EFFECTS OF ARTIFICIAL REEF IMPLEMENTATION ON FISH POPULATIONS IN A MARINE PROTECTED AREA: BLUEFIELDS BAY, JAMAICA

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Master of Science, Biology

By

Joshua Harrison Rudolph

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ABSTRACT

Severe overfishing has presented a substantial dilemma in Jamaica. The fish populations within the country's boundaries have been decimated over an extensive period of time. Neighboring Caribbean countries use Jamaica as a worst case scenario as far as fisheries management is concerned. To alleviate the problem, the Jamaican government has implemented a number of measures in order to allow fish populations to rebound. An artificial reef was created within Bluefields Bay Marine Sanctuary, a newly created no-take preserve. The goal of the artificial reef is to provide protection and habitat for various fish populations. Once the population reaches carrying capacity, fish should expand outwards of the protected zone and increase surrounding artisanal fisheries harvests. This study's purpose was to provide a picture of the resident fish populations before and after the artificial reef was installed. Data collections took place in June 2011, January 2012, and June 2012. Results indicated statistically significant differences between the artificial reef and various other habitat controls. Species richness, abundance and diversity increased over time in the Bay, although the increase of a single species, the French grunt, was the dominant factor in this trend. Fish populations are under severe threat in Jamaican waters and this marine protected area provided an example of how conservation efforts can be productive.

KEYWORDS: Jamaica, Bluefields Bay, artificial reef, marine protected area, fish population.

This abstract is approved as to form and content

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INTRODUCTION

Caribbean marine resources are under threat from both anthropogenic and natural environmental factors. Threats include degradation of habitats and marine resources (Burke and Maidens 2004), increasing hypoxic zones (Selman et al. 2008), channelization for ship commerce or beach renourishment projects (Jaap 1999), increased sedimentation and water pollution (Burke and Maidens 2004), disturbances by coastal development (Agardy and Alder 2007) and hurricanes (Wilkinson and Souter 2008). Coral loss and disease has become common in Caribbean waters (Gardner et. al. 2003; Eakin et al. 2010) as well corresponding shifts in dominance from coral to algal communities due to eutrophication (Mumby 2009). Finally, the Caribbean has been affected by an invasive species, the Indo-Pacific lionfish (*Pterois volitans* and *P. miles*) which has become an apex predator in the ecosystem (Green et al. 2012). These threats have significantly altered the fish communities across the Caribbean as declining fish stocks from overharvest and excessive bycatch have been reported (Appeldoorn et al. 1992; Paddack et al. 2009).

Jamaica's Marine Fishery

Jamaica's marine resources have been plagued by a series of events including two hurricanes (Woodley et al., 1981, 1989; Hughes 1994), additional coral loss due to coral disease (Goreau 1992; Green and Bruckner 2000; Aronson and Precht 2001), collapse of the long spined sea urchin, *Diadema antillarum*, and its poor recovery (Hughes et al. 1985; Carpenter 1988; Edmunds et al. 2001; Lessios et al. 2001; Aronson and Precht 2006; Mumby et al. 2006a; Dudgeon et al. 2010) and long term serial overfishing

(Allison 1992; Sandeman and Woodley 1994; Sary 1995; Sary et al. 1997; Kent 1998; Hawkins et al. 2004; Carr et al. 2009). Munro (1983) conducted the first modern fish stock survey from 1969 until 1973, where the extent of overfishing was clearly noted. Out of twenty seven dives on the south coast, no large groupers or other predatory fish were observed (Munro 1983, Hardt 2009). Hawkins (2004) also noted that virtually all fish larger than 10 cm are harvested. Overfishing has been identified by Roberts (1995) to be one of the top three threats to coral reefs. Jamaica's government finally stepped in to alleviate severe overfishing by creating a number of Marine Protected Areas in 2009.

The majority of Jamaica's fishery is comprised of subsistence artisanal fishers. Polunin (1999) discusses a number of reasons why fishers typically practice this occupation, mostly attributed to economical and financial concerns. This aspect provides many hurdles for the proper management of marine species. In order for the fishermen to survive they must be able to harvest fish in some manner. However, the severity of the situation is somewhat overlooked and uncontrolled. Currently a top down effect exists. Almost all predatory fish have been harvested except for a number of small grouper species and several seasonal pelagic species. After all the predators were removed, the fishermen began to fish down the food chain, a practice that dramatically affects biological communities by causing cascading effects down food webs that decrease diversity or productivity (Beddington, 1984; Agardy 2000). Currently fishermen are harvesting various coral reef fish species (Munro 1983; Aiken and Haughton 1987; Koslow et al. 1988; Aiken 1993; Aiken and Kong 2000). They are now fishing at the bottom of the food web, essentially harvesting all juvenile fish. Once the remaining fish of this cohort are harvested, there will not be any fish left. Klomp's (2003) AGGRA survey of the north and west coast of Jamaica counted more than 6,000 fish and determined a mean length of only 12 cm, also noting that terminal phase male parrotfish over 20 cm were highly uncommon.

Spillover by Marine Protected Areas

MPAs offer protection to marine life and habitats within its borders. However, surrounding areas can also benefit. "Spillover" occurs when fish move from within the MPA into areas outside it, aiding in the recovery of an entire ecosystem providing that proper management practices are in place and enforced (Palumbi 2003; Halpern et al. 2004; Hilborn et al. 2006; FAO 2010). Marine Protected Areas have been shown to provide emigrants to areas outside of the boundaries, whether in the form of post larval recruits or adults (Roberts and Polunin 1991; DeMartini 1993; Rakitin and Kramer 1996; Johnson et al. 1999; Russ 2002; Halpern 2003). Gell and Roberts (2002) have shown noteworthy increases in surrounding fisheries due to migration of fish from within various MPAs outwards. Halpern (2003) has also shown that fish biomass, size, population density and species diversity all increased in a review of more than one hundred studies on MPAs. Additionally, Palumbi (2004) has provided reviews of a large number of studies including Halpern's study (2003), and has indicated confirming results, but noted that not all species benefit from MPAs. Roberts et al. (2001) showed in St. Lucia, the Florida Keys, and Merritt Island that commercially important fish populations grew substantially in numbers rather quickly, and even provided record sport catches along the edge boundaries of the MPA according to International Game Fish Association (IGFA) records. Even in Jamaica, Polunin (1999) has shown increases in fish biomass, species diversity and abundances within MPA boundaries compared to outside locations.

Polunin and Roberts (1993) noted that harvested fish biomass created by spillover documented within Belize MPAs is exported specifically to Jamaica for consumption.

Other studies have shown that export of fish biomass will not be noted within the first year of boundary identification, however mature MPAs should exhibit emigration (Coorless et al. 1997). One study in the Philippines reported reduced harvest rates for target species once an MPA was resolved, showing emigration was responsible for previous commercial harvests (Alcala and Russ 1990). Rakitin and Kramer's (1996) study in Barbados at a relatively equal MPA (depth 10m), determined that fish (target) concentrations were greater in the center of the MPA, whereas those fish closer to the edge appeared to be more inclined to travel outside the MPA. Additionally, those species which are not targeted for harvest should be equally spaced throughout the MPA (Rakitin and Kramer 1996). Applicable fish to this scenario would be those of little monetary value or small fish which are not harvested (i.e., blennies, gobies, etc). Bluefields design is rather long and narrow; those fish near the eastern edge (shoreline) to the middle of the MPA would be more applicable to Ratitin and Kramers "center". Those closer to the western edge where the deeper reefs are located would be those considered close to the boundary and more inclined to disperse.

Any recovery will take time, but we cannot say how long the process will take. Target species may take years to develop sustainable levels; however they can also be rapidly depleted (Russ and Alcala 1999). A study conducted in Kenyan MPAs revealed that recovery of herbivorous fish populations did not peak until a substantial time period elapsed, up to 37 years (McClanahan et al. 2007). Furthermore, depletion of piscivores should be measured in generation times when attempting to determine recovery of a community (Rice and Houston 2011; UNCOVER 2010). The ecosystem eventually should return to a state where environmental factors affect the area greater than anthropomorphic factors (Hilborn et al. 2003; Knowlton 2004; Levin and Lubchenco 2008). In Belize, McClanahan et al. (2011) determined that piscivore abundance increased within MPA boundaries compared to fished areas outside, with a relative steady state in herbivorous populations throughout the study area.

Bluefields Bay Artificial Reef Installation

Bluefield's Bay is located on the southwest coast of Jamaica. It was declared an MPA by the government in 2009. In order to improve the fishery recovery and the effectiveness of the the spillover effect, and artificial reef system was installed in summer 2011. The main purpose of the artificial reef project is to increase the productivity of the fish populations within the Bluefields Bay area. The fish populations within Jamaica are severely diminished and it is their hope to reestablish these populations so that local fishermen can provide for their families as most are subsistence living and relatively poor. According to marketing information for the project,"The [artificial reef] modules have been engineered to meet the specific ecological needs of fish and corals, to be easily installed with a minimum of logistics, and to provide a functional, aesthetically-pleasing marine ecological enhancement suitable for coastal developments, impact mitigation and resort/watersports use" (EcoReefs Inc. 2011).

Purpose and Objectives of this Research

The purpose of this study is to determine how the installation of artificial reef modules into Bluefields Bay alters the fish community over a 1.5 year study period. In its present condition, large predator fish are absent from the bay and artisanal fishermen are harvesting relatively small juvenile fish and those filling niches at the bottom of the food chain. Artificial reef implementation will provide vital structural habitat for food substrate and cover which is currently lacking in the bay, particularly in extensive sand and grass beds. While the overall goal of the sanctuary is to increase artisanal harvests surrounding the area to improve the livelihood of local communities, the artificial reefs are expected to act as the nucleus of recovery. The objectives of this study are to:

1) Perform a baseline population survey of fish species present in coral reef, grass bed, and sand bed habitats and compare results to fish surveys within the artificial reef complex.

2) Publish a comprehensive fish list will be produced for all species residing in the bay. Trophic structure within the bay will be assessed. Currently, little biological information has been collected for this ecosystem. Determination of fish abundance, richness and diversity are main factors which will be addressed; and

3) Provide information about Bluefields Bay fisheries to various Jamaican partners including the Bluefields Bay Fishermens Friendly Society (BBFFS), Bluefields People's Community Association (BPCA), wardens and administrative staff of Bluefields Bay, and, finally, the Jamaican Ministry of Fisheries Division. By providing this information management practices can be created and implemented to protect fish populations within the bay. This study was itself supported and implemented by multidisciplinary collaboration among the Departments of Biology, Geography, Geology, and Planning, and Sociology and Anthropology at Missouri State University.

BACKGROUND

The establishment of a marine protected area is a rather involved process. A MPA is defined by the IUCN as “A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values” (Dudley 2008; Laffoley 2008). The Bluefields Bay Fishermens Friendly Society petitioned the government for the Fisheries division to consider their bay. During the process of establishing the marine protected area, the government attempted to consult the local fishermen and those who use the area for various purposes. This is a more appreciable method of establishing an MPA as users opinions are heard and taken into account. Some countries like France have shown success when user opinions have been implemented in their decision making processes (Francour et al. 2005). Vanuatu successes can be attributed to governmental sponsors producing plays for villagers around the island to watch; support for closures were enacted by various chieftains immediately, and eventually these areas were termed MPAs (Bartlett et al. 2010). Other countries such as Chile used a different process where the government authorities and experts decided where to create their MPAs without consulting any locals and resulting conflicts occurred (Rojas-Nazar et al. 2011; Thiel et al. 2007). A number of studies worldwide have shown that user involvement is paramount in MPA success (Gelcich et al. 2005, 2008; Bartlett et al. 2010; Rojas-Nazar et al. 2011). If fishers can relate their own personal experiences to the fish populations within an area they may be more inclined to comply with regulations which are imposed on them (Sen and Nielsen, 1996). Some MPAs are established based on their lack of resources or present fishing conditions, which are easier to establish because of less political strain (Agardy et al. 2003; Ray 2004; Edgar et al. 2008).

