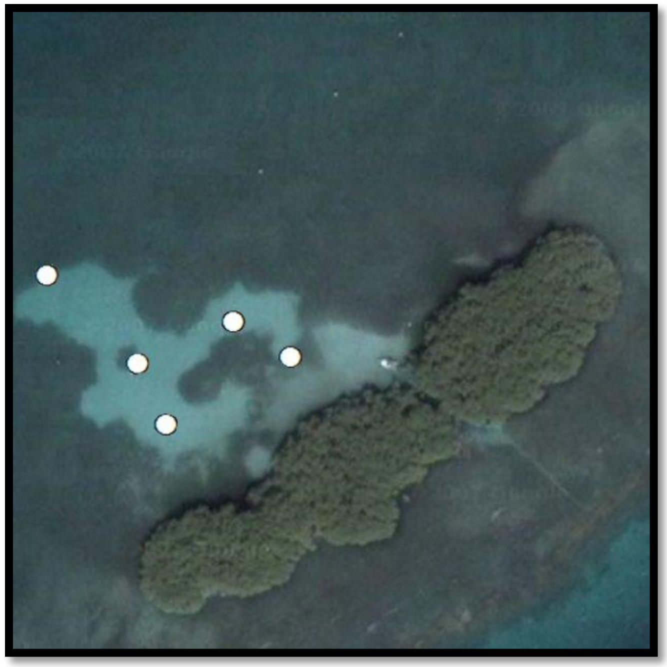


Figure 17: Mooring Buoys at the Cay of Collado at Parguera

The cay of Enrique, shown in Figures 18 and 19, contains six mooring buoys in seagrass. The depths at the buoys are consistently four feet, except for one in 15 foot deep water. Arranged in a linear configuration, these buoys are spaced an average of 126 feet apart.

Figure 18: Mooring Buoys at the Cay of Enrique at Parguera

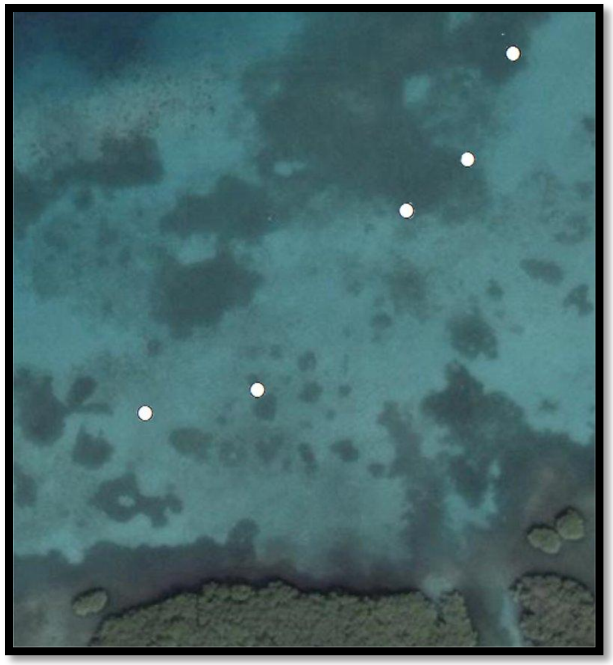


Figure 19: Mooring Buoys at the Cay of Enrique at Parguera

Figure 20 shows Caracoles, the last cay we visited in Parguera. The 17 mooring buoys installed at this location sit in water with a range of depth from two to thirteen feet. The average spacing between buoys is 100 feet, which allows for larger boats to moor in this seagrass field.

Figure 20: Mooring Buoys at the Cay of Caracoles at Parguera

We observed that all the buoys are located between the coast of Puerto Rico and the small islands. No buoys at this time have been placed on the far side of any of the small islands that we visited. This is probably because conditions closer to Puerto Rico are more protected and placid, thus safer. Also, another contributing factor is that after travelling out to one of the small islands, Puerto Rican boaters do not want to waste gasoline and time to circumnavigate the island when there are convenient moorings nearby in calm waters. Therefore the DNER decided to place almost all of their buoys on the sheltered, or lee, sides of islands surrounding Puerto Rico.

4.2 Evaluation of the Conditions of the Buoys

The conditions of the buoys varied drastically between the sites we visited, with damage ranging from none to severe. Most of the buoys had microecosystems growing and flourishing on the downline and thru-line beneath the surface of the water. These microecosystems depend upon the buoys for the structural support provided as well as the freedom from competition with other denizens of the seafloor. They are capable of flourishing in calm shallow waters, but we did not observe any microecosystems in places where the water was rough. If the waters are too rough, as was the case at Fajardo and Culebra, there were no microecosystems on the lines. The DNER leaves these ecosystems on the buoys, and to our surprise, they also choose to leave bird feces on the buoys because the nitrates enrich the surrounding seagrass. Something to note is that our observations show the buoys with bird feces are the ones with the thickest algae on the bottom.

Figure 21: A Propeller Scar in the Buoy

The buoys around Guánica had been cleaned and repaired only two weeks prior to our evaluation, thus their good condition. Most of the physical damage to the buoys was concentrated on the various lines. However, all the damage that we observed at Guánica was caused exclusively by natural means. Other than the accumulation of algae, coral, and sponges, the buoys around Guánica had no visible damage. After our evaluation of Guánica, we found that our efficiency could be improved by setting the default value of damage to “None” on our electronic evaluation form. This greatly reduces the time spent evaluating the condition of a buoy that has little to no damage, or isolated damage.

While cataloguing the buoys around Salinas, we found them all to be in good working order. These mooring buoys were installed to protect mangroves from people tying up to them and damaging the root systems of the trees. Most of the buoys there were recently replaced and had new components with no prior damage. However, four of the other buoys needed to be cleaned of algae and other plant growth, which was done by DNER snorkelers with knives. The cleaning is required due to the fact that the buoys and lines become weighed down by the growth and will float lower in the water. When this happens it is hard for boaters to see the pickup lines and the buoys, which often leads to boaters driving over the lines, cutting them with their propellers.

Figure 22: A Mooring Buoy Missing Its Pickup Line

At the islands off of Fajardo, the mooring buoys were in fairly good condition with some exceptions. Several buoys were missing their pickup lines, which make it difficult for boaters to tie up to, though some still managed. An example of a missing pickup line can be seen in Figure 22. While most of the buoys we observed were in working condition, they were all showing signs that replacement will be necessary shortly if the present rate of deterioration continues. At Palomino, there were multiple instances of buoys that showed scars from boat collisions. It appeared that after the vessels run over the buoy, the propeller then lacerates it, leaving deep scars and a need for replacement. The buoys that were in the best condition were the four buoys that were located off of the small cay of Palominto. These buoys were both clean and in good condition and did not need immediate DNER attention.

We observed that the majority of the mooring buoys located off the cays surrounding Parguera were in working condition with little damage. However, at one of the cays, Caracoles, there were multiple mooring buoys that were missing their pickup lines. Coincidently, this cay had the highest number of buoys out of all the sites around Parguera.

In general, all of the areas have similar types of damage with the only major difference being the levels of severity. These levels have changed in relation to the remoteness of each site. The more popular the site, like Fajardo, the more damage there is, while less frequented areas, such as Guánica, have less damage. Our observations are slightly biased, however, because we did not visit sites at the same time interval since the last maintenance was performed. This makes it difficult to compare different areas to each other based on the levels of damage.

The types of damage were fairly consistent from site to site. Each of the sites we visited had either no damage or the damage was mainly focused around the pickup line, indicating that boaters are using the mooring buoys in a similar manner all around Puerto Rico. The damage to the pickup line is more severe because it is the only part of the buoy system, aside from the buoy itself, which is on the surface of the water. This, when combined with the fact that the line is harder to see than the buoy, makes it more likely to be run over by passing boats. Also, the pickup line is the point of contact between boaters and the buoy, meaning that it is more likely to be mishandled and damaged through human interaction.

4.3 Assessment of the Surrounding Ecosystems

While evaluating the mooring buoys' conditions we assessed their effect on the surrounding ecosystems. We observed that the seagrass environments surrounding Puerto Rico are in various stages of recovery. For instance, at Guánica the seagrass had no visible damage and according to our liaison, the site was recovering from prior harmful boating practices. Similarly, at Salinas, much of the seagrass was healthy without any recent damage. It is believed that Salinas's sandy mangrove channel used to contain a large seagrass meadow, which was completely uprooted by a hurricane. There was also a significant amount of visible damage surrounding the islands off the coast of Fajardo. At Palomino and Wolf's Den, there were numerous bare patches interspersed with the recovering seagrass. The primary causes of these bare spots are anchors set from recreational crafts visiting the islands. At one of the buoys off

Figure 23: Greg Coffey Photographing the Surrounding Ecosystems

the coast of Wolf's Den there were many cases of blowholes and scarring in the seagrass. One particularly large spot near Palomino was caused by a barge grounding and trying to get free. At Parguera, we observed that the further from shore we traveled, the better the condition of the environment. At the first cay we approached, there was no visible damage to the seagrass around the buoys. However, damage became more apparent the closer we traveled to the cay's shore. This damage was only moderate compared to the damage around Caracoles, which was very severe, containing long wide scars in the seagrass and uprooted patches where anchors had clearly been dropped.

Not all of the locations we visited fostered the growth of coral, but those that did exhibited moderate amounts of damage, mainly due to fragmentation and scraping of the hard corals. For instance, at Icacos we observed an area of localized fragmentation near a buoy. Around the buoy's downline, there was a large area of eroded hard coral, which, contrary to our other observations of the area, was sparsely populated by soft fan corals. An example of negative human interaction in the area was a heavy steel cage that had plummeted to the seabed breaking off large pieces of coral. Scraping was also prevalent along the coral reefs at Icacos and Palomino showing that anchor damage is still a major concern in the protection of coral environments.