Habitat mapping is an important aspect to consider when managers are designing MPA boundaries as well. However this information has not been compiled on Bluefields Bay region. High productivity areas are often considered more important than areas like sandbeds when boundaries are being created (Agardy 1995, 2000). It is unrealistic to incorporate all processes which occur in an ecosystem for all species when determining MPA boundaries (Rice and Houston 2011).

Ministry of Fisheries Division

Jamaica's Fisheries Division's role includes providing technical support, Protected Area Committee (PAC) membership, management of fish sanctuaries and input towards the Fishing Industry Act as defined by the United Nations Development Programme (UNDP) (UNDP 2010). They are also responsible for providing guidance to MPA managers, determining fishing activities, creating replenishment zones, sustainable management of the shared resources of the Caribbean Large Marine Ecosystem (CMLE) and the Pedro Banks and Cays Conservation Project (UNDP 2011). In 2009 the Jamaica Fisheries Division along with the Ministry of Agriculture declared eight marine sanctuaries. Memorandums of Understanding were established with local community groups such as Bluefields Bay Fishermen Friendly Society, which act as co-management entities (UNDP 2010).

UNDP has instituted a project titled "Strengthening the operational and financial sustainability of the national protected area system" and its goal is to consolidate the operational and financial sustainability of the National System of Protected Areas (UNDP

2010). Jamaica's National System of Protected Areas (NSPA) is a collection of all protected areas (PA) within Jamaica. A rating system otherwise known as METT, was established in order to identify effectiveness of PA management and is scored as High (75-100), Medium (55-74), Low (<55)/ (UNDP 2010). Data from 2009 shows that the average METT scores for all protected areas within Jamaica's NSPA was 38.375(UNDP 2010). Bluefields Bay Fish Sanctuary itself had a METT score of 33 as of December 2009 and the target goal is to increase it by 25% to 41 by the end of the project (UNDP 2010).

UNDP (2010) has determined that the Fisheries Division intends to develop conservation goals and management objectives for each site; however, not much evidence has been established thus far. Polunin (1999) has also identified a lack of interpretation of political and social issues pertaining to MPA development within Jamaica as most fishermen are dependent on harvests. They further conclude that the eventual result will be inadequate conservation measures followed by the continued decline of Jamaica's resources if corrections are not made (UNDP 2010). Additionally, Sary et al. (1997) identified that the trap fishery nationwide is unregulated, although great strides to alter fisher perceptions of small wire traps is practiced at least in Discovery Bay where results have provided firsthand knowledge to fishers and their success in conversion of materials used. Basically, the fishermen have personal experience catching fish of larger size because of the increase in mesh size of the traps. Even global leaders in MPA development, the Belize Fisheries Division, demonstrate these same concerns with lack of funding and human resources (McField 2000; Cho 2005). Goreau et al. (1997) discussed that the long term sustainability of Jamaican MPAs will require national funding in addition to tourism based revenue.

A declining faith in governmental agencies has been noted in Jamaica (Goreau et al. 1997; Haley and Clayton 2003) with views geared more towards "community" based governance (Carrier 2012). The issue lies in the fact that the government is not able to fund conservation initiatives and thus rely on other organizations that provide tourism based attractions (Christie and White 1997; Carrier 2001; Haley and Clayton 2003; Carrier 2012). Furthermore, community involvement in MPA initiatives and activities has increased the lack of faith by local fishermen in government assistance (McNeely 1994; Carrier 2012).

Bluefields Bay Fishermens Friendly Society

The Bluefields Bay Fishermens Friendly Society is a Non-Governmental Organization (NGO) which was established as a Friendly Society in Jamaica on 02/25/2006 under the Friendly Society Act of 1966. According to Wolde Kristos, Bluefields Bay Fishermen's Friendly Society acting chairman, the Society seeks to educate its members in sustainable fishing practices and provide alternatives that will enhance the quality of life and preserve Bluefields' natural environment (personal communication 2011).

The organization has a number of objectives, including creating a sustainable environment through educational outreach by representing Westmoreland's Environmental Display at Denbigh, as well as the Bluefields Bay Marine Conference held at Sandals Whitehouse, and the Bluefields Bay Marine Festival at the Belmont Fishing Beach. Additionally, the Society aims to create sustainable livelihoods for fishermen through a cold storage project, a Fisher's and Farmer's Gear Store and Craft and Vegetable Market, Food for the Poor boat project, providing assistance after natural disasters, and lastly educational training for fishermen including: business, entrepreneurial, seamanship, game warden training, fish handling practices, first aid, and environmental sensitivity (Fishermen's Friendly Society 2011).

According to UNDP only a single NGO has developed and implemented a management plan as of 2010, although the exact PA was not specified. Bluefields Bay management plan was created by the BBFFS in cooperation with Matthew Colvin from United States Peace Corps, Jamaica. An exact date is not noted on the document. Additionally implementation of management goals are still being executed (Wolde 2012). Montego Bay Marine Park and Negril had management plans enacted in 1998 (Carrier 2001; Garaway and Esteban 2002). Implementation of those goals may be lacking and excluded from UNDP's assessment. In order to be termed an IUCN categorized PA, management objectives have to be matched with IUCN protocols and be in place in order for a categorization to be awarded (Dudley 2008).

In addition, BBFFS has procured a permit at the cost of $10,000 JMD ($113.18 US) from NEPA as of March 31, 2010 to install marine buoys to mark the boundaries of the sanctuary (Kristos 2012). This permit has been reinstated every March 31st until the project's completion. A number of buoy anchors were installed by Jamaica Fisheries. However, the majority of the anchors were incorrectly placed. As of January 2011, only six buoys were installed, five of which were not properly placed. The following May, all buoys were removed due to fishermen non-compliance. The wire used to attach the buoys to the anchors was too thin allowing for cutting. BBFFS requested assistance from Missouri State University in determining the proper location for all buoy sites. Forty GPS locations were marked for the sanctuary staff using painted cinder blocks and a Trimble GPS device, allowing very accurate positioning of the boundary line. Blocks were installed on the bottom by a free diver up to 9.2m deep, and deeper sites were completed by a scuba diver (personal observation). As of June 2012, buoy anchors were being corrected and installed in the proper positions as dictated by the marking efforts performed in May (personal communication).

Cho (2005) has identified that, in comparable MPAs in Belize, staffs are often unable to enforce legislation but depend on the understanding and awareness of users. Currently in Bluefields Bay, non-compliance as defined by Garaway and Esteban (2003), specifically illegal fishing within the area and cutting of buoys, is still a problem faced by MPA managers and wardens. Through increased educational outreach and modification of buoy lines to metal wire, the BBFFS hopes to curtail the undermining of management objectives within the MPA.

Artificial Reef Site Selection

The exact site of the artificial reef installation is N18°10’18.4” W078°02’34.0”. This site was selected due to the number of juvenile fish within the vicinity as well as the depth of the water column (Haley 2011). At 7.92 meters or 26 feet deep, it is the deepest section of the marine sanctuary (Haley 2011). Montego Bay, Jamaica was also selected as a site for the same construction. The modules were placed where sand patches are of sufficient size for the installation, as the National Environment and Planning Agency (NEPA) will not allow EcoReefs, Inc. to actually place the modules on the seagrass itself. Another element taken into consideration was the proximity of good (by Jamaican standards) natural reefs nearby to act as a source for biological life (Haley 2011). Artificial reef creation is also consistent with IUCN category IV objectives for active management strategies (Dudley 2008).

Artificial Reef Module Design and Construction

"Each assembled module weighs 25 kg, and is approximately 1m across x 50cm high. Each module has 30 branches, two settling plates (each with three transplant wells) and a central anchor hole. Additional module types can be manufactured upon request to meet specific needs" (EcoReefs Inc. 2011).

The units are composed of ceramic, which is pH neutral, semi-porous, and considered a better recruitment material than concrete (Haley 2011). It also provides the highest degree of rugosity, as it resembles staghorn coral (*Acropora cervicornis)*. According to EcoReefs, concrete is not a very effective artificial reef material, and depending on the additives that are used, concrete can often end up with alkaline microlayers next to the surface of the structures that inhibit growth and settlement of corals. "EcoReefs modules have patented features to help facilitate the successful settlement of microscopic coral larvae, including shaded settling plates raised off of the bottom for protection, fluted surfaces to generate turbulence, and a microporous surface texture for improved coral adhesion" (EcoReefs Inc. 2011).

Artificial Reef Module Implementation

Three hundred and fifty EcoReefs' modules were placed in a sand bed area by scuba divers, in a large ovoid shape, not stacked, and anchored with a small piece of rebar in July 2011 (Haley 2011). The modules were pre-constructed on the shore and placed in boats. The boat then ferried the modules out to the placement site. They are then lowered in the water until they reach the bottom substrate. At that point the scuba diver uses an underwater jack to place a piece of rebar through the middle of the module. The jack compresses the rebar deep into the sand. A small portion of rebar is left above the module. Once they are positioned at the proper height from the sand bed the next module is then placed in conjunction with the previous units. Due to the branching pattern of the modules, they are able to overlap by interlacing the artificial branches. "When installed in large, close-packed arrays of hundreds to thousands of modules, the turbulence generated by the module branches slows water flow over the site, stabilizing sediment and creating conditions conducive to rapid coral reef establishment" (EcoReefs Inc.).

Artificial Reef Module Functionality

The artificial reefs target reef species, not mid-water pelagics. However, under ideal conditions, multiple species reside within the reef modules, while others feed on or around the modules and others may dive down into the modules when threatened. Also schooling fish should aggregate around fixed structures (Haley 2011). A number of pelagic species were noted in the initial survey of the sanctuary. Including albacore tuna (*Thunnus alalunga*), juvenile greater amberjack (*Seriola rivoliana*), blue runner (*Caranx crysos*) and the most numerous pelagic species noted in the sanctuary was the bar jack (*Caranx ruber*). Being pelagic, these species will traverse the area momentarily as they are passing from one area to another.

A primary goal of module placement is to attract commercially important fish species such as snapper or groupers. On the initial survey of the sanctuary five species of snapper, five grunt species, and two grouper species were noted. However, these populations are threatened by fishermen on a daily basis. The two grouper species noted were the rock hind (*Epinephelus adscensionis*) and the coney (*Epinephelus fulvus*), both of which are small members of the genus. No large groupers were noted during our initial or secondary surveys. However a large red grouper (*Epinephelus morio)* was harvested just outside of the sanctuary boundaries following the second collection trip. Exact size of the fish was not quantified by the fisher, however photographic evidence was presented (Kristos 2012). The artificial reef was constructed with hopes to recruit larger grouper species by providing vital habitat to allow for production of the prey species. However, the modules were not created to provide adequate overhead protection. Groupers typically prefer large crevices which they can ambush prey and hide from predators. With enough prey species within the vicinity, groupers may move into the area for food purposes. Both piscivorous fish and their subsequent prey may be migratory or pelagic, however different aspects of their life cycles can be portrayed in different habitats (Halpern and Warner 2003; Rice and Houston 2011; Di Franco et al. 2012). Dispersal scales can be different for larval fish of various species, for example Di Franco et al. (2012) found that white seabream (*Diplodus sargus sargus*) had a maximum dispersal rate of 200 km. However Palumbi (2004) has noted that dispersal rates are difficult to quantify or establish and information is thus lacking.

One aspect that must be taken into account is that most grouper species tend to breed in large spawning aggregations. Some shark species have been documented to aggregate for various reasons as well (Weber and Fordham 1997; Heyman et al. 2001). Sharks are predisposed to overfishing as they mature late, have a low reproduction rate, and slower growth rates compared to other fish species (Hoenig and Gruber 1990; Bonfil 1994; Smith et al. 1998; Musick et al. 2000; Frisk et al. 2001). The aggregations will need to be protected from harvesting to increase the viability of the offspring. Mitcheson et al. (2008) noted that almost all groupers proposed for listing as threatened on the World Conservation Union (IUCN) Red List, form spawning aggregations. Spawning aggregations of Lutjanidae and Serranidae occur in deeper water typically in reef passes, channels, and outer reef-slope drop offs (Mitcheson 2008). Favorable conditions are present just outside the sanctuary on the western border. Under ideal conditions the offspring would be recruited and protected within the bay. Currently we cannot predict exactly were spawning aggregations would occur, but deeper water to the west would provide proper conditions where these activities are typically noted. Munro et al. (1973) recorded spawning aggregations of *Epinephelus guttatus* and *Epinephelus striatus* within Jamaican waters (Port Royal and offshore banks) typically from February to April.