We found that in deep water seagrass meadows there are some small bald spots where the anchor-pin of a mooring buoy is located. These may be attributed to the installation process of the anchor, as there must be a rod drilled into the substrate, which would undoubtedly damage roots and vegetation. Another proposed cause of the bare spots is that sting rays use the mooring buoys as "scratching posts," which destroys the vegetation and root systems around the anchors (E. Rodriguez, personal communication, March 27, 2009). The plant itself would then take roughly nine years to recover due to the less than ideal growing conditions of the deeper water. This disparity in depth also accounts for why the seagrass in the shallows surrounding Guánica and Salinas has recovered fully since installation.

Aside from one noticeably recent break we observed in a hard coral, the majority of the damage we saw appeared to be from before the installation of the mooring buoys. The buoys, having been installed for less than two decades, have not been in place long enough for any large-scale recovery of hard coral to present itself. Hard coral that was killed off prior to the installation could take up to a century to regenerate, making our observations premature.

We also observed that trash and lost traps collect in the vicinity of mooring buoys, which was reiterated by the locals interviewed at Parguera. They blame the tourists and out-of-towners that arrive during long weekends for the pollution of the waters and some of the locals take it upon themselves to retrieve trash from the seafloor. When assessing the environment around Parguera, we observed beer cans, chain linking, and other such garbage that were most likely dumped over the holiday weekend. Trash has also been visible at other locations and implies that it is a common practice to find boaters dumping their trash before leaving the mooring buoys.

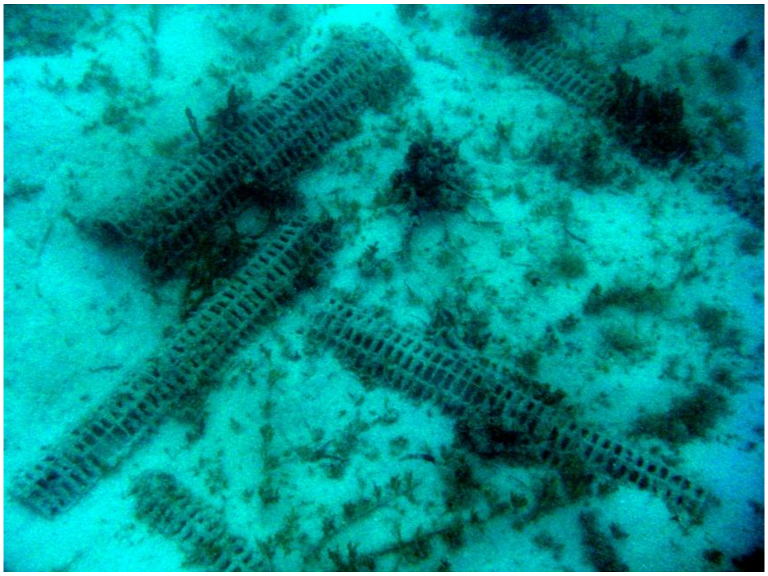


Figure 24: Lost Traps Demonstrate the Negative Impact of Humans

Seagrass has proven itself to be very durable and can easily recover given adequate respite from major damage. At Guánica the seagrass appeared fully recovered from a hurricane, while in Parguera, the seagrass is in the process of recovering. What were once bare patches now have sparse seagrass growth. This seagrass is not quite as thick as a normal meadow should be, but its recovery is still quite evident.

4.4 Identification of Boating Activities

While cataloguing the buoys around Puerto Rico, we witnessed only a small number of boats using the mooring buoys. This is most likely due to the times we frequented these locations: normal business hours.

While at Palomino, we observed a 41 foot craft with a family aboard, which was tethered to a mooring buoy. The family was using the buoy to keep the boat stationary while enjoying the location and climate. They were, however, using the mooring buoy incorrectly by setting an anchor at the stern of the boat as well. The anchor was dropped in order to keep the boat in one place so that it does not swing around the buoy, making it safer and easier to keep an eye on the children. The reasoning behind why boaters are not supposed to drop anchor while connected to a mooring buoy is because it has the potential to damage the ecosystems, and even if it is in a sand bottom, it could lessen the chances of the environment recovering in that area. This is problematic for boaters who wish to stabilize their craft because the other alternative, a system involving two mooring buoys, is not a viable option. The variability and size of the boats, chance of entanglement, maintenance, and costs are all reasons why a dual mooring buoy system cannot be implemented.

We returned to Palomino and visited its small neighbor, Palominto, on a weekend where more than twenty boats total were sighted anchoring very close to the beach. Many of these boats were also rafted together so that the boaters could better enjoy each other's company. Besides anchoring along the beach, other boats were using the mooring buoys, the majority of which were using the buoys correctly. Only two boats were seen using buoys incorrectly. One boat was tied up correctly, however it was too large a vessel to use the mooring buoy. It put so much strain on the lines that the buoy was completely submerged, which could cause the buoy to become detached from the anchor. The other boat tied the pickup line of the mooring buoy directly to its cleat, which also puts unnecessary strain on the lines (Figure 25).

Figure 25: Two Boats Tied to Mooring Buoys. The first picture is the correct way to moor by tying a line from the boat to the pickup line. The second picture shows the incorrect way to moor by tying the pickup line directly to the boat.

During our fieldwork in Parguera, we interviewed two boaters who frequent the area and regularly use the mooring buoys. Our interviews indicated that these boaters believe mooring buoys help protect the environment and the only improvement that could be made would be to supply more mooring buoys. One boater said that when he visits the cays near Parguera, all of the mooring buoys are usually being used by other boaters. As a last resort he either has to drop anchor farther away from where he wants to be or tie up to the mangroves since there are simply not enough mooring buoys for everyone. The boater also stated that he would prefer to be closer to shore, so that his small children can play safely in the shallow water.

We conducted four group interviews at Culebra, three of which were comprised of locals, while the other group was from California. The Californians were sailing through the British Virgin Isles, and were visiting Puerto Rico for the first time. While they were looking for a safe place to anchor, they were delighted to find a DNER mooring buoy they could tie up to instead of dropping anchor. They believe that these mooring buoys protect the environment and were pleased that the DNER had installed them for public use. Most of our initial interview questions were not applicable to the visiting Californians because they were intended for people that are familiar with the local mooring buoys.

The responses we received from the locals around Culebra were all very similar. They believed that the mooring buoys prevent damage to the environment, are primarily used by recreational boaters, and are placed in the proper locales. However, all of our subjects would like to see more mooring buoys installed and one interviewee thought that the buoys should be placed closer to shore. Another common theme between the locals was that some of the buoys are too close together, creating an unsafe distance between moored boats. They believe the distance should be larger to prevent collisions and entanglements.

The suggestion from our interviews at Parguera and Culebra, to have mooring buoys closer to shore, corresponds with observations from aerial surveys depicting many boats anchored along the shoreline. Unfortunately, this suggestion is not feasible because the water is too shallow to allow boats to moor at a buoy without damaging the ecosystems. The boat could ground and the buoy and downline could scrape the environment, causing excessive amounts of damage.

From our interviews two suggestions became prevalent: there is a need for more mooring buoys and the buoys must be placed farther apart. In many locations, these two suggestions would conflict with each other. This is because an increase in mooring buoys would force the buoys to be installed too close to one another. For example in Caracoles, the buoys are spaced approximately 100 feet apart to prevent collisions. Adding more mooring buoys would reduce this distance while increasing the chance of collisions and entanglements. The only safe way to add mooring buoys is to maintain the distance and place them farther from the islands. This, however, would be incompatible with the prior suggestion that the buoys be placed closer to shore.

4.4.1 Educational Outreach Interviews

As a supplement to our own interviews, Kevin Vayda, Daniel Cafferty, and Jason Carmichael provided results from a section of their survey for our use. They worked with the Educational Outreach division of the DNER to assess the common knowledge regarding marine ecosystems around Puerto Rico. When we received their data, they had interviewed 283 subjects at marinas, beaches, and the DNER vessel registration office. The data provided concern the public's perception and use of the DNER mooring buoys. From their results, 60% of people surveyed were aware that the DNER has provided public mooring buoys for their use and 52% of these subjects use the buoys. However, only 20% believe that there are enough mooring buoys along the coast of Puerto Rico. Additionally, 6% of the people have dropped anchor on coral reef and seagrass (Vayda, Cafferty, & Carmichael, 2009).

Even though 6% can be seen as a small number, the total number of subjects for these surveys is not very large compared to the number of registered boats of Puerto Rico. If this sample is representative of the entire population of boaters, 6% would be an extremely large number. There could be a number of reasons why boaters knowingly drop anchor on fragile marine ecosystems: boaters may not be cognizant of the damages they are inflicting on the environments or perhaps the boaters do not care about the damage they cause. Another reason, which concerns this project, is that maybe there were too few buoys for all of the boaters to tie up to. From the survey, 20% believe that there are not enough mooring buoys, which agrees with the interviews that we conducted at Culebra and Parguera. The interviews state that there are plenty of mooring buoys during the week, but during the weekends and holidays, there are simply not enough to handle the influx.