Education programs are currently being implemented within the Bluefields community about the importance of the MPA, however harvesting of large predators like groupers and sharks is not. Anderson and Waheed (1999) showed that sharks are more of an incentive for locals which can be supported by tourism, bringing in about $3300 US per year compared to the value fishermen can produce by harvesting the animal, which is around $32 US. The belief in harvesting larger predatory fish in order to increase numbers of prey species should be dispelled as predators play an integral role in the marine ecosystem (Jennings and Kaiser, 1998). Also, Bohnsack (1982) showed that populations of larger species of piscivores can be greatly diminished from spearfishing activities which subsequently alters reef fish community structure.

A number of marine reserves in the Caribbean were surveyed and it was determined that only ten percent of marine reserves explicitly consider spawning-aggregation management in their management strategies (Appeldoorn & Lindeman 2003). Mitcheson et al. (2008) noted that these spawning aggregations are not seen as natural events in need of management, but are viewed as opportunities for efficiently catching large numbers of fish. From our experiences and observations of fishermen and their harvest techniques, this scenario would be confirmed in Jamaica. Colin et al. (1987) recorded a spawning event of *Epinephelus guttatus* off southwestern Puerto Rico. They determined that Jamaica along with a number of other countries can be recruited by larvae (Colin et al. 1987). The Jamaican Fisheries Division will have to take into account how the various species reproduce and adjust their policies accordingly in order to protect these vital aggregations. Different approaches to managing transient and resident aggregations may be needed (Domeier & Colin 1997). Mitcheson et al. noted that species whom display transient aggregations, should at least receive seasonal protection; whereas species which are display residential aggregations or multispecies spawning sites should receive protection year round (2008). If the spawning aggregations occur within the limits of the sanctuary boundaries, they will already be protected. However if the aggregations were to occur outside the boundary lines, a management plan would need to be created to protect them efficiently.

EcoReefs Inc. indicates that "the modules create a dense, naturalistic reef thicket with abundant, dimensionally complex space for herbivorous fish and juvenile fish. Small reef fish living in EcoReefs installations naturally keep algae and soft coral overgrowth under control, creating favorable conditions for rapid coral colonization."(2011). Artificial structures have been shown to contain diverse communities of invertebrates and algae (Connell and Glasby 1999; Glasby and Connell 1999; Glasby et al. 2007). McKinley et al. (2011) suggests that due to increases in invertebrate food webs a subsequent increase in abundances of recreational fish species will be observed.

Another issue which is highly debated at this time is whether artificial reefs act to increase fish populations (enhancement) or simply act as attraction devices for fish already in the area (attraction) (Bohnsack 1989; Grossman et al. 1997; Lindberg 1997;

Powers et al. 2003). In other words, the debate is whether artificial reefs contribute to the new production of fish versus the concentration of fish already present within the area (Bohnsack et al. 1994). Powers et al. (2003) suggests that a number of aspects need to be taken into consideration in this debate; firstly, one must consider whether the recruitment of the species is limited by naturally occurring habitat. It is important to determine if the natural habitat within the region has the ability to sustain fish populations. Carr et al. (1997) specified the significance of comparing artificial reefs to natural reefs and determined that natural reefs typically accumulate more fish; both in the number of individuals and species richness. Overall, Carr and Hixon (1997) determined that greater vertical relief and shelter availability of the artificial reefs did not compensate for greater structural complexity and natural forage areas which the coral covered natural reefs allowed. Secondly, Peterson et al. (2003) described a process where the addition of habitat may provide protection to prey species and thus increase production (e.g. Hixon 1998). However, on the opposing spectrum, Grorud-Colvert (2006) found that larval supply or recruitment did not differ between multiple areas within the Florida Keys which were of different protection levels.

As Bluefields Bay Marine Sanctuary is on the southwest shelf of Jamaica, another set of scenarios can be employed to weigh the significance of this debate. Four scenarios were established and described by Powers et al. (2003). The first scenario relates fish population abundances being directly and specifically attributed to the artificial reef (Grossman et al. 1997). The second scenario suggests that the addition of the artificial reef will increase fish production by enhancing recruitment into an area which is currently limited by reef refuges size and associated prey resources within the area (Peterson et al. 2003). The third scenario takes into account that the addition of an artificial reef onto a shallow continental shelf enhances fish recruitment and possibly growth; however the mortality is increased due to the fishermen targeting the new concentrations of fish (Polovina 1991; Friedlander et al. 1994; McGlennon and Branden 1994). The fourth and final scenario includes the increase in the mortality rate with the attraction to the artificial reef (Powers et al. 2003).

A number of factors were suggested to affect the ability of recruitment as well, including spatial size of the management area and the distribution of natural reef resources within the protected area (Carr et al. 1997). In Jamaica the severe overfishing may limit the number of recruits which are available to seed the newly constructed artificial reef. Sala et al. (2001) determined that certain marine fish groups such as groupers, which are overfished on continental shelves, have a high probability of limiting fish populations due to low levels of available recruits. A number of authors have noted that the recovery of overfished stocks of recruitment limited fish located on a shallow continental shelf, such as what is present on the southwest coast of Jamaica, does not require construction of new reefs, but of proper management of existing marine resources (Lubchenco et al. 2003; Powers et al. 2003).

A number of fishermen were observed as they spearfished for various grunt and parrotfish species outside the boundaries of the sanctuary. The fishermen aimed their spears at a school of fish and fired, typically harvesting or injuring more than one fish per shot (Personal observation 2011). Harvest data for the Bluefields Bay are lacking. Artisanal fisheries are also supported by a small commercial conch fishery and a lobster fishery. Unfortunately the Jamaican government has not implemented any control measures for the harvesting of marine fish to limit numbers harvested per person per day, or species length restrictions. It would be difficult for the Fisheries Division of the

Ministry of Agriculture to enforce these regulations if they were implemented. Such is the case for the Caribbean spiny lobster, *Panulirus argus*. The lobster season is closed during the periods of 1 April until 30 June of each year. However, a number of fishermen continue to harvest lobster on a daily basis from Jamaican waters. For instance, while on patrol with a Bluefields Bay Warden, on two separate occasions boats were searched and lobsters were discovered to be in possession out of season, and they were incredibly small in size. Although they were not measured, the carapace length was less than three inches (Personal observation 2011).

One case was pursued and the man was fined, but this was only possible because he was fishing specifically within the sanctuary limits and the wardens were provided jurisdiction by the government to detain the individual. He was also in possession of conch, and was fined a total of twelve dollars (US). Another poacher was caught within the sanctuary on July 2, 2012 and was fined a total of JA 400.00 (4.76 US); however, more importantly, his nets were confiscated, which is a larger penalty for the fishermen as he is dependent on them for food (Kristos 2012).

The difficulty is that the wardens only have the ability to penalize violations which occur within the boundaries of the sanctuary. Fishermen still have the ability to harvest lobster outside of the boundaries even though the season is closed. Richards (2002) has identified “serious loopholes” when prosecution of individuals is concerned, citing lack in understanding by Magistrates and lack of new legislation current with MPA guidelines. Bluefields local magistrate preferred to fine the man more for his actions but under the current law was only able to enforce the current highest limit allowed by law (Kristos 2011).

There are usually two different types of boats which the fishermen use. The most basic being a dugout canoe, made from local tree species. They hold two fishermen each and are man-powered using oars. The fishermen who use these are typically older individuals who are attempting to maintain traditional fishing methods. These canoes do not have the ability to travel long distances or during inclement weather situations. So they must fish within a certain limit of the shoreline to be safe. This presents a problem, as all of the fish have been harvested close to shore. Interviews with local fishermen (personal communication) have noted that they must travel further and for a longer period of time in order to catch the same number or mass of fish as they previously did. The other style of boat is also a canoe, with outboard engines on the rear. These boats have the ability to travel further offshore and for a longer period of time. During the period of our initial survey of the sanctuary, fishermen utilizing this method of transportation brought in a catch of albacore tuna (*Thunnus alalunga*) upwards of 350 pounds. However, the largest fish measured was noted to be only 27 cm in length (personal observation). Local fishermen reported that harvests like these are seasonal and rare (personal communication). During the third data collection in the spring of 2012, a year from the initial observed tuna landings, fishermen reported that the tuna moved through the local area for a week and a half with very low harvest rates reported (personal communication).

Importance of Seagrass beds

The majority of Bluefields Bay Marine Sanctuary is comprised of sea grass beds. Two species dominate the grass flats including Turtle Grass (*Thalassia testudinum*) and Manatee Grass (*Syringodium filiforme*). The scope of this thesis was not to address the seagrass structure or quality of the beds but to address the fish assemblages which might be using the habitat within Bluefields Bay. Seagrasses have been hypothesized to provide feeding grounds for various species of fish, specifically those which are nocturnally active (Ogden and Zieman 1977; Orth et al. 1984; Nagelkerken et al. 2000). Seagrass beds have been documented to be used for refuge purposes during the day by juvenile and sub-adult grunts (*Haemulidae*) and snappers (*Lutjanidae*) (Verweij et al. 2005, 2006). The French grunt (*H. flavolineatum)* was shown specifically by watching behavioral characteristics to use the seagrass primarily for feeding purposes (Verweij et al. 2005).

Fishing in Jamaica

A number of fishing methods are used in Jamaican waters. Most notable are the fish traps. Other methods include spear fishing, hand lining, gill nets and reportedly even dynamite. Fish traps, also known as fish pots, are abundant and effective. The traps can be left at sea when the fishermen cannot. This allows fish to be effectively caught around the clock. This also leads to a method of fishing known as "ghost fishing", where these pots continue to catch fish when lost at sea. The downside to this method is that the fishermen use woven wire also known as "chicken wire" in the construction of the traps. Due to the small diameter of the wire, they are increasing the number of juvenile fish which are caught (Sary 1997). Community structure of fish populations can be altered depending on the gear and methods used by fishers (FAO and DANIDA 1999; Stevens et al. 2000). The Ministry has attempted to regulate this method by increasing the diameter of the wire used in the construction of the traps. A mesh exchange program was implemented in Discovery Bay by the University of the West Indies under their Fisheries Improvement Programme (FIP) in order to eliminate smaller mesh sized pots (Sary et al.

1992; 1997). However, the fishermen debate that it is their livelihood and that it is more effective to use the smaller wire even though studies have been published showing increases in biomass from larger diameter fish traps (Sary et al. 1992; 1997). This struggle highlights the conditions which need to be addressed and corrected if the fishery is to become viable once again.

Dynamite fishing is reportedly still an issue within Jamaican waters as well, however documentation of events is lacking. Only construction workers have access to the material. The companies must report how many sticks of dynamite they use, however the amount reported and the amount actually used vary. Once the dynamite is procured it is then traded to fishermen in the hopes that they will provide food in return. The effects are widespread. Not only are fish killed due to the rupturing of their swim bladders, but the coral and reef structure are degraded in the process (McManus et al. 1997; Cornish et al. 1998). Although an event was not observed, a majority of the members in the community knew about the practice or that was still being employed in Jamaican waters. The spearfishermen were the most consistent individuals to report such occurrences as they could hear the blasts underwater from long distances away. Goreau (1992b) reported blast fishing occurring between Savanna la Mar and Bluff Point to the Northwest; however documentation of these specific events is absent or unavailable.

STUDY AREA

Bluefields Bay Marine Sanctuary is a no-take Marine Protected Area on the southwest coast of Jamaica. The Jamaican government created the sanctuary on July 28, 2009, along with seven other sites around the country. It extends from Bluff Point (N18°12’ 12.23” W78°05’ 10.64”), southwards to Belmont, Westmoreland, Jamaica (N18°09’ 17.21” W78°01’ 57.57”).

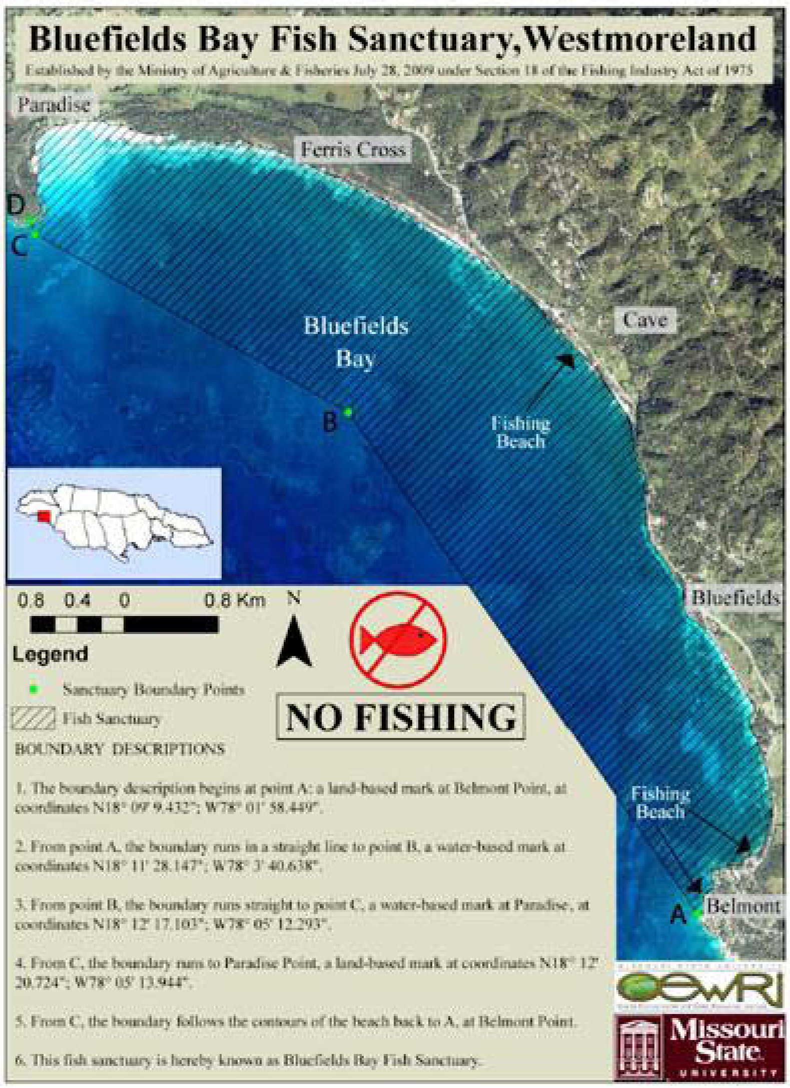

Figure 1: Geographic Information System (GIS) map of Bluefields Bay, Westmoreland, Jamaica. Map was created by OWERI staff in 2009.

The eastern boundary of the sanctuary is marked by land, which extends from the two points in a crescent shape. The western edge is open ocean and marked by forty buoys tethered to the sea floor. The area is composed mainly of sea grass beds, open sandy areas, and multiple patch reefs, a larger reef section is in deeper water just outside the boundaries of the sanctuary. Primary currents within Bluefields Bay are from the southeast (Goreau 1992a; Haley 2011). Jamaica lies in the path of the northwesterly trade winds, and calmer ocean currents are noted between the periods of October and February (Munro 1983, Aiken 1993, Aiken and Kong 2000).

Bluefields Bay Marine Sanctuary is 1359.4 hectares in size; only Galeon Harbour Fish Sanctuary located in the parish of St. Catherine is larger with 1668.9 ha of protected habitat (UNDP 2010). Bluefields Bay Marine Sanctuary is denoted as an IUCN Category IV Protected Area (UNDP 2010). The categorization designates that the area is a "Habitat/Species management area which is managed mainly for conservation through management intervention" (Dudley 2008; Laffoley 2008; UNDP 2010; Lausche 2011). Although it has been noted that not all MPAs will fit into clearly defined categories (Dudley 2008), Bluefields Bay was associated to category IV as the management objectives are similar. Dudley (2008) defines the objectives of category IV as being "protection of a particular species, protection of habitats, active management to maintain target species, active management of natural or semi natural ecosystems and active management of culturally defined ecosystems and help to restore flora and fauna species of international, national or local importance". Salm (2000) further substantiates a category IV PA to have both "Preservation of species and genetic diversity" and "Maintenance of environmental services" to be the primary management objectives. However, the goal for Bluefields Bay is to protect all fish species, not just a specific one.

The severe overfishing has reduced all target species nationwide. Protection is aimed towards multiple habitats within the bays ecosystem and is important not only to the locals, but the nation as well.

Bluefields Bay being rather large for Jamaican MPAs (1359.4 ha), consists of a variety of different habitats including sandbeds, seagrass flats, mangroves, patch reefs, and larger reef structures. This area was determined to be an important area as many different aspects of the fish life cycle can be completed when different habitat units are accessible (Rice and Houston 2011). Many studies have shown that estuaries and bays are important areas for larval fish (Johnson et al. 1999; Beck et al. 2001). Whitman and Dayton (2001) showed that shallow benthic communities allow for most life cycle stages of a large number of benthic species as well as a number of pelagic species. Theil et al. (2007) concurred by determining that shallow benthic communities allowed for complete life cycle processes within sub-tidal areas. Mangroves provide vital habitat as well and have been shown to increase biomass of Caribbean reef fish communities (Mumby et al 2004). Bluefields Bay is rather shallow, with the deepest portion 7.9m deep at high tide. This study did not address all aspects of the ecosystem or trophic levels. Phytoplankton communities, zooplankton, and productivity within the benthos and the water column, other than that provided by fish were not studied. These aspects are valuable keys to the puzzle when determining nutrient regeneration, transport processes, and migratory patterns in the selection of MPA boundaries (Ji et al. 2008; Frid 2011; Rice and Houston 2011).

Bluefields has a nine freshwater inputs which may carry fluvial sediments, although none are relatively significant to alter the water chemistry throughout the bay (Ebert 2010). However an alluvial fan can be noted during rain events at some sites.

Water clarity is superb during both the rainy and dry seasons as bottom structures can be identified from the boat suggesting the bay is relatively oligotrophic (Goreau 1992). During the rainy season the water becomes turbid after rain events as expected, but it could be attributed to various factors including fluvial sediments washing down the mountainside and into the bay, currents producing chop thereby disturbing the consistency of the bottom sedimentation, or nearshore wave action. Increased sedimentation has been shown to inhibit reef development although some species can withstand the conditions (Mallela et al. 2004).

Bottom morphometry is rather flat for the majority of the bay, such as the sandbed and seagrass areas. Areas of reef are considered bathymetrically extensive as structure is present and some vertical relief is present. Different areas of the bay contain different reef structures. In the southeast corner of the bay just west of the Bluefields River input, a patch reef was noted, where as a larger fringing reef is located on the slope of the western edge boundary. However, coral communities within the bay have been altered by hurricanes resulting in the loss of Acropora, pillar corals and staghorn (Hughes 1994; Kristos 2011). Decreases in structural complexity of corals have been noted Caribbean wide (Hughes 1994; Gardner et al. 2003; Alavez-Filip et al. 2009; Schutte et al. 2010). Hurricane Allen was a 1980 Category 5 hurricane causing extensive damage to shallow reef areas and subsequent movement of large coral pieces by wave action damaged inner reef areas containing large concentrations of *Zoanthus* (Hughes 1994). Knowlton et al. (1981, 1990) determined that Acropora fragments had poor survival as well as poor recruitment after the hurricane. However, roughly ten to twelve Acropora colonies were discovered during the third data collection within the sanctuary. Certain events, such as hurricanes or storms, can cause destruction of the seagrass beds within the bay also. During these events weed lines will form parallel to the shore as they are moving inward.

Anthropomorphic alterations to the area include construction, agriculture, ranching and fishing. Historically the land adjacent to the bay was used extensively for agriculture and native trees were cleared (Wedenoja 2012). Sugar cane was the primary product of the area. Since then, trees and other foliage have been reestablished, with small scale subsistence agriculture still implemented. However, not all foliage may be considered native (Kristos 2011). Ranching of goats is present within a hundred yards of the shoreline in the southeast corner of the MPA. No other livestock has been noted surrounding Bluefields Bay (personal observations).

SURVEY LOCATIONS

A number of natural reef structures were surveyed to provide numerous controls to the artificial reef. The initial sand bed in which the artificial reef was placed was surveyed before the installation occurred. An adjacent sand bed located twenty one meters away was surveyed to compare a natural sand bed habitat. This replicates conditions which were previously present before the artificial reef was implemented. Eight natural reef sections inside the sanctuary were surveyed as well as a natural reef outside of the sanctuary. They include Control Reef, North Reef, Near Reef, Edge Reef, Moor Reef, Anchor Reef, River Reef, Fisherman's Reef, and Ball Reef (Fig. 2).

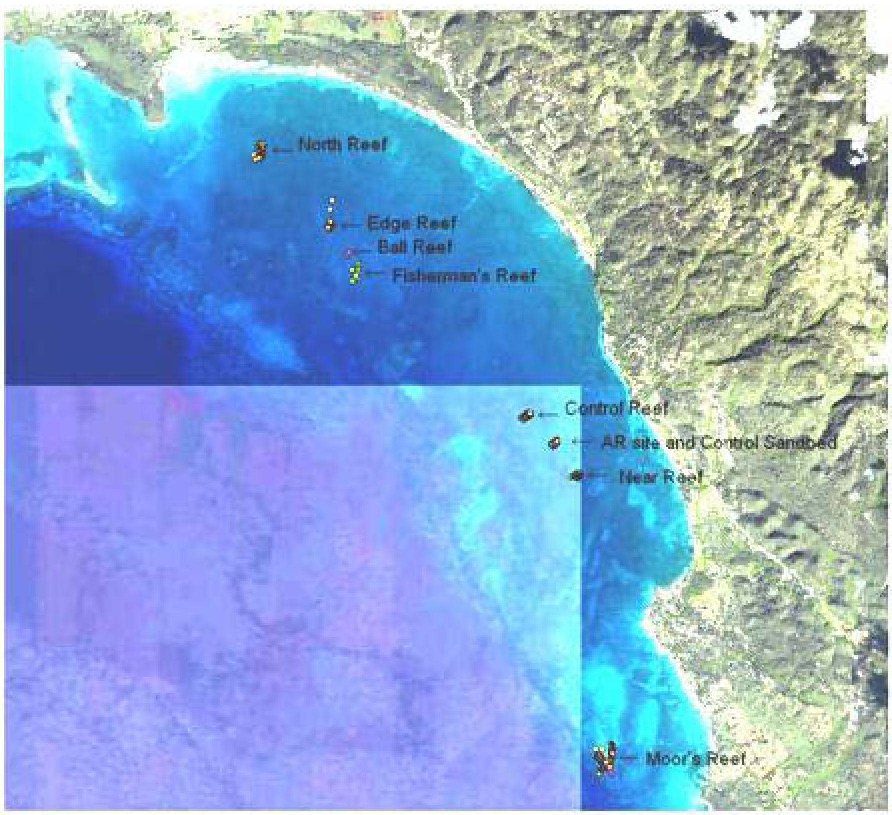

Figure 2: Survey location sites throughout Bluefields Bay, Jamaica.