4.4.2 Aerial Surveys

The DNER conducted aerial surveys over Easter to view the boating distribution during this very busy weekend. Among others, Guánica, Fajardo, and Salinas were photographed to best show how all the boats were using the buoys. The photographs showed that many mooring buoys were being used improperly, but even with the large number of boats not all the buoys were

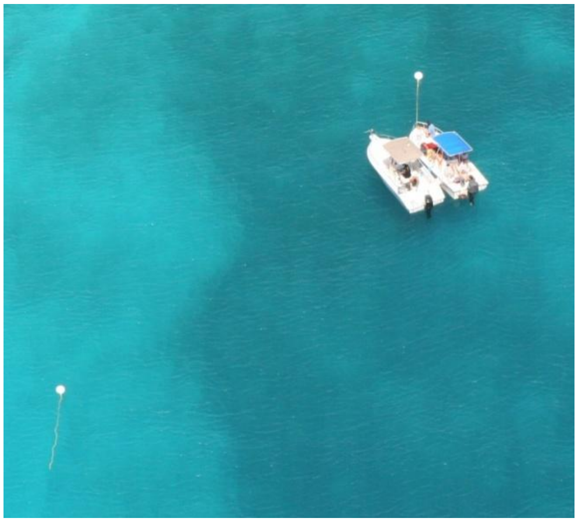


Figure 26: Two boats rafting at Fajardo. Notice how the other buoy is ignored.

being used. This may be because boaters prefer to moor closer to shore or to raft together rather than being farther apart at separate buoys.

Other bad practices observed were boats lining the beaches and mangroves. The boats dropped anchor along the sand, and with such a large number of boats, this can cause serious erosion to the beach. Along the mangrove channels in Salinas a long row of boats had tied their lines to the mangrove branches. This causes damage to the mangroves by breaking its branches and roots. If there was not enough room near the beach or next to the mangrove forest, the boaters proceeded to drop anchor wherever they wanted. At Salinas, a large boat deliberately dropped anchor upon the seagrass bed (Figure 27).

Figure 27: Large Boat Anchored in Seagrass at Salinas

Buoys can be seen used improperly in the aerial photography of Salinas, where a buoy can be seen pulled from the water and hovering above the surface (Figure 28). It cannot be determined how the boater is using this buoy, but it is certainly improper. In this area that contains 34 boats and only four buoys it was surprising to see one buoy being completely ignored.

Figure 28: Improper Mooring Buoy Use at Salinas

Icacos was the only area where all the mooring buoys were used during this holiday weekend. Unfortunately, Icacos only contains one mooring buoy. All the other sites had quite a few buoys that were not being used even though the number of boats in the area was much higher than the number of buoys. Table 1 compares the number of boats to the number of buoys that were not used when these data were taken.

Table 1: Buoys Not Being Used

Site	Total Number of Boats	Total Number of Buoys	Total Number of Buoys Not Being Used
Guánica	17	14	3
Salinas	85	8	1
Palomino	70	22	5
Wolf's Den	3	3	3
Icacos	64	1	0

There are a few possible reasons why boaters were not using the mooring buoys. The mooring buoys may have been in disrepair, rendering them unusable to boaters. Since the aerial surveys were collected on Sunday, at the end of Easter weekend, these buoys could have been damaged earlier in the weekend. Another reason is that the boaters decided to go wherever they desired rather than limiting themselves to locations with buoys. With the holiday festivities and the large number of other boats, a boater has more confidence to drop anchor in seagrass or coral environments if there are others doing the same. With this data and the aerial photography, it appears as if boaters go where they please with little regard to the environment.

When it comes to aquatic activities, people tend to go where they want. From our observations we witnessed that most boaters will go closer to shore and drop anchor in the sand. Although this practice is not illegal, it is discouraged by the DNER because it erodes the beaches. Boaters avoid fines for dropping anchor in seagrass or coral by getting close enough to shore that there is only sand. However, we observed that if their interest coincides with that of a mooring buoy location then some of the boaters will use the buoy instead of dropping anchor.

Figure 29: Boating Traffic at Palomino over Easter Weekend

4.5 Analysis of Boat Traffic

While we were cataloguing the buoys around Puerto Rico, we observed a relatively small number of boats in the vicinity of the mooring buoys. At Guánica and Salinas we witnessed a total of seven boats; all except one were just passing through. In general it appears that boaters would prefer to drop anchor close to shore in sand rather than tie up to a mooring buoy. At the sites around Fajardo, we observed fourteen recreational boats, six of which were anchored in sand. Another common boat activity is ferrying people from one destination to another. This happens because people, especially tourists who do not have their own watercraft, still wish to visit the offshore locations. We witnessed a total of four ferries at Guánica and Fajardo. There were only a few boats at Parguera and they were mostly small recreational vessels that were either anchored, tied up to mooring buoys, or just passing through.

To try to ascertain a better idea of the boat traffic during the weekend; another excursion was undertaken to Fajardo and Culebra on a Sunday. Compared to when we visited Palomino previously, there were over 49 boats present in this location and this was only at one of the many islands off the coast of Fajardo. Most of these boats were anchored next to shore, but the rest were using all of the mooring buoys in that area. While at Culebra we counted 43 boats in different areas around the island. There were other parts of the island that were populated with many boats but we were unable to travel to them due to time constraints.

Figure 30: Boat Traffic at Icacos over Easter Weekend

To showcase the difference between the number of boats during a holiday weekend and a common weekday, Table 2 shows how many boats was present Sunday during Easter Weekend and how many boats were present during an average weekday.

Table 2: Comparison of Boat Traffic

Site	Total Number of Boats During Weekday	Total Number of Boats During Easter Sunday
Guánica	4	17
Salinas	3	85
Palomino	8	70
Wolf's Den	1	3
Icacos	7	64

Another issue regarding boat traffic around the buoys is that many of the boats are large yachts. These boats are too large for using the mooring buoys and put too much stress on the lines, which can detach the buoy from its anchor. Another issue is that if the yacht is too large, it cannot fit into certain coves where the depth of the water is relatively shallow. This, however, does not deter them from trying. At the island of Culebra there is an area that is protected as a nature reserve and a yacht that was approximately 85 feet was anchored in the seagrass. Between the yacht anchored in the seagrass and being much too large for the nature reserve, the DNER was obliged to report it to the authorities.

It seems as if the influx in boating traffic on weekends is too great to handle with the mooring buoys currently in place around Puerto Rico. The DNER can install more mooring buoys, but they just do not have the resources to install enough mooring buoys to handle the traffic that occurs during weekends and holidays. There is a need for enough mooring buoys to be in place to handle the week and the average weekend traffic. This would allow the ecosystems to recover between major holidays. If the mooring buoys do not meet these needs, there would just be a continuous onslaught of boats with their anchors.

4.6 General Analysis

Damage to the surrounding ecosystems is proportional to the number and concentration of boats in the area. More remote places like Salinas and Guánica have little damage to their ecosystems, while places like Fajardo, more specifically Palomino, have significant levels of damage caused by anchors and boater negligence. Sites that are frequented mainly by charter companies, however, have in general lower levels of damage to the surrounding ecosystem. One of the reasons might be because the charter boats both want to preserve the environments for the sake of their business. Since they transport more people per boat, there are not as many vessels in the area. Although charter boats stem damage to the ecosystems by educating their passengers on how to interact with the reef safely, the largest emergent pattern of our results is that the popular sites are still the areas that sustain the most damage.

These popular areas contain the most damage to both buoys and ecosystems. The reason for the popularity is that these areas are close to major cities and large resorts, which allow tourists easy access. These places are also well known for their swimming and marine activities. Because they are used so frequently, the ecosystems have a hard time recovering from all the traffic. More remote places are allowed to recover because they only experience an influx of visitors during major holidays and weekends. The more popular the site, the more boats there are. These boats tend to crowd where there are not enough mooring buoys so they have to drop anchor, which damages the ecosystems. While the ecosystems are being damaged so too are the mooring buoys meant to protect them. Because of the sheer number of boats using these buoys, they sustain more damage from improper use and general wear, rendering them unusable. During the weekends and holidays, when there is an increase in boaters, damages to buoys are exasperated, diminishing the number of mooring buoys which leads to the deterioration of the surrounding ecosystems.

Figure 31: Bare Patches in a Seagrass Meadow

Seagrass is often located on the calmer side of the small islands and is observed to be the best at rebounding compared to soft and hard corals. If there is only an occasional flux of boaters, seagrass has the time and capability to recover quickly, especially in shallow waters. In Guánica for instance, we observed seagrass flourishing in the shallows where before, according to our liaison, the seagrass had been significantly reduced by boating practices. At the more popular sites for boating activities, the seagrass has had less time to recuperate. This is evident in the numerous bare patches interspersed within the seagrass meadows off the coast of Fajardo.

There was a noticeable difference in pickup lines between the calm waters of Guánica and Salinas and the rough bay of Fajardo. The pickup lines had the same amount of damage, but the amount of growth was significantly varied. The pickup lines at Guánica and Salinas were weighed down by a large collection of algae, sponges, and other organisms whereas the pickup lines at Fajardo were relatively clean. There are two possible reasons why pickup lines at Fajardo lack the marine accumulation seen elsewhere: the rough waters hamper the growth on the pickup lines or the frequent use of these mooring buoys due to their popularity does not allow for algae to collect. At this time, it is not clear which is the contributing reason. It may be a combination of both.