Twenty of the closest reefs were determined using ArcGIS. The distances ranged from 0.33km to 4.90km from the artificial reef site. Eight sites were chosen at random, four were later disregarded as not being applicable to the parameters of the study and will be discussed shortly, those being Anchor Reef, River Reef, Fisherman's Reef, and Ball Reef. The areas were chosen in order to provide natural habitat to compare with the artificial reef. Carr and Hixon (1997) recognized and advocated for the importance of comparing natural reef structures to artificial reefs. Three aspects were identified as being important in these comparisons, those being size of the reef, age and isolation (Carr and Hixon 1997). To properly address these issues a number of natural reef structures were surveyed. Most reefs were of comparable size to that of the artificial reef sandbed although some ranged larger or smaller. These reefs were identified using ArcGIS and were ground-truthed before surveying was initiated. Moor Reef is the only reef located outside of the sanctuary boundaries. Sizes ranged from the smallest: Ball Reef at 1553m^2 to the largest; North Reef at 10,764 m^2. Distances from the artificial reef to other surveyed locations ranged from Near Reef at 0.33km to North Reef at 4.90km which is an important aspect to address as larval recruitment may play a large role in ecological patterns when comparing population dynamics (Carr and Hixon 1997). Survey sites will be discussed in order of introduction.

Artificial Reef Sandbed

The middle point of the sandbed is located at 18°10'18.947"N 78°2'33.518"W. The total estimated area of the sandbed was 1609 m^2. The sandbed is relatively ovoid in shape and runs southwest to northeast at an angle of 48.384 degrees. Directionality was determined using the COGO report function in ArcGIS 9.3.1. The artificial reef was installed in the southwest corner of the sandbed. The midpoint of the artificial reef is located at 18°10'18.248"N 78°2'34.398"W (Fig. 3). However, the sandbed extends further and is surrounded by seagrass. This site was surveyed during all three data collection periods.

Figure 3: Depiction of GPS location representing center of the Artificial Reef, Bluefields Bay, Jamaica.

Control Sandbed

The Control Sandbed was located at 18°10'17.836"N 78°2'33.116"W (Fig. 4) just 21 meters southeast of the artificial reef sandbed. Bare sediments play an important role in exchanges of energy and according to Barrio-Frojan et al. (2009) should be considered just as valuable links in trophic chains as other areas. Tropical sedimentary habitats have been overshadowed by more complex habitats such as reefs, seagrasses and mangroves and thus data has not been properly collected to connect the different areas (Duarte and Cebrian 1996; Duarte 2000; Jackson et al. 2001; Kathiresan and Bingham 2001). Management objectives are usually tailored to support the more complex habitats which depress the overall biodiversity (Dayton et al. 2000; Halpern 2003; Roberts et al. 2003; Weinstein and Reed 2005).

The sandbed size was not quantified by divers; however GIS data determined the size to be 1160 m^2, which is comparable to the artificial reef sandbed. Orientation of this sandbed is 50.634 degrees, similar to the artificial reef sandbed. Directionality of sandbeds and reefs may be attributed to incurrent wave action during nearshore approach. Various aspects affect nearshore approach such as bathymetry, coastline morphology, and wave defraction/refraction (Pavlowsky 2012). Primary currents within the bay are driven by northeast Trade winds, which on the south coast of Jamaica; provide “east-northeasterly winds at an average speed of 34 kpm (18 knots)” (FAO 2008). A headland is located at 18°7’43.801”N 78°1’35.834”W, as a wave line approaches; the waves are wrapped around the headland changing the angle at which wave sets move toward the shore within the bay. Main currents continue towards Saav-la-maar further from shore in a southeast to northwest manner. Waves in the bay would then be altered by the bottom morphometry, reefs, etc., to their final endpoint at shore. Sandbed directionality (parallel to wave approach) could then be attributed to the angle at which the waves wrap around the point and progress to shore.

Differences of reefs structural and taxonomic compositions have been noted within Jamaica due to effects of various hurricanes and their frequencies (Woodley et al.

1981). Hurricanes have been shown to alter reef structure by enormous wave energies, causing large portions of reef to be dislodged and moved (Woodley et al. 1981). This movement can cause further damage to coral and other reef structure as well as scour the bottom. Spatial patterns dictate along with extent of damage how bottom morphology will be affected (Woodley et al. 1981). Additionally, Woodley et al. (1981) determined that Hurricane damage occurred as deep as 50m along the north shore of Jamaica. The specific effects of Hurricanes have not been addressed within Bluefields Bay. Directionality of sandbeds was determined using the COGO report function in ArcGIS 9.3.1. This site was also surveyed during all three data collection periods.

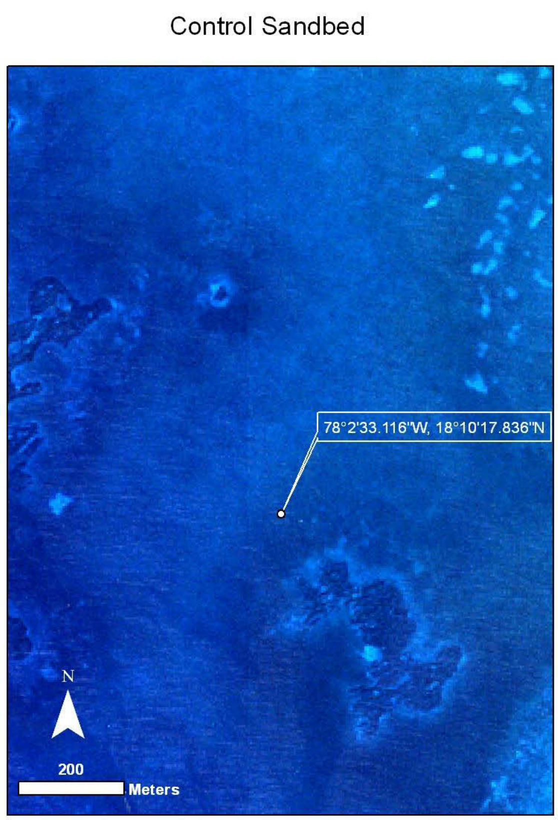

Figure 4: Depiction of GPS location representing center of the Control Sandbed, Bluefields Bay, Jamaica. Particular sandbed does not contrast well enough to visualize edges distinctly.

Control Reef

Located at 18°10'27.695"N 78°2'50.905"W (mid-point) is a larger sized reef with a unique layout (Fig. 5). The portion that was surveyed included the northeast section of the reef. Multiple sandbeds were located within the interior of the structure. From the boat the researchers did not understand the complexity of the reef until updated ArcGIS layers were purchased in July 2012. At the time of surveys the reef was understood to be relatively equal to the artificial reef site, because of disconnections in reef structure the reef section was not expected to be so large. It appeared much smaller. Connection between the various portions was hard to distinguish on the ocean due to the large number of sandbeds. Measurement was conducted with Polygon features of ArcGIS 9.3.1. with a final area of 60,439 meters, more than 37 times the size of the artificial reef. This reef was relatively close to the artificial reef site; at a distance of 0.42 km. This site was surveyed all three data collection periods and provides information on population and assemblages of fish species present within the natural environment. The reef is not near the boundary line and is within sight of the warden station. Fishing was not noted and may be deterred because of its location. No fishing pots or signs of anthropomorphic alterations were noted at this site during any survey period.

Control Reef

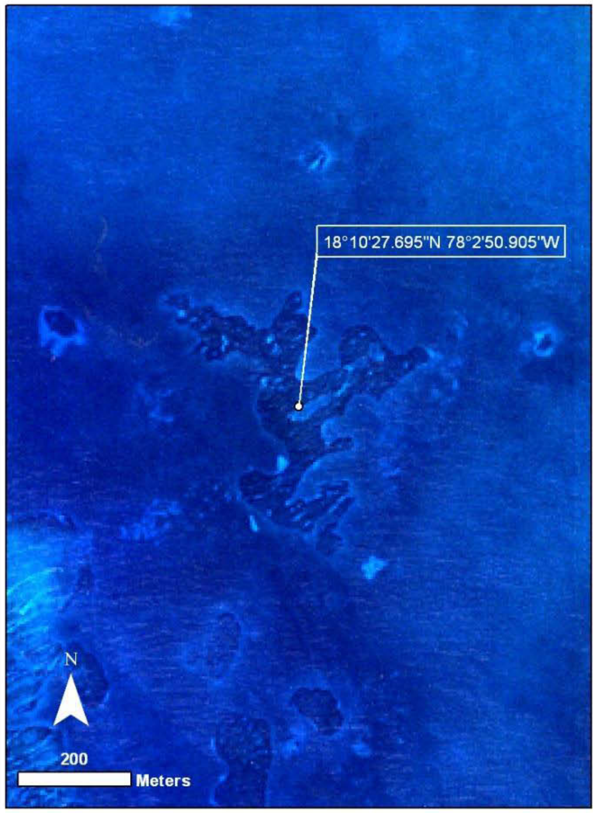

Figure 5: ArcGIS imagery of Control Reef, Bluefields Bay, Jamaica.

North Reef

The North Reef was located at the far north section of the sanctuary at 18°12'10.33"N 78°4'32.963"W (Fig. 6). Slightly northwest, it was close to the border of the sanctuary and fishermen still worked the area. A number of fish traps were located within the sanctuary during our initial surveys at this location, and during the third data collection period. The reef is 156 meters long by 69 meters at its widest point (10,764 m^2) and is the largest reef surveyed. A distinct sandbed ring defines the reef from the surface and it's attributed to be an "urchin halo" (Hay 1984). Urchins have been described to leave their protection within the reef at night and forage, returning to the safety of their crevices in the morning. Thus a ring is created around the reef as algae species are grazed profoundly. Coral is relatively healthy at this location however it is obvious that the site contained elkhorn coral prior to hurricane damage as large remnants lay strewn across the reef. No viable elkhorn colonies were observed by either video or snorkelers, although dead coral is providing substrate for other coral colonization during the first 2 data collection trips. During the third data collection trip in May 2012, one colony was discovered on the southeast corner of the reef. Although it was not measured, the colony was roughly 31 cm tall by 26 cm wide and 23 cm tall. Beyond the sand ring lies a vast bed of seagrass on all sides. The reef lies off the coast 946 meters from its northernmost point. The closest reef structure is 710 meters to the south according to GIS information, although ground-truthing of that specific reef was not accomplished. North Reef provides the largest (10 times larger) and farthest comparable reef. It also allows for comparisons to internal sites which are still subjected to fishermen influences

North Reef

Figure 6: ArcGIS imagery of "North Reef", Bluefields Bay, Jamaica.

Near Reef

Near Reef is a relatively large reef located southeast of the primary artificial reef site at 18°10'7.537"N 78°2'25.444"W. It is the closest reef structure to the artificial reef site. This reef displays the same characteristics as Control Reef. During data collections the reef was not expected to be as large as depicted on the imagery. It appeared to be of comparable size to the sandbeds. The south portion of the reef was examined as it was the only reef suspected of being present. A small sand ring was surrounding the edge of the reef. Past the sand ring sea grass beds were present on all sides. The seagrass noted at the time of collection may not be depicted on the imagery. Additionally, a small connection appears to be present within the imagery; however the quality of the image is not defined well enough to determine consistency of bottom morphology. The sand ring is also attributed to an urchin halo at this site as well. This reef was also within site of the warden station and far interior to the boundary. No anthropomorphic alterations or influences were noted at this location.

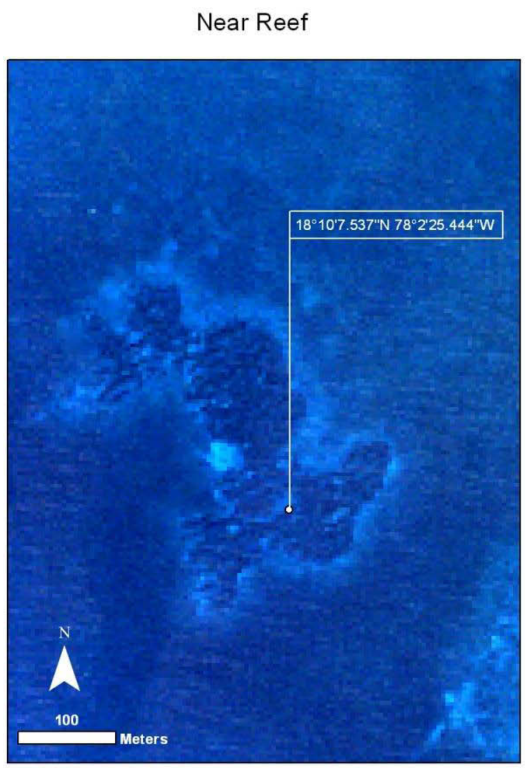

Figure 7: ArcGIS imagery of “Near Reef”, Bluefields Bay, Jamaica.