From our interviews and the aerial surveys it seems as if there is a difference in attitude towards the marine environment and the mooring buoys between locals that use these ecosystems around their home and the vacationers who arrive on major holidays. During our weekend fieldwork, we witnessed boaters both anchored and actively dropping anchor in seagrass environments, contrary to during the week where we only observed boats anchored in sand. In the interviews we conducted, the boaters spoke of trash that had accumulated near the mooring buoys and stated it was leftover from vacationers who do not live in the area, but who travel there on weekends. If buoys were being used, most of them were used improperly. Again, it may be because of the overwhelming number of boats, but it seems as if the vacationing boaters do not show as much respect to the environment as the locals do.

4.7 Concluding Remarks

The results obtained by our fieldwork are lacking in data due to the simple fact that we catalogued only 98 of the 270 mooring buoys. With a full catalogue of all the mooring buoys, the DNER will be able to properly construct maintenance schedules. However, the buoys we catalogued provided a testing area for refining procedures allowing the DNER to catalogue the remaining mooring buoys more easily. Other than the number of buoys catalogued, insufficient data were collected through interviews assessing the public's opinion of the use of mooring buoys. Even though we were unable to achieve a sizable sample, the interviews we did collect provided vital insight into the mindset of the boaters using the mooring buoys, while simultaneously reinforcing observations gathered in the field.

To date our analysis has shown that the buoys are helping the ecosystems by facilitating the recovery of seafloor environments through prevention of anchor damage. The use of the buoys does have an impact on their condition, however, as we found buoys in the more traveled regions to have damages such as propeller scarring, which was not seen in more remote locations. These scarred buoys will be replaced now that they have been catalogued as severely damaged. The cataloguing of the buoys will greatly help the DNER to identify where to allocate installation and maintenance. The other benefit of an exact coordinate for each buoy is that if one of them should be lost, the anchor pin can be found far easier than if only the general location was known.

CHAPTER 5: CONCLUSION

Marine damage is a common problem around the world. Mooring buoys are a part of a solution to prevent damage caused by humans. Although human impact is a small aspect of the damage, it is easily exacerbated by other causes. Because the buoys have such a positive impact on the environment, the DNER wants to manage them effectively. Puerto Rico has many offshore natural wonders that need protection from the surge of tourists and locals looking to experience them. Practices were put into place to try and preserve these environments, while allowing many people to experience them. This is a great benefit of mooring buoys: that people can still see the natural environment without inflicting damage. The goal of our project was the creation of a GIS database that would allow the DNER to easily manage these buoys. This was accomplished through the cataloguing the buoys' locations, evaluating the conditions of the buoys, assessing the surrounding ecosystems, identifying boating activities, and analyzing boat traffic.

By constructing a GIS database to contain all of the relevant information gathered through fieldwork, we have effectively created a tool that can provide quick and efficient access to information regarding the mooring buoys surrounding Puerto Rico. With this database, the DNER will be able to effectively manage the mooring buoys by creating maintenance schedules and assessing the impact of the mooring buoys on the surrounding ecosystems.

The factors that contribute to the destruction of Puerto Rico's marine habitats range from hurricanes and diseases to careless boating practices. While some of these factors cannot be controlled, the DNER has targeted the direct influences from human boating behaviors, one of which is the setting of anchor while in the marine ecosystems. This small action causes disproportionally large amounts of damage; however, it can be deterred through the installation of mooring buoys.

With the database effectively managing these buoys, an accurate survey on whether the soft and hard corals are truly recovering can be ascertained over a long period of time, seeing as their regeneration will take at least a quarter of a century. Since the mooring buoys have allowed seagrass to recover at some of the shallower locations, it appears that they will also allow the soft and hard corals as well as deep water seagrass to recover. These organisms take a much longer period to recover and, hopefully, mooring buoys are giving them that chance.

5.1 Recommendations

We recommend the installation of more mooring buoys in the Palomino and Icacos sites, as these areas are still being affected by boaters dropping anchor. There are not enough mooring buoys to handle all of the vacationers, especially during major weekends and holidays, and these islands receive a lot more visitors during the week when compared to sites such as Guánica and Salinas. The ecosystems surrounding Guánica and Salinas are able to recover during the week when there is slow boat traffic. In the more popular places, there are simply not enough mooring buoys, because the islands are visited more frequently during the week and even more so on the weekend. The ecosystems cannot recover due to the boaters' excessive use.

Another recommendation is to do maintenance immediately following a major holiday, when there is a large increase in use of mooring buoys. The buoys and the environment exhibit high levels of disrepair, especially in extremely popular locales. The sooner maintenance can be provided to these areas the less time the buoys will have to deteriorate. Immediately addressing damage can improve the lifetime of the buoys and also allow the ecosystems to recover if the buoys are still operational. If the buoys are not repaired immediately, boaters have no choice but to drop anchor on the seafloor.

We recommend that the database be regularly updated so that it remains current and pertinent. The DNER will be able to plan maintenance schedules for the mooring buoys as well as monitor the surrounding ecosystems. Also if a version was published on the DNER website and continuously updated then the public could access it and learn the locations of the mooring buoys. To a lesser extent, this would also allow the DNER direction in how to proceed in organizing a volunteer workforce to clean the mooring buoys.

Another idea is that the DNER could expand upon the Adopt-A-Buoy program to allow for the public to play an active role in maintenance as well as sponsoring a buoy. As responsibilities, the adopter would have to maintain the buoy's cleanliness and report any and all damages to the DNER. A possible benefit to adopting a buoy would allow the adopter to place their name or logo underneath the "DRNA" already written on the buoy.

This database will allow the DNER to easily manage the locations and the current conditions of all the buoys. It will also provide supplementary information in the form of what kinds of boaters are using the buoys and how they are using them. With data from the database, the DNER can better protect the environment from human abuse and overuse and future projects can be easily planned and executed.

REFERENCES

Boaters Land. (2009). *How do I use a mooring buoy? - taylor made mooring buoys.* Retrieved 2/13/2009, 2009, from http://www.boatersland.com/mooring.html

CIA. (2009). *CIA - the world factbook -- Puerto Rico.* Retrieved 2/12/2009, 2009, from https://www.cia.gov/library/publications/the-world-factbook/geos/rq.html

Creed, J. C., & Amado Filho, G. M. (1999). Disturbance and recovery of the macroflora of a seagrass (halodule wrightii ascherson) meadow in the Abrolhos Marine National Park, Brazil: An experimental evaluation of anchor damage. *Journal of Experimental Marine Biology and Ecology, 235*(2), 285-306. doi:DOI: 10.1016/S0022-0981(98)00188-9

Dawes, C. J., Andorfer, J., Rose, C., Uranowski, C., & Ehringer, N. (1997). Regrowth of the seagrass thalassia testudinum into propeller scars. *Aquatic Botany, 59*(1-2), 139-155. doi:DOI: 10.1016/S0304-3770(97)00021-1

Dinsdale, E. A., & Harriott, V. J. (2004). Assessing anchor damage on coral reefs: A case study in selection of environmental indicators. *Environmental Management, 33*(1), 126-139. Retrieved from http://dx.doi.org/10.1007/s00267-003-3056-9

Environmental Systems Research Institute. (1997). *Getting to know ArcView GIS : The geographic information system (GIS) for everyone* (2nd ed.). Cambridge: GeoInformation International.

García-Sais, J. R., Appeldoorn, R., Battista, T., Bauer, L., Bruckner, A., Caldow, C., et al. (2008). The state of coral reef ecosystems of the commonwealth of Puerto Rico. *The State of Coral Reef Ecosystems of the Unites States and Pacific Freely Associated States: 2008. NOAA Technical Memorandum NOS NCCOS 73., 73*, 75-116. Retrieved from DSpace at Mote Marine Laboratory database.

gastropod. (n.d.). *Dictionary.com Unabridged (v 1.1)*. Retrieved April 16, 2009, from Dictionary.com website: http://dictionary.reference.com/browse/gastropod

Green, E. P., & Short, F. T. (2003). *World atlas of seagrasses*. Berkeley: University of California Press.

Gullström, M., Castro, M. d. l. T., Bandeira, S. O., Björk, M., Dahlberg, M., Kautsky, N., et al. (2002). Seagrass ecosystems in the western Indian Ocean. *Ambio, 31*(7/8, The Western Indian Ocean), 588-596. Retrieved from http://www.jstor.org/stable/4315313

Harriott, V. J. (2002). *Marine tourism impacts and their management on the great barrier reef* No. 46). CRC Reef Research Centre, Townsville: CRC Reef Research Centre and School of Tropical Environmental Science and Geography, James Cook University. Retrieved from http://crcreef.jcu.edu.au/publications/techreport/pdf/Harriott46.pdf

Hastings, K., Hesp, P., & Kendrick, G. A. (1995). Seagrass loss associated with boat moorings at rottnest island, Western Australia. *Ocean and Coastal Management, 26*(3), 225-246. Retrieved from http://dx.doi.org/10.1016/0964-5691(95)00012-Q

Hemminga, M. A., & Duarte, C. M. (2000). *Seagrass ecology*. Cambridge, UK ; New York, NY: Cambridge University Press.

Jaap, W. C. (2000). Coral reef restoration. *Ecological Engineering, 15*(3-4), 345-364. doi:DOI: 10.1016/S0925-8574(00)00085-9

Jackson, J. B. C., Kirby, M. X., Berger, W. H., Bjorndal, K. A., Botsford, L. W., Bourque, B. J., et al. (2001). Historical overfishing and the recent collapse of coastal ecosystems. *Science, 293*(5530), 629-637. doi:10.1126/science.1059199

Jameson, S. C., Ammar, M. S. A., Saadalla, E., Mostafa, H. M., & Riegl, B. (2007). A quantitative ecological assessment of diving sites in the Egyptian Red Sea during a period of severe anchor damage: A baseline for restoration and sustainable tourism management. *Journal of Sustainable Tourism, 15*(3), 309-323. doi:10.2167

Jennings, S., & Polunin, N. V. C. (1996). Impacts of fishing on tropical reef ecosystems. *Ambio, 25*(1), 44-49. Retrieved from http://www.jstor.org/stable/4314417

Larkum, A. W. D., Orth, R. J., & Duarte, C. M. (2006). *Seagrasses : Biology, ecology, and conservation*. Dordrecht, The Netherlands: Springer.

Larsen, M. C., & Webb, R. M. T. (2009). *Potential effects of runoff, fluvial sediment, and nutrient discharges on the coral reefs of Puerto Rico* Retrieved from http://find.galegroup.com/itx/infomark.do?contentSet=IAC-Documents&docType=IAC&type=retrieve&tabID=T002&prodId=AONE&docId=A192974474&userGroupName=mlin_c_worpoly&version=1.0&source=gale

marine ecosystem. (2009). In *Encyclopædia Britannica*. Retrieved April 16, 2009, from Encyclopædia Britannica Online: http://www.britannica.com/EBchecked/topic/365256/marine-ecosystem

Moberg, F., & Folke, C. (1999). Ecological goods and services of coral reef ecosystems. *Ecological Economics, 29*(2), 215-233. doi:DOI: 10.1016/S0921-8009(99)00009-9

Moreno, P. S. (2005). Ecotourism along the meso-american caribbean reef: The impacts of foreign investment. *Human Ecology, 33*(2), 217-244. Retrieved from http://dx.doi.org/10.1007/s10745-005-2433-9

National Wildlife Federation. (2007). *Wildlife conservation funding.* Retrieved 1/30/2009, 2009, from http://www.nwf.org/congressandglobalwarming/wildlifeconservationfunding.cfm

Orth, R. J., Carruthers, T. J. B., Dennison, W. C., Duarte, C. M., Fourqurean, J. W., Jr., K. L. H., et al. (2006). A global crisis for seagrass ecosystems. *Bioscience, 56*(12), 987-996. Retrieved from http://www.jstor.org/stable/4488220

Robert B. Ditton, Don J. Clark. (1994). *Charistics, attitudes, catch and release behavior, and expendatures of billfish tournament anglers in Puerto Rico*. Texas A&M University: Department of Wildlife and Fisheries Sciences.

Rosenberg, E., & Loya, Y. (2004). *Coral health and disease*. New York: Springer-Verlag.

Spalding, M., Ravilious, C., & Green, E. P. (2001). *World atlas of coral reefs* University of California Press.

U.S. Dept of Agriculture National Agriculture Statistics Service. (2007). *2007 census of agriculture island profile Puerto Rico*

U.S. Dept of Homeland Security, & United States Coast Guard. (2008). *Boating statistics 2007* No. P16754.21)United States Coast Guard.

Vayda, K., Cafferty, D., & Carmichael, J. (2009). *Maintaining marine ecosystems* (WPI IQP. Worcester MA:

Woodley, J. D., Chornesky, E. A., Clifford, P. A., Jackson, J. B. C., Kaufman, L. S., Knowlton, N., et al. (1981). Hurricane Allen's impact on jamaican coral reefs. *Science, 214*(4522), 749-755. doi:10.1126/science.214.4522.749

GLOSSARY

Blowhole: An excavation of an area of seagrass and ocean floor caused by a high amount of turbidity from a boat propeller (C. Matos, personal communication, March 24, 2009).

Buoy Cleaning: The process of removing algae growing on a mooring buoy's various components. It is performed using a knife to scrape off the algae weighing the buoy down.

Fragmentation: Damage that has caused pieces of coral to break off (C. Matos, personal communication, March 24, 2009).

Gastropod: "Any mollusk of the class Gastropoda, comprising the snails, whelks, slugs, etc" (Dictionary.com Unabridged, 2009)

Grounding: The act of a boat's hull physically coming into contact with a seafloor environment.

Halas [anchor system]: An anchor for mooring buoys that is used in hard-bottom sea floor environments, such as coral. Installed by boring into the top of a rock or coral outcrop, inserting the Halas anchor with pin on tom, then filling with hydraulic cement (C. Matos, personal communication, March 27, 2009).

Laceration: Damage caused by contact with ropes, chains and the weight of the anchor (C. Matos, personal communication, March 24, 2009).

Manta [anchor system]: Used in soft-bottom sea floor environments as an anchor for mooring buoys. Found in seagrass beds and mangrove cays where mooring buoys have been installed. It is installed by drilling the anchor into the substrate to a depth before pulling up on it to engage steel arms that act as barbs, holding the anchor in place (C. Matos, personal communication, March 27, 2009).

Pulverization: Maceration or grinding of coral (C. Matos, personal communication, March 24, 2009).

Primary Production: The transformation of energy to organic substances using photosynthesis or other chemical means. (Encyclopædia Britannica, 2009)

Rafting: The process of one boat using a mooring buoy, anchoring, or tying off to something while other boats tie to the boat already moored (C. Matos, personal communication, March 30, 2009).

Reef walking: A water activity where the participants walk on and along the coral reef.

Scrape: Mild physical contact with some scarring or removal of the outer layer, mainly used regarding coral reefs (C. Matos, personal communication, March 24, 2009).

Scar: A long trench cut into a seagrass bed that is formed most commonly by boats and propellers (C. Matos, personal communication, March 24, 2009).

Trimble GPS Transponder: A handheld device that takes GPS coordinates. It also can use data forms to create features that can be displayed using a Geographic Information System client and stored easily in a database.

APPENDIX A: MISSION STATEMENT

The Department of Natural and Environmental Resources mission statement: “To protect, conserve, and manage the natural and environmental resources of the country, balanced so as to guarantee future generations their enjoyment and to promote a better quality of life.”

APPENDIX B: PROPOSED TIMELINE

The following table was the projected layout of our timeframe while at the project site. We scheduled it in the most logistical fashion, beginning with assessment and planning, and development of the database. Interviews and buoy evaluation have multiple weeks allotted for their completion due to the sheer magnitude of the task. Analysis of boating traffic was dependent upon data gathered while evaluating buoys and documents provided by the DNER. The last two weeks were reserved for the finalization of both the database and the report.

Table 3: Proposed Timeline

TASK	Week							
	03/15-03/21	03/22-03/28	03/29-04/04	04/05-04/11	04/12-04/18	04/19-04/25	04/26-05/02	05/03-05/06
Assess Information and Plan Fieldwork	**Assess & Plan**							
Develop Database	**Develop Database**							
Interviews		**Interviews**						
Buoy Evaluation		**Buoy Evaluation**						
Analyze Boating Traffic		**Analyze Boating Traffic**						
Finalize Database						**Finalize Database**		
Finalize Report						**Finalize Report**		

APPENDIX C: PUERTO RICO BACKGROUND INFORMATION

The island of Puerto Rico is located south and east of the Dominican Republic, and is roughly three times the size of Rhode Island, at 8870 km^2. With a fairly consistent Caribbean environment, Puerto Rico enjoys warm temperatures year-round on the majority of the landmass, including the coastal plains and sand beaches. Some lower temperatures may be experienced in the mountainous regions inland where it is also marginally more arid than the lower, northern parts of the island. (CIA, 2009)

Due to its geographic location, Puerto Rico experiences many hurricanes throughout the summer months, often leading to problems on and off the island (CIA, 2009). Because of past and current agricultural trends, torrential rain can lead to erosion and washout. This runoff, when it feeds into the tributaries and rivers, will eventually flow out to the ocean. This presents the problem of sedimentation, which is damaging to the local ecosystems and ultimately leads to a drop to their economic production (Hemminga & Duarte, 2000; Larsen & Webb, 2009).

Both seagrass beds and coral reefs can offer valuable commodities to the mainland, including fish and mollusks, as well as an attractive place for tourists. As of 2007 the aquaculture of Puerto Rico enjoyed a market value of $832,725 (U.S. Dept of Agriculture National Agriculture Statistics Service, 2007). Interestingly enough, however, fish is one of Puerto Rico's larger imports (CIA, 2009), even in light of the publicity enjoyed as an excellent sport fishing location (Robert B. Ditton, Don J. Clark, 1994).

Puerto Rico's dependence on foreign fish is due to the island having become a large industrial center, with many U.S. businesses investing money there. What was once a major agricultural center focused on sugar production has now devoted its fields to dairy and livestock, while allowing production facilities for chemicals and pharmaceuticals to become a main source of revenue (CIA, 2009).

A 2004 statistic gives that roughly 5 million tourists visited Puerto Rico that year (CIA, 2009). With regard to statistics concerning revenues, none have been found that break down the "goods and services" into finite areas. Because of this, little is known about how much monetary value any given sphere of business will have. Boating, diving, fishing and other forms of marine recreation are present in Puerto Rico, but the actual distribution patterns cannot be traced by economic means.

APPENDIX D: ADDITIONAL MOORING BUOY INFORMATION

D-1: How Mooring Buoys Are Cleaned

Because of their fairly stable position on the ocean surface, mooring buoys tend to accrue marine vegetation on any component that stays continuously submerged. The creation of these microecosystems would be beneficial if not for the fact that the added flora weighs down the buoy and increases the likelihood of boats colliding with and damaging the buoy and its parts.