Edge Reef

Edge Reef is a comparable natural reef area located just inside the boundary line demarcated by the Jamaican government located at 18°11'41.998"N 78°4'4.718"W (Fig. 8). Although easy access could be obtained by fishermen as the reef is near the boundary and far from the view of wardens, the reef is also in deeper water. Most free divers prefer shallow depths to harvest fish as more time can be spent under the surface on one breath. This reef was located between 7.62m and 8.53m deep depending on the tide. Excellent comparisons can be made as reef size and depth are quite similar with an area of 2108 m^2. Edge Reef also maintains directionality from southwest to northeast as well, although a slightly smaller angle of 26.017 degrees, the shape is rather unique and not ovoid. The southwest portion of the reef is smaller and the northwest area of the reef expands resembling an inverted triangle. Edge Reef is located a distance of 3.68km from the artificial reef sandbed.

Edge Reef

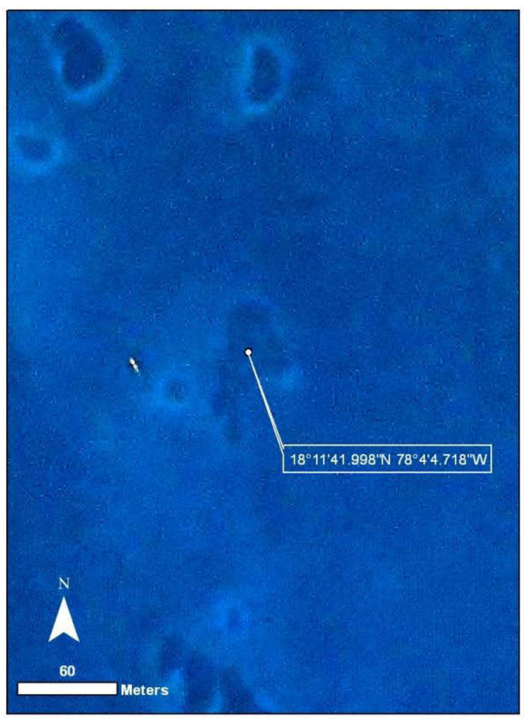

Figure 8: ArcGIS imagery of “Edge Reef”, Bluefields Bay, Jamaica.

Moor Reef (Outside Sanctuary)

Moor Reef, as the locals call it, is located south east of the sanctuary at 18°8'17.732"N 78°2'11.862"W (Fig. 9). The crest of the reef on the western edge takes enormous beatings from the prominent currents originating from the southeast and altered by the headland to the south. The main body of the incoming currents whips around the northern side of the reef. The eastern side of the reef contains large areas of broken coral and rubble from previous storms and hurricanes.

This site was primarily chosen and surveyed due to its location. Moors Reef is not protected under the provisions of the MPA. McKinley et al. (2011) noted that previous literature regarding MPAs have lacked external references when comparing fish assemblages. Thus Moors Reef allows for comparisons to external sites which are still subjected to fishermen influences. Multiple studies have shown that continued fishing activities can have major impacts on fish assemblages within a region and thus cause problems with conservation goals (Denny and Babcock 2004; Jennings et al. 1996; Samoilys et al. 2007). Long term studies would be ideal to delineate the differences between fish assemblages; however some alterations in assemblages are apparent from the study and will be discussed in detail later. A few studies have suggested that comparisons should be conducted within the same coastal system and nearby fishing zones whether commercial or recreational (Halpern 2003; Lester et al. 2009).

Within the Bluefields Bay area, no commercial fishing or recreational fishing is practiced. All fishers within the area are subsistence fishing, with few fishers selling small quantities on the road side when they harvest an abundance of fish. Other studies have detailed the impacts of human alterations of fish assemblages by comparing heavily modified, as in the case of almost all Jamaican waters, with unmodified areas (Agardy et al. 2003). Bluefields Bay was once modified as it has been overfished for a long period of time and continues to be disturbed in some form by users. However, the MPA could be characterized as a "less anthropogenically modified" environment as legislation is now in place to protect its resources including the fish assemblages (Micheli 1999; Islam and Tanaka 2004; Breitburg et al. 2009).

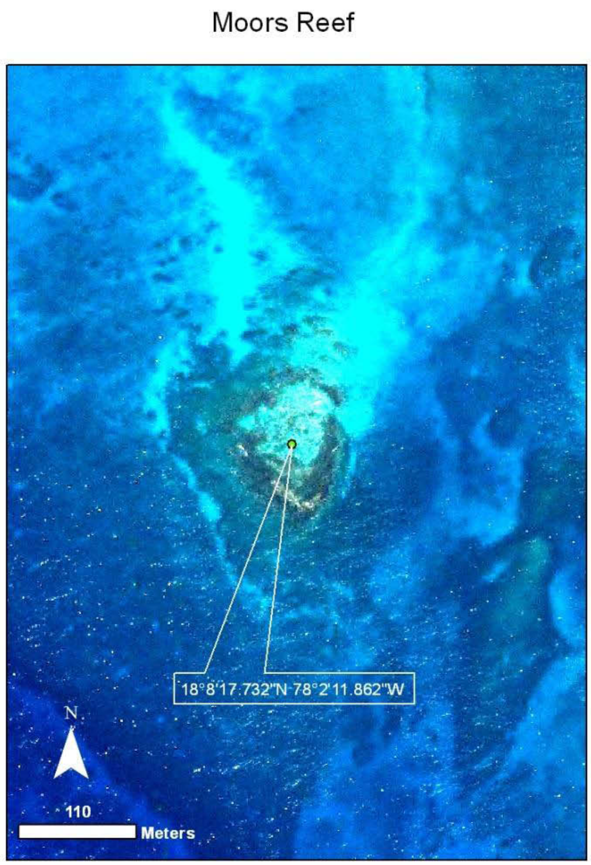

Figure 9: ArcGIS imagery of "Moor Reef", Bluefields Bay, Jamaica. Reef edge which is above sea level appears white as wave's crash on the structure.

Fisherman's Reef

Fisherman's Reef was another natural reef located within the boundaries of the sanctuary at 18°11'24.024"N 78°3'54.979"W (Fig.10). Fisherman's Reef was named because it is the site where fishermen were caught harvesting fish within MPA boundaries while on patrol with the wardens. Fisherman's Reef was sampled during the first data collection period but not following periods because the size was too great. The area of the reef was 32,774 m^2. Data was thus not included.

Fisherman's Reef

Figure 10: ArcGIS imagery of "Fisherman's Reef", Bluefields Bay, Jamaica. Reef sections to the south were not observed in conjunction with surveys at this site.

Ball Reef

Ball reef on the other hand was almost the same area as the sandbeds at 1529m^2. Located at 18°11'30.763"N 78°3'57.722"W (Fig. 11), Ball Reef is adjacent to Fisherman's Reef. This reef was not subjected to fishermen pressure as the larger reef was nearby. The shape of the reef was completely circular and had no directionality to it as most reefs in the bay. Additionally, although the depth was comparable, the habitat rugosity was very poor. Ball Reef was surveyed during the first data collection but not subsequent trips.

Ball Reef

Figure 11: ArcGIS imagery of “Ball Reef”, Bluefields Bay, Jamaica.

River Reef

River Reef was located in the mid-south region of the sanctuary where the Bluefields River empties into the bay (Fig. 12). This reef extends from the river mouth close to shore out into the middle of the sanctuary and is mostly comprised of patch reef and corals separated by sand. Patch reef communities have been shown to be un-uniform in fish community structure and more likely to be affected by larval recruitment, structural relief, and seasonality (McClanahan and Arthur 2001; Huntington et al. 2010). A number of videos were taken of this area. However due to the randomness of applicable structures found within the video, they were not included in the ANOVA analysis. A number of video point surveys were conducted with the assistance of snorkelers. Two locations were found which contained huge numbers of grunts, lionfish, wrasses, squirrelfish and parrotfish. These fish collection sites were primarily very large (~15 foot wide) dome shaped corals, which have been shown to resist increased sedimentation (Mallela et al. 2004), and would be confirmed by the location of sites in comparison to the freshwater input. The sites were also validated to be of greater structural complexity compared to surrounding sandbeds and sources of possible recruitment judging by the number of larval grunts which were present. Four large groupings of larval grunts were located at different locations on the same coral structure. Juveniles appeared to be separated by size classes and possible cohorts. Sizing of juveniles was not quantified as collections are not permitted within the MPA. These videos were limited by water column depth and the breathing ability of the diver, as well as possible bias to include specific areas or fish within the reef structure. These videos were not included in the data set either.

Anchor Reef

Anchor Reef was located on the southeast corner of the sanctuary. It was located deeper than River Reef, but extended from the same general location. The reef was named because of a large ship anchor found in between the patches of corals during an Archeological expedition conducted in June 2008 (Wedenoja 2012). The information compiled from this site was not directly applicable to this studies purpose and thus the information was also not included in the data set. Distance and area of reef were difficult to determine as the area was a collection of small patch reefs separated by sand.

River Reef

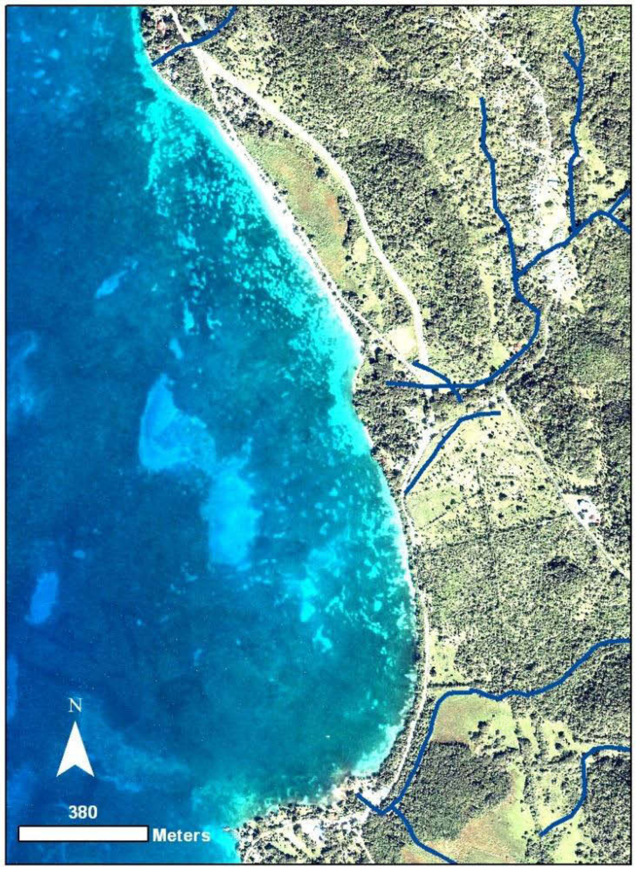

Figure 12: ArcGIS imagery of “River Reef” at the confluence of Bluefields River and Bluefields Bay.

FISH POPULATIONS

Powers et al. (2003) suggests that the first step in determining the estimation of levels of enhancement of fish production by construction or restoration of a habitat is to gather data on fish abundance in that habitat. Still photos were taken of most species that were present which allowed visual identification of the species to provide a baseline for future video transects. Additional photos were taken on subsequent trips to verify species located within the area to account for variations in seasonality. *Reef Fish Identification* by Paul Humann and Ned DeLoach (2002) was used to verify indentified fish. Due to the size (maximum radius of 21 cm; Guzman and Guevara 2002) and ease of identification, cushion sea stars (*Oreaster reticulates*) were noted along with the fish during video review.