When a buoy has amassed enough plant matter to warrant cleaning, the first step is to approach the buoy and expose the underside with the growth on it. From here, all vegetation that can be pulled off by hand is removed. Next, the spine of a utility knife, about one foot long, is used to scrape down the rest of the surface shaving off any residual plant matter. When the flora has grown and covered the pickup line of the mooring buoy, it cannot be easily cleaned without damaging the fibers of the line, so the DNER replaces it with a new clean line.

D-2: The Installation of Mooring Buoys

Mooring buoys can have a service span of over five years in calm fresh water. The buoys off the coast of Puerto Rico, however, are installed in saltwater and at times are located in very rough environments either through natural wave action or poor boating practices. Due to these less than favorable conditions, the buoys can detach from their anchors and become lost from time to time.

Buoy damage usually initiates at the pickup line and propagates downwards to the anchor pin. In the case that the entire buoy is missing, the anchor pin usually remains in the seafloor. In this case, the installation requires finding the existing pin. Next, a downline is prepared by passing rope through a section of plastic pipe, used to prevent frictional damage, and then weaving the rope back into itself so that the pipe with rope inside forms a loop. This loop is then connected to a shackle, which then fastens to the anchor pin. The downline is then tied to a through-line, which passes through the buoy and is connected to the pickup line by another looped knot. A consideration in this process is the depth of the water in which the buoy sits: SCUBA divers are needed for deep water while snorkelers suffice for shallower areas. Additionally, the ropes must be of the proper length to allow the right amount of slack so that the tension does not pull out the anchor.

APPENDIX E: DESCRIPTIONS OF MOORING BUOY SITES VISITED

E-1: Guánica

The site at Guánica is a small mangrove island less than a mile off the coast. Surrounding the island are fourteen mooring buoys that are available for public use by boaters. This island, called Cayo Aurora (affectionately called Gilligan's Island) is very popular among the locals. On the weekend following our fieldwork; over 600 people were predicted to arrive to enjoy the crystal clear waters.

E-2: Salinas

The Salinas site is another island that is located close to the coast. It is primarily a mangrove island and has eight mooring buoys, four of which protect seagrass while the rest defend mangroves from boaters tying to their roots. This island, Cayo Matias, is an excellent spot for snorkeling among the mangroves making it a popular destination for both tourists and locals. Without the mooring buoys present, damage would inevitably occur to this environment.

E-3: Fajardo

The islands surrounding Fajardo are further away from the coast than the cays around Salinas and Guánica. The major islands are Icacos, Palomino, and Wolf's Den; there is also a very small cay near Palomino named Palominto. There are mooring buoys installed around each island: one at Icacos, twenty-two at Palomino, four at Palominto, and three at Wolf's Den. The buoys are placed there to stem anchor damage to the coral and seagrass environments that surround these islands. These islands are not made of mangroves but instead have sandy beaches with grass and palm trees. Palomino and Icacos are the largest islands around Fajardo and the area around Icacos is part of a large coral reef. This area is popular for snorkeling and many charter boats bring their patrons here to enjoy all the ocean has to offer. These islands are very popular because they are close to the mainland of Puerto Rico and also are the closest to the commonwealth's capital, San Juan.

E-4: Parguera

Parguera is a small town located in southwest Puerto Rico. The small mangrove islands around Parguera are all in shallow waters with seagrass surrounding them. We visited three of these cays: Colloado, Enrique, and Caracoles. Each of these areas was outfitted with mooring buoys to protect the mangroves and seagrass. Colloado had five, Enrique eight, and Caracoles seventeen. Due to the warm shallow waters of the Caribbean, boaters here enjoy snorkeling and swimming in the sea.

E-5: Culebra

Culebra is a large island off the coast of Puerto Rico that is world renowned for its beaches. This island is different from the other cays that we have visited because it is large enough to support a town, population 1, 868 (U.S. Dept of Agriculture National Agriculture Statistics Service, 2007). Surrounding the island are clear waters filled with seagrass and coral. These waters range from very shallow to about 40 feet deep. The deeper areas around the island are where the coral environments are located. A popular activity for boaters is to snorkel around these coral reefs. To protect this beautiful area, a large number of mooring buoys were installed. However, when we visited Culebra, we did not have enough time to catalogue all of the mooring buoys around the island. We were only able to catalogue 15 buoys that were installed off of Carlos Rosario Beach. The DNER will catalogue the remaining buoys at a future point in time and import them into the database.

APPENDIX F: DATABASE USE

F-1: Trimble Data Collection

The Trimble GPS transponder allows for easy collection of fieldwork data by applying just a click. Collecting data on a Trimble helps eliminate clerical errors that can arise while transferring data from paper to an electronic form, such as a database. The Trimble allows for simple entry of data in one convenient location rather than multiple datasheets. Below are instructions on how to use the Trimble to gather field data.

On the Trimble desktop, double tap the TerraSync software icon to open the data collection program.

Figure 32: Trimble Desktop

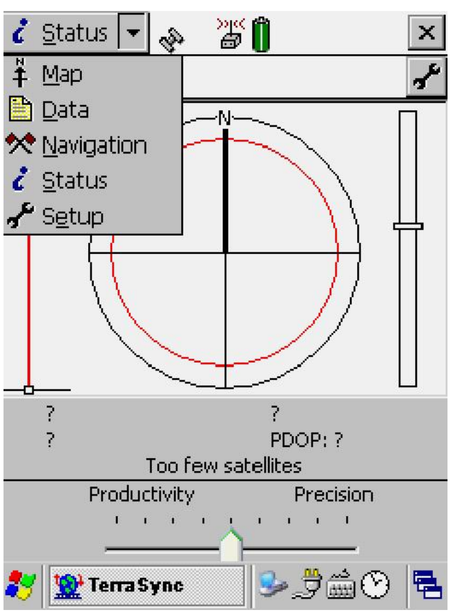


Figure 33: TerraSync Status Screen

TerraSync opens by displaying the Status screen. Adjusting the slider at the bottom of this screen adjusts precision (accuracy) and productivity (speed) of the GPS while recording the coordinates. A balance between these settings ensures that data collection can be done in the field rapidly, while still taking valid coordinates.

To begin taking data, change to the Data screen by tapping the dropdown arrow in the upper left next to “Status” and then tapping “Data”.

The Data screen begins with a new data file. In the bottom right hand corner, tap the keyboard icon to open the on screen keyboard. Input the desired name of the file by tapping each letter. Scroll down, or close the keyboard to select the "PR Mooring Buoy 3" data dictionary. This data dictionary is the most current version for collecting mooring buoy data. Tap "Create" to save the file and begin collecting features.

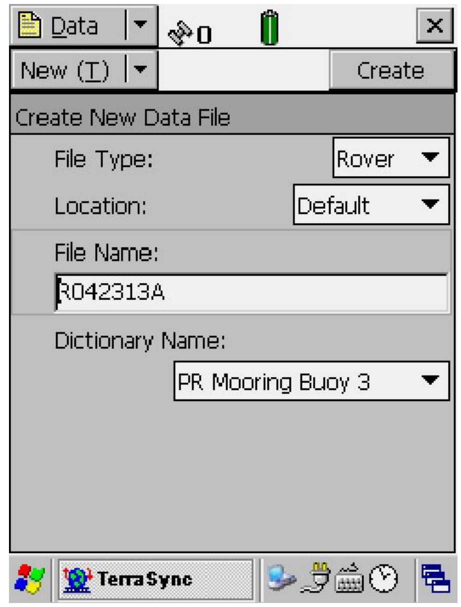


Figure 34: TerraSync Data File Creation

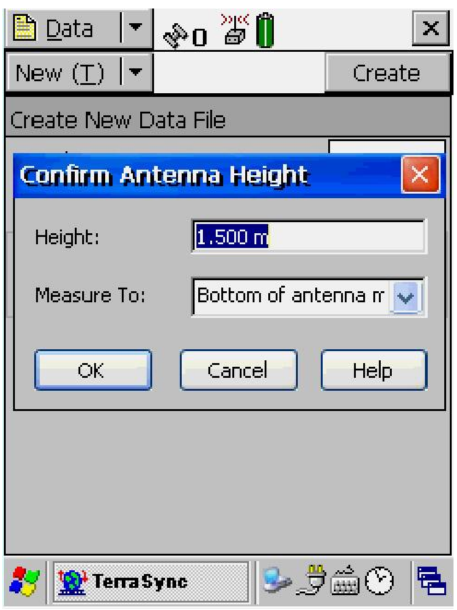


Figure 35: TerraSync Antenna Height

The antenna height is determined by how the Trimble is used, either handheld or using the backpack antenna. Enter the height of the antenna in meters and then tap "OK". Change the "Measure To" to the appropriate setting.

Select the feature that you would like to create and then tap "Create". For example, how to create a buoy feature is shown below.

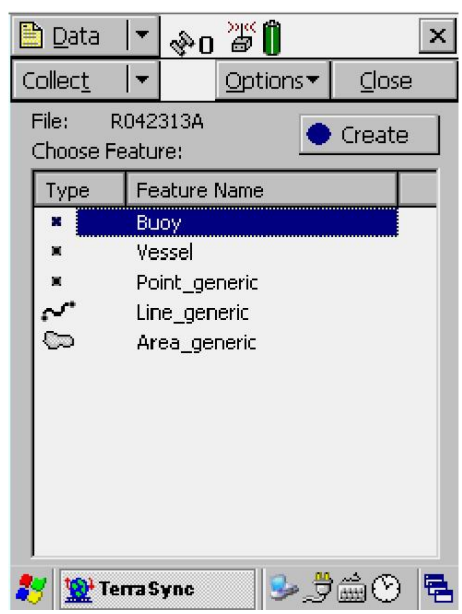


Figure 36: TerraSync Data Screen

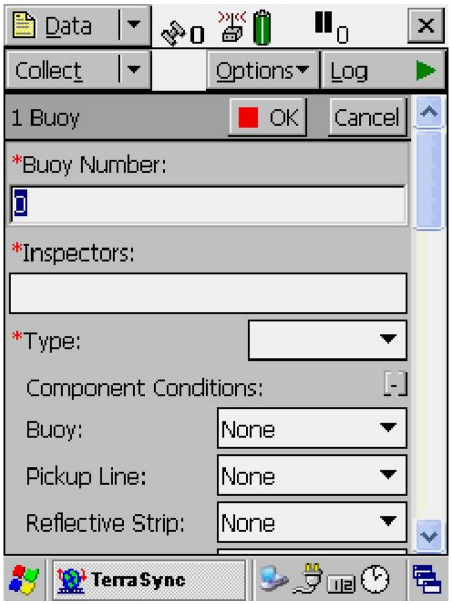


Figure 37: Buoy Data Form

Any fields with a red asterisk are required to be entered before continuing. The text fields can be entered by using the onscreen keyboard. Drop down menus give a choice of options to select. Afterwards, scroll down and enter the rest of the information for the buoy.

To take the position of the buoy, tap “Log”. The pause icon above “Log” will transition to a play icon and the “Log” will change to “Pause”. Wait until the 0 changes to a 1. If more than one position is taken then the average of all the positions will be the final position. Then tap “Pause”. When all information has been entered and the position calculated, tap “OK” and the feature will be saved. For the best results make sure that four or more satellites are displayed in the top center. Fewer than four does not provide a sufficient amount of accuracy.

If a feature needs to be edited, tap the drop down arrow next to “Collect” and then tap “Update”. Select the feature that you want to change and then tap “Begin”. Modify the feature in the same manner as creating a new feature.

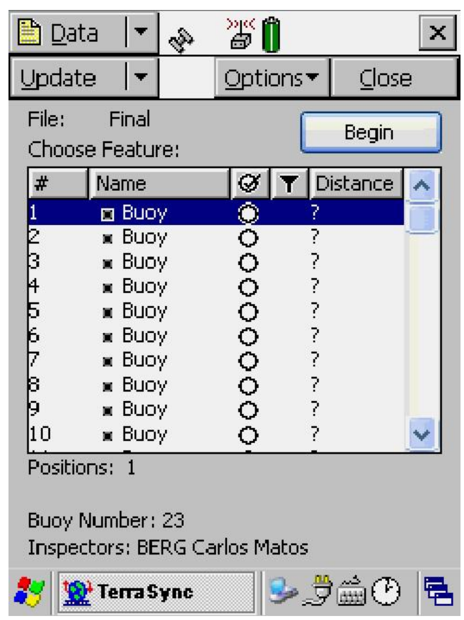


Figure 38: TerraSync Data Update Screen

F-2: Updating the Database

Once all the data in the field have been collected, the Trimble can be connected to a computer to update the database. First connect the Trimble using a USB cable and then open the program GPS Pathfinder Office. Once the program finishes loading, select the "Utilities" menu and then select "Data Transfer". In the pop-up window, click on the "Receive" tab and then click "Add". Select the data files that need to be transferred from the Trimble to the database, click "OK", and then click "Transfer All". Once it is complete, click "Close".

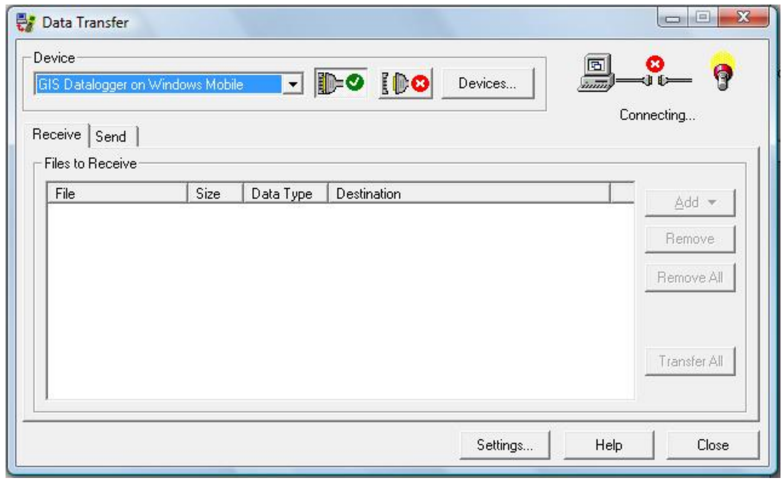


Figure 39: Transferring the Data from the Trimble

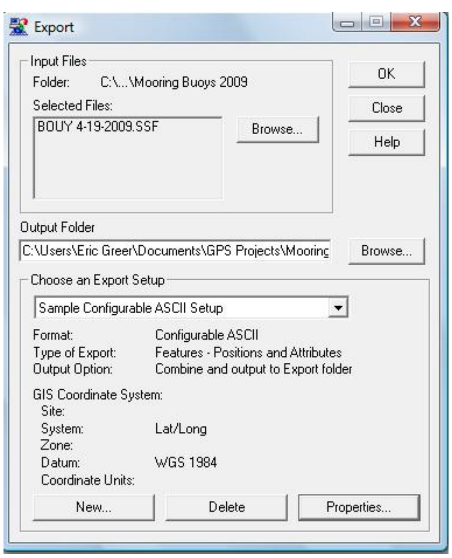


Figure 40: Exporting the Data into the Database

The next step is to export these data into the database. Click the "Utilities" menu again, but click "Export" this time. In the pop-up window, click on the "Browse" button and select all the data files that need to be exported. Then select the output folder that will hold this file. When choosing the export setup, confirm that "Sample Configurable ASCII Setup" is selected. Then click on the "Properties…" button and select the "Configurable ASCII" tab (Figure 41). Confirm that the "Buoy" template is selected and that "All Feature Types in Same Set of Files" is selected. Click "OK" and "OK" again to close the window.

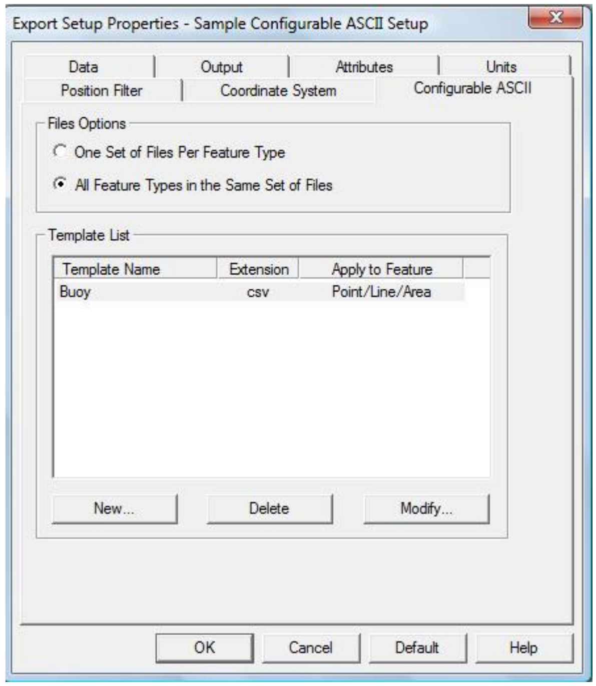


Figure 41: Export Setup Properties

Once all the data are exported, GPS Pathfinder Office can be closed and an internet browser opened. Navigate to the data upload website, click "OK" in the dialog box and then "Open" to allow the file to run. Enter in a username and password, then click "Upload a File" and select the file to be uploaded to the database website. Then click "Open". The data will be uploaded to the database website automatically. This process can only be used to insert new buoys and new vessels and modify buoys that are already in the database. To modify vessels that are already in the database, a program such as Quantum GIS must be used.

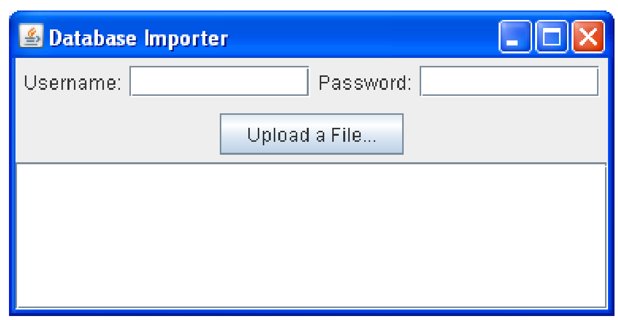


Figure 42: Database Importer

F-3: The Database Website

The user can read information about mooring buoys in two different ways: "MAP" and "DATA". When the user is toggled to "MAP" (Figure 43) the mooring buoy locations are represented on a map of Puerto Rico that is powered by Google Earth. Each pin represents a mooring buoy. Using the key in the top left corner of the map, the user can pan up, down, right, or left and also zoom in or out. The type of map can also be changed by clicking on the buttons that are in the top right hand corner of the map. The legend of the map indicates that each color of the pin represents a certain type of buoy.

Figure 43: Database Website, Map

Mooring buoys can be located in two different ways. The empty field titled "Search" allows the user to type in the type of anchor or what substrate the buoy is located in. This field is only useful when trying to locate buoys because it searches the database for any buoys that contain that value. For instance, typing in "pickup line" would not be helpful because it would not filter any buoys, since all include a pickup line.