Alterations of coral reef fish communities have been well documented to modify normal trophic cascades (Bohnsack 1982; Roberts 1995; Jackson 1997; Rogers and Beets 2001; Friedlander and DeMartini 2002). It has been well documented that the trophic cascades around Jamaica are in disarray (Munro 1983; Koslow et al. 1988; Hughes 1994). MPAs have been shown to increase the average trophic level of an area with subsequent increases in abundances of harvested species in nearby waters (Evans and Russ 2004). It is well known that both commercial and recreational fishers target larger fish species which are typically apex predators or those higher in the food chain (Pauly et al. 1998; Essington et al. 2006; McKinley et al. 2011). Greater numbers of larger fish species have been attributed to increased productivity (Ryther 1969; Pauly and Christensen 1995; McKinely 2011) and ecosystem health (Munawar et al. 1989). For example, the triggerfish *Balistes vetula* has been shown to be an influential predator of sea urchins within the Caribbean and they are highly susceptible to spearfishing and trapping activities (Roberts 1995). By protecting the area, it is assumed that larger predatory fish species will return and restore the balance within the food web. Multiple authors have shown that predators established in a MPA will create a proper "top down" effect (Grigg et al. 1984; Shears and Babcock 2002; Micheli et al. 2004) and provide a more natural setting illustrating how fish assemblages would be comprised if not altered (Randall 1982). Lastly, even when larger predators like sharks are present, both groupers and parrotfish populations can increase (Mumby et al. 2006b). Palumbi (2004) has provided information on at least twenty studies which showed that predators show the best response to MPA creation compared to other trophic levels.

SURVEY METHODOLOGY

Surveys were conducted with an underwater camera system developed by SeaViewer. This camera was attached to a telescoping pole system created at Missouri State University. The pole system was composed of six foot sections of aluminum poles, 2 inches in diameter. A number of holes were drilled at various locations so that multiple poles could be pinned together to extend up to thirty six feet (10.9m). At one end of the pole a larger diameter sleeve was wielded onto the pole so that another pole would slide into this sleeve providing an attachment point. To anchor this system to the boat, the top piece of the pole system was unique. It had a bracket attached to it with multiple drilled locations allowing for the height of the unit to be adjusted. This bracket also allowed for the system to be stabilized to the boat. It was held onto the boat via two clamps and additional support from an assistant. The camera portion was held on the bottom pole by another bracket and a number of 7/16 inch nuts and bolts. The camera angle could be altered by providing tension on a rope which was tied to an eye bolt on the backside of the camera housing. The angle was kept at 90 degrees in order to look straight downward. Horizontal applications did not provide warning of bottom structures and quality of footage with extended distance (10m) was poor.

Trophic Classifications

All observed fish within Bluefields Bay and the surrounding area were categorized based on trophic level by relevant supporting literature (Birkeland and Neudecker 1981; Pitts 1991; Bohnsack et al. 1994; Clarke 1999; Oxenford and Hunte 1999; Sazima and Sazima 2001; Bohnsack et al. 2002; Chaves and Umbria 2003;

McCawley et al. 2003; Randall 2004; Bromhead et al. 2004; Randall et al. 2005; Auster et al. 2005; Franks et al. 2007; Whiteman et al. 2007; Albins and Hixon 2008; Halpern and Floeter 2008; Sandin et al. 2008; Araujo et al. 2009; Lewallen et al. 2010; Stevens et al. 2010). Unfortunately, no one paper covered all applicable species which were observed which lead to multiple sources to support classifications. Categories are described as Apex predator (AP), Browser (B), Corallivore (C), Coral/Colonial Sessile Invertivore (CSI), Herbivore (H), Insectivore (I), Macroinvertivore (MA), Microinvertivore (MI), Mobile Benthic Invertivore (MBI), Planktivore (PL), Piscivore (P) and Unclassified Demersal Species (UDS). The comprehensive fish list can be found in Appendix I.

Furthermore, the International Society for Reef Studies has suggested that by categorizing data into taxonomic groupings, that biomass effects are more strongly shown (2004). Taxonomic groupings can be found in Appendix I as well.

Survey Methodology Considerations

One survey methodology considered was described by Bohnsack and Bannerot (1986), and is known as the stationary point count. This method consists of counting fish in a 7.5m radius from substrate to surface. However this method was thrown out due to possible bias at selected sites as described in the River Reef Section previously. Belt transects are the primary method to be used, described by Brock (1954) with slight alterations. There are advantages and disadvantages to each method. With video recording, each method produced the same concern. These methods will misrepresent some benthic and cryptic species, especially in sea grass areas. When using the stationary point method, it is recommended to use scuba in order to maintain a stationary position within the water column/survey site (Bohnsack and Bannerot 1986). This was not applicable due to constraints of our study and location of materials initially.

Visual census techniques in clear water provide a relatively reliable estimation of reef associated species (Bohnsack 1994; Power et al. 2003). However, pelagic species can often be underrepresented as they pass through an area momentarily. Pelagic and deep water habitats within and around a reserve should be assessed in order to properly determine the areas biodiversity (Kendall 2004). Pelagic species were documented either by fishermen harvests, snorkelers within the sanctuary, or by video. Sixteen pelagic species were identified in Bluefields Bay as annotated by Appendix II with five additional species preferring reefs also.

The video recording method was preferred as AGGRA surveys were too complex for the constraints of the location and time period. At the beginning of data collection scuba diving surveys were not viable as equipment would have to be either trucked or moved by boat from Negril, Jamaica. Also, because the area is considered a MPA, rotenone sampling was discouraged as all fish are protected from all harvesting methods. Unfortunately the video sampling method of surveying misrepresents cryptic and benthic fish of small size (Smith-Vaniz 2006). Cryptic species typically are not large enough to provide sustenance and thus have been overlooked with great regularity (Smith-Vaniz 2006) although the composition and biodiversity can be altered by fish which are inside the reef structure (Brock 1982). For the purpose of this study, the identification of cryptic fishes is not an important aspect to account for the fish biomass within the region. The fish species expected to be within the bay, cardinalfish for example, do not provide enough economic value and are not pursued by fishers with one exception being the squirrelfish (*Holocentrus adcensionis*). The squirrelfish are large enough to visually identify with ease using this video sampling method unless they are deep within the reef structure. Most occasions the squirrelfish are noted at the edges of overhangs or near an escape route. When the camera passed over a location containing a squirrelfish, they would actually turn to look at the camera. The camera was not sufficiently obtrusive to cause any other obvious alterations in their behavior.

Visual censuses have been shown to provide more species counted over intense rotenone sampling (Greenfield 1985; Smith et al. 2003). Smith et al. (2003) discussed the implications of using divers and the introduction of bias as an individual will concentrate on specific aspects of the study area. A number of their observers keyed in on either species which were higher in the water column or those that were partially cryptic. With video sampling this bias is not introduced as the area covered was haphazard, dependent on the ocean currents at that point in time and space. Some researchers have used underwater video camera stations which are baited and assembled into a specific configuration for optimized fish sampling, otherwise known as BRUVS or baited remote underwater video stations (Cappo et al. 2004; McKineley 2011).

Due to malfunctions in camera equipment during the third data collection period, June 2012, a new but comparable method of video recording was needed. The author performed a number of scuba dives at the sites previously sampled and made recordings with a portable handheld camera held out at arm's length six feet off the bottom to replicate conditions previously practiced. Vertical positioning remained constant regardless of bottom morphology. A distance of six feet was maintained. Detection of individuals could be different due to alterations in methodology, however all identified biases were addressed and avoided. Swimming replicated previous transects. Swimming patterns consisted of concentric circles from the edge of the reef inwards. Visual benchmarks were determined underwater for turns and to make sure the same area was not covered multiple times. A snorkeler on the surface maintained visual tracking of the scuba diver and relayed information to the boat which maintained a position over the diver to collect GPS data. Transects were not governed by ocean currents, but followed the shape or changes in the reef architecture. The initial reef edge or sandbed edge determined the transect shape as the diver swam the length at a constant pace to enable visually identification of fish on video. The camera was held at a constant angle, except during turns.

Transect Determination

The artificial reef site was a known site. Controls were determined as suggested by literature review. A sandbed adjacent to the artificial reef site was selected to act as a control. Natural reefs within the area were selected randomly based on perceived size and ArcGIS information. Transects were determined by beginning at the upcurrent side of reef and allowing natural currents or wind to move the boat. Some areas were defined and snorkeler assistance was required to keep the boat within the confines of the structure to be surveyed. Distances were determined by the time which was standardized per transect. Transects were 15 minutes in length. Recording by the DVR device placed limitations on file size. Some sites had more videos per site but the time remained the same per sampling effort. Three samples were taken at each site to provide repetition. Every 1 minute of elapsed time, a GPS location was noted. Length of transects was determined following data collection using GPS locations and ArcGIS 9.3.1.

Transect Distances

Specific transect distances with corresponding time periods and videos can be found in Appendix III which is a compilation of all data for all time periods at all sites. Data are presented as distance traveled, which is the length traveled by the boat or scuba diver while video recording was in progress. Table 1 provides information relevant to all data collection periods and the video transects which were completed during that time. Distance data are presented sequentially, with initial comparisons to each specific period versus the same time frame. Transects were performed at each location. Distances were determined by time. Each transect was 15 minutes long. Due to recording limitations, some sites had multiple videos for each transect. Distance travelled was dictated by ocean currents and those time constraints.

Special considerations

During video review some fish remained around the camera. These were typically bluehead wrasses and were tracked throughout the progression of the video and only counted once. When they re-entered the frame of view, this was noted, but they were not recounted. Some individuals moved in and out of the frame for up to four minutes. Finally, the artificial reef does not extend to cover the full area of the sandbed. All fish observed in this zone or this particular distinct ovoid sandbed were considered to be at the artificial reef site.

No transects were completed at night, so the nocturnal fish assemblage was not determined. In seagrass areas fish were easier to identify if the quality of the seagrass bed was compromised, a leading edge with a sand bed, or in a patch structure. The sand between seagrass clumps provided enough contrast to allow for movement to be identified from fish. Depth of the water column was another aspect which needed to be taken into consideration. In order to identify fish hiding within the blades of the seagrass, the camera had to be a certain distance from the bottom, which might preclude other fish species higher in the water column. Thus all seagrass transects completed were not included in the data set.

Simpsons Diversity Index

The Simpsons Diversity Index is a statistical analysis method used to determine changes in biodiversity taking into account the frequency, abundance and dominance of all species present. The absolute abundance is the number of individuals per species whereas the relative abundance is the number of individuals of a species compared to the total number of individuals at a location. Four locations were compared, the Artificial Reef (AR), Control Reef (CR), Control Sandbed (CS), and Moors Reef (MR). Diversity indexes were calculated for each location during each time frame (June 2011, January 2012, and June 2012). Variance and T values were calculated from diversity indexes.

$$D_s = 1 - \sum_{i=1}^{S} \frac{n_i(n_i - 1)}{N(N - 1)}$$

The formula incorporates the number of species (n_i) and the number of individuals (N). Values range from 0 to 1, indicating low to high diversity. Variances (s^2) were calculated for each location. Relative abundance (P_i) was determined for each location at each time frame.

$$s^2 = 4\left[\frac{\sum p_i^3 - (\sum p_i^2)^2}{N}\right]$$

To test the null hypothesis tests for differences between sites, T values are compared against critical values. Critical values α= 0.05, df =∞ provides a t_{cv} = 1.96 (Brower et al 1998). Diversity for each site was compared to itself over time. Hypotheses all reflect whether a change occurred from one time span to another.

$$t_{calc} = \frac{[(D_{Sa}) - (D_{Sb})]}{(S_a^2 + S_b^2)^{\frac{1}{2}}}$$

If the $T_{calculated}$ is greater than the $T_{critical}$ then the null hypothesis is accepted, indicating differences occurred between the two time periods. Conversely, if the $T_{calculated}$ is less than $T_{critical}$, then the null hypothesis is rejected. That is, no differences occurred at the site between the two tested time frames.

Maps were created and various analytical factors were determined using ArcGIS 9.3.1. During each data collection trip, GPS locations were taken every one minute using either a Trimble or Garmin GPS device while video footage was being compiled. Transects lasted 15 minutes. This allowed distances to be determined as well as comparisons of various sites over different time scales.

Moors Reef

Figure 13: Compiled GPS information for Moors Reef showing six different transects.