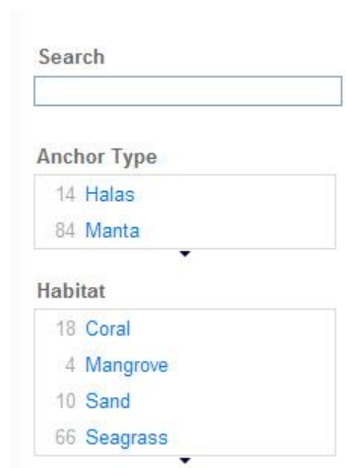


Figure 44: Database Website, Sidebar

Another way to filter buoys is by clicking on any of the hyperlinks located in the right hand column. When clicking on a value, only the buoys of that value will appear on the map. This is very useful because the user can click on multiple values, thus narrowing the search. The user can search for buoys according to anchor type, habitat, cleanliness, and types of damage to the buoy, and surrounding environment. For example, in clicking "Manta" for type of anchor and "Coral" for type of seafloor, the map will show three buoys in the Fajardo area. These buoys have a Manta-type anchor and are protecting corals.

In the “DATA” version, the user can see data on each mooring buoy in a tabular form (Figure 45). The user can still use the filters at the right of the screen to highlight buoys of particular interest. All of the information pertaining to the mooring buoys will be listed under each buoy number.

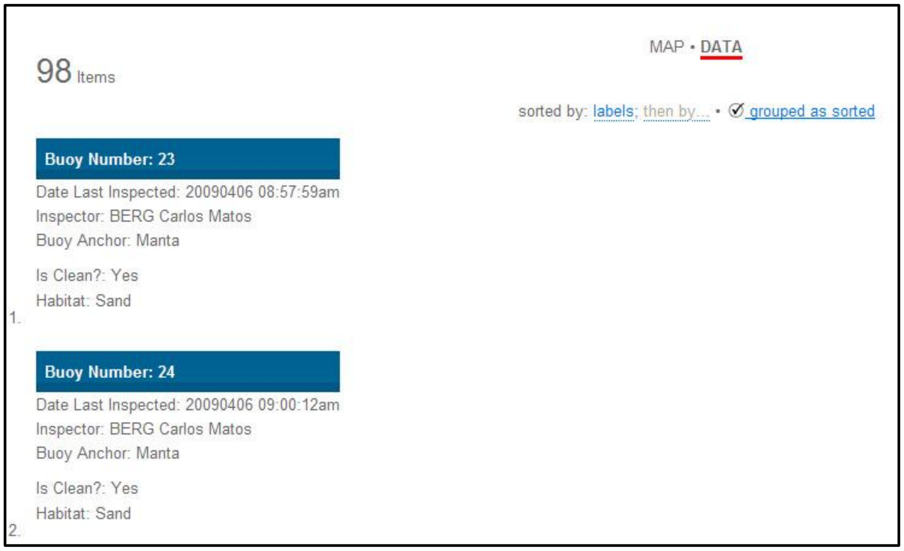


Figure 45: Database Website, Data

APPENDIX G: MOORING BUOY ANALYSIS FORM

G-1: Paper Form

Mooring Buoy Analysis Form

Inspectors: ____________
Time: ____:______
Date: ____/____/____

Buoy Number: __________
GPS Coordinates:
Lat: ____°____'___"___
Long: ____°____'___"___
Dec: __________ , ___________

Buoy Conditions:

	Present	Rating	Additional Observations
Buoy			
Pickup Line			
Reflective Tape			
Thru-Line			
Lead Weight			
Down Line			
Shaffing Tube			
Swivel			
Anchorage Halas or Manta			

Rating: None (N), Low (L), Moderate (M), Severe(S)

Environmental Conditions:

Habitat Type: Coral Seagrass Sand Other: ___________

Significant Anchor Damage: No Yes

Magnitude of Damage: None Low Moderate Severe

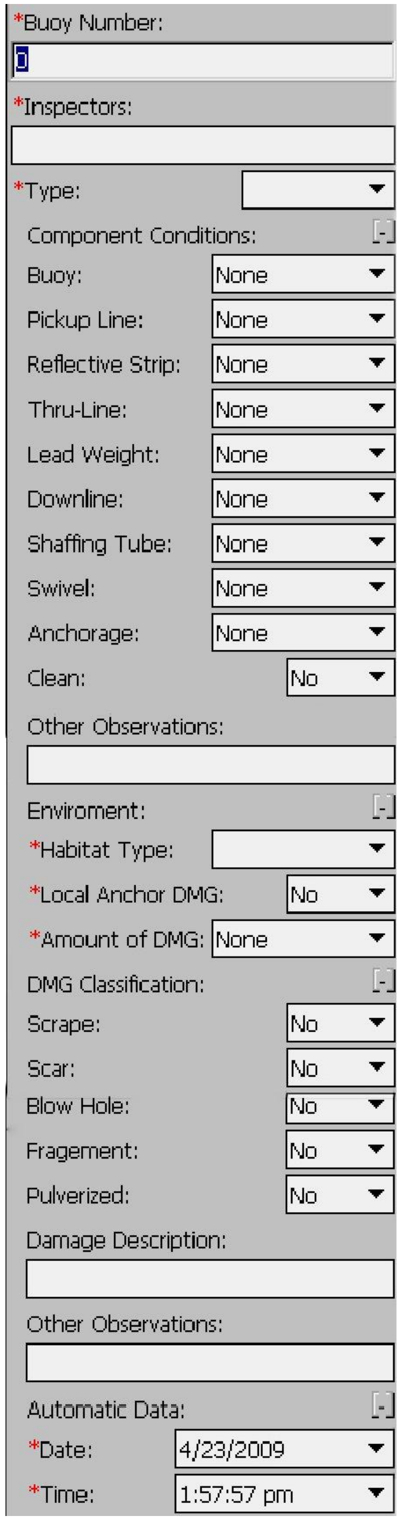
Classification of Damage: Scrape Scar Blowhole Fragment Pulverized

Description of Damage: ______________________________

General Comments:

Signature or Initials: __________________ Date: ______/_______/_______

G-2: Electronic Trimble Form


*Buoy Number:
0
*Inspectors:
*Type:
Component Conditions: [-]
Buoy: None
Pickup Line: None
Reflective Strip: None
Thru-Line: None
Lead Weight: None
Downline: None
Shaffing Tube: None
Swivel: None
Anchorage: None
Clean: No
Other Observations:
Enviroment: [-]
*Habitat Type:
*Local Anchor DMG: No
*Amount of DMG: None
DMG Classification: [-]
Scrape: No
Scar: No
Blow Hole: No
Fragement: No
Pulverized: No
Damage Description:
Other Observations:
Automatic Data: [-]
*Date: 4/23/2009
*Time: 1:57:57 pm

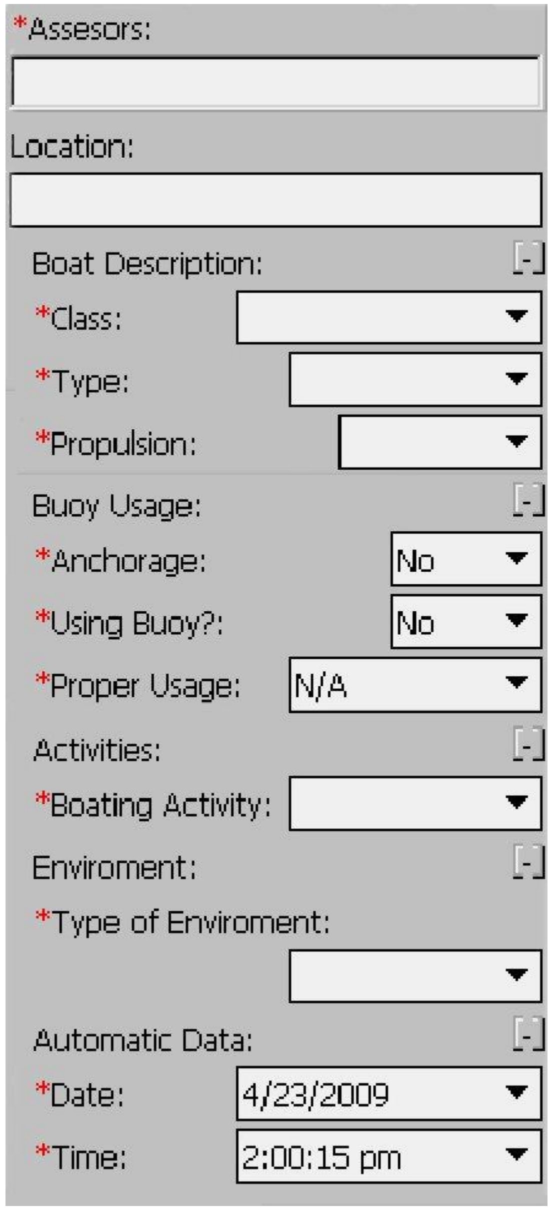
APPENDIX H: BOATING TRAFFIC ANALYSIS FORM

H-1: Paper Form

Boating Traffic Data Form

Location	Class	Type	Propulsion	Activity	Using Buoy	Anchored	Type of Bottom	Date	Time	Initials

H-2: Electronic Trimble Form



*Assesors:

Location:

Boat Description: [-]

*Class:

*Type:

*Propulsion:

Buoy Usage: [-]

*Anchorage: No

*Using Buoy?: No

*Proper Usage: N/A

Activities: [-]

*Boating Activity:

Enviroment: [-]

*Type of Enviroment:

Automatic Data: [-]

*Date: 4/23/2009

*Time: 2:00:15 pm