Figure 13 is an example of how GPS locations were used to create maps showing each video transect individually and comprehensively. During this specific collection period (January 2012) three transects were completed on both the west and east side of Moors Reef. Each individual transect was color coded uniquely and provided a line feature to distinguish length. Measurements were determined using the Measurement tool in ArcGIS. Additional maps can be found in Appendix IV. The appendix shows each location at each individual data collection site, as well as all time periods together. Overlap of transects shows coverage of the reef or structure.

RESULTS

Various descriptive statistics are presented and refer to the distance traveled for all data collection periods (Table 1). One notable difference was the number of transects performed during each data collection. “N” indicates the number of transects completed during that specific time frame. The number of transects was diminished due to camera malfunctions during June 2012. Additionally, some sites were not sampled for other various noted reasons.

Table 1: Descriptive statistics for distance data of all video transects completed in Bluefields Bay, Jamaica during all three data collection periods.

	June 2011 Distance (m)	January 2012 Distance (m)	June 2012 Distance (m)
N	34	21	13
Mean	113.86	130.12	221.96
Std. Deviation	62.27	40.03	64.40
Range	265.51	146.67	176.60
Minimum	6.16	54.85	149.44
Maximum	271.66	201.52	326.04
Sum	3871.54	2732.59	2885.48

The mean distance traveled per transect increased from one data collection to the next (Table 1). The total distance traveled for all transects during each data collection decreased over time although a slight increase was noted between data collection 2 and 3. The third data collection had the least amount of videos recorded, but the mean distance per transect traveled was greater than the previous two data collection trips. The maximum distance traveled for a single transect occurred during the third data collection trip. The range decreased from the first to the second data collection with a slight increase from trip 2 to 3. Although the number of transects decreased from one collection period to the next, from June 2011 to January 2012 to June 2012; the minimum and maximum values are greater in June 2012 than the two previous trips. Differences could be due to many reasons such as the rate of movement, ocean currents, human error, or GPS tracking via the boat.

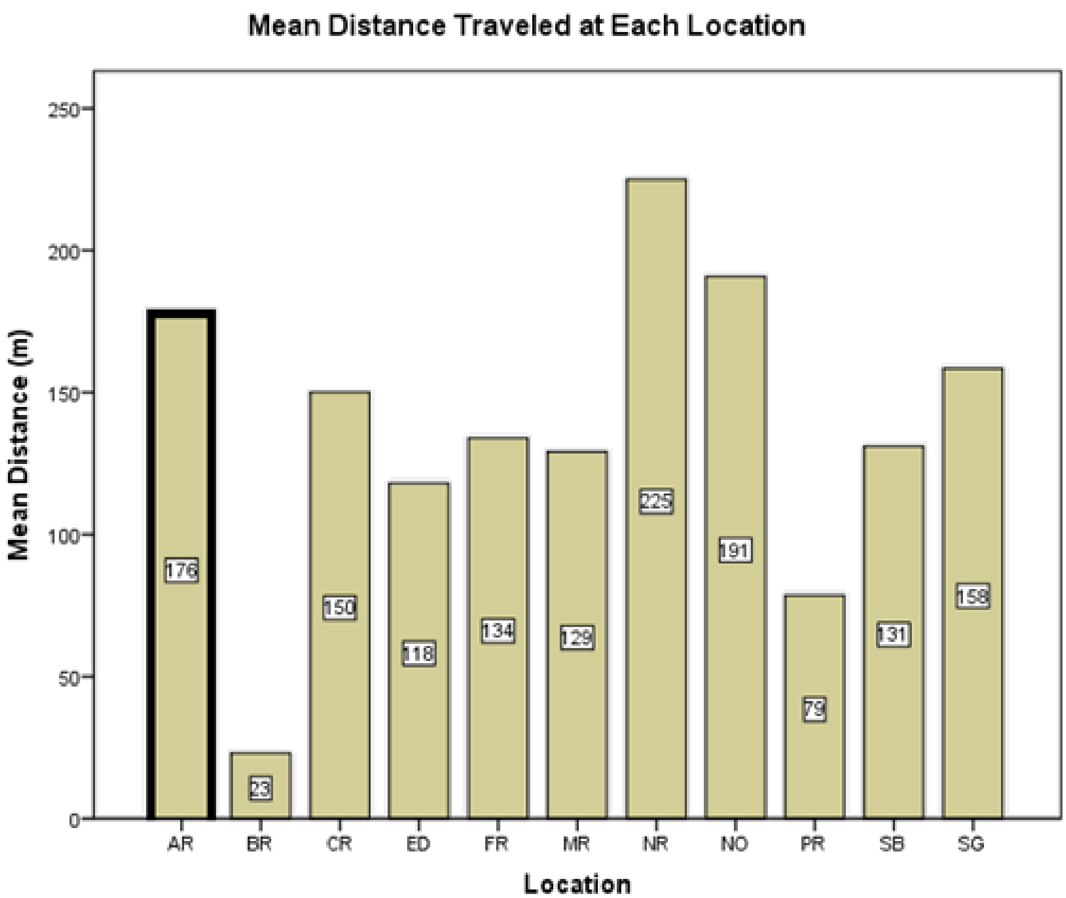

Figure 14: Mean distance traveled per transect at each location. Locations: Artificial Reef (AR), Ball Reef (BR), Control Reef (CR), Edge Reef (ED), Fishermans Reef (FR), Moors Reef (MR), Near Reef (NR), North Reef (NO), Patch Reef (PR), Sandbed (SB), Seagrass (SG).

Eleven sites were sampled over the course of all data collection periods. The mean distance traveled per transect at each site is annotated by Figure 14. The artificial reef is bolded in order to provide a reference. Not all sites were sampled over all time periods as discussed in the survey location section. An example of this would be Ball Reef or Fishermans Reef. Ball Reef was very small so the distances traveled were not that great per transect. However Fishermans Reef was significantly larger and thus the mean distance traveled per transect was greater as more reef section could be covered without alterations in travel patterns to stay within the limits of the reef boundaries. These values reflect all transect data over the 3 data collection periods.

Site Comparisons

A 1x4 independent measures ANOVA was conducted using a general linear model (GLM1) univariate procedure in IBM SPSS version 2.0. The ANOVA was conducted to examine differences in the mean number of fish documented per meter in four locations, over three data collection periods. The locations sampled were the Artificial Reef (AR), the Control Reef (CR), Control Sandbed (SB) and Moors Reef (MR). The location where the artificial reef would be constructed was sampled during the first data collection trip, but was only a sandbed at that time. Table 2 contains the overall means and standard deviations for all surveys conducted at each of the four locations.

The ANOVA performed three matching simple contrasts to determine if differences occurred among the locations with the artificial reef as a reference. Table 2 illustrates the number and site location, as well as the number (N) of transects at each site. The mean for fish per meter (4.72) is significantly higher for the artificial reef than the other locations (1.85, 0.51 and 1.00). Means are reflections of a corrected model (weighted).

Table 2: Overall Descriptive Statistics for Four Locations in Bluefields Bay, Jamaica. Calculations include all transect data for all time periods. Mean is an average number fish documented per meter traveled among transects. "N" signifies number of samples at each location.

Four locations to be compared	Mean	Std. Deviation	N
Artificial Reef	4.72	4.31	9
Control Reef	1.85	1.26	7
Control Sandbed	0.51	0.25	9
Moors Reef	1.00	0.44	8
Total	2.06	2.82	33

A secondary 3x4 independent measures ANOVA was conducted using a general linear model (GLM1) univariate procedure in IBM SPSS version 20. This ANOVA was conducted to examine differences in fish per meter at specific locations over individual data collection periods.

The design of this ANOVA test (GLM1) compares four locations over three time periods. Marginal means were calculated to determine interactions between means (Table 3). These mean values were calculated because of the unequal numbers of transects recorded at each site. Marginal means are adjusted for the various covariates. This information shows there are statistically significant differences among means. However, to address where the significant differences are, the contrasts of means between sites were determined by the post hoc test.

Table 3: Estimated overall marginal means of four locations over three time periods in Bluefields Bay, Jamaica. Means are calculated for fish per meter. Data were collected on June 2011, January 2012, and June 2012.

	First Data Collection		Second Data Collection		Third Data Collection		Totals	
Location	Mean	SE	Mean	SE	Mean	SE	Mean	SE
AR	0.269	0.546	4.26	0.546	9.629	0.546	4.719*	0.546
CR	0.376	0.945	1.201	0.546	2.992	0.546	1.523*	0.679
CS	0.635	0.546	0.403	0.546	0.483	0.546	0.507*	0.546
MR	1.386	0.669	0.876	0.386			0.754*	0.352

Note: Asterisk indicates statistically significant differences among collections.

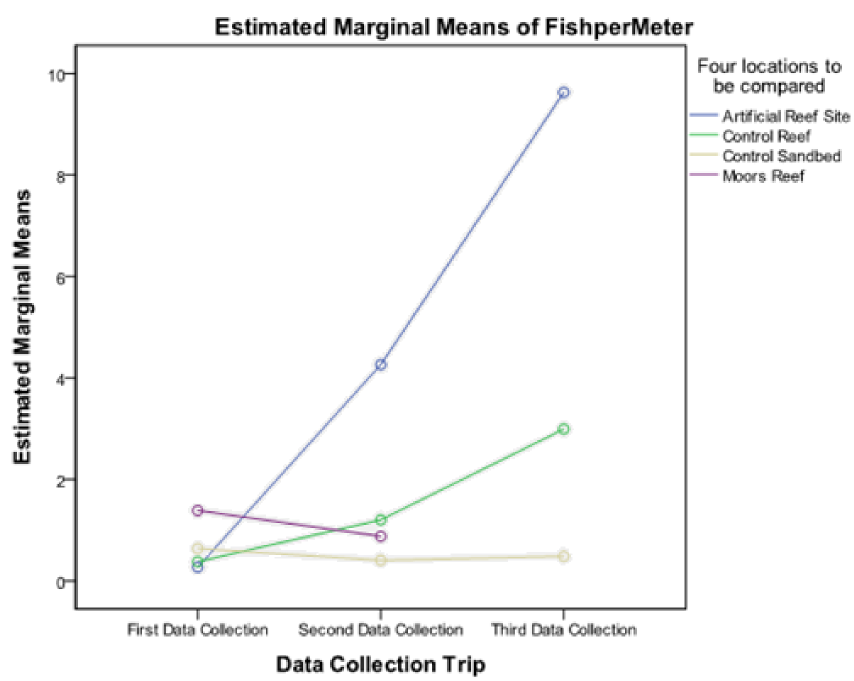

Figure 15: Estimated marginal means of fish per meter over the three data collection periods with interactions between sites determined by comparisons using GLM1 ANOVA. First data collection (June 2011), second data collection (January 2012), third data collection (June 2012).

Figure 15 illustrates that the artificial reef transects had a greater mean fish per meter than the other locations. During June 2011, the artificial reef site was a natural sandbed and was no significantly different from other sites. The Control Reef, Control Sandbed and Moors Reef marginal means were relatively similar to each other. The only statistically significant difference was detected between the Control Reef and the Control Sandbed (*M*=1.34, $p<.001$) (Table 3). The mean fish counts at the artificial reef were greater than all sites. This signifies that the artificial reef is doing well in terms of aggregating biomass. More fish were present per meter than at any other site. Moors Reef was significant to include in this analysis as it is the only reef which is subjected to substantial fishermen influence due to its location. Other sites could possibly have fishermen influence, but are within sanctuary boundaries and should be offered protection. However, Moors Reef was not sampled during the third data collection due to previously discussed mechanical errors. The Control Reef is located within the sanctuary boundaries and although the means are essentially equal, the mean is slightly increased from Moors Reef, outside of the boundary. Although not statistically different, the difference could indicate that the protected Control Reef has a greater fish density than Moors Reef. However, Moors Reef was not sampled during the third data collection and may be misrepresented.

A significant main effect is noted for trip; $F(2, 22) = 31.30$, $p<.001$, ${}_{p}\eta^2 = 0.74$ (Table 4). The F test ($F=17.06$) tests the differences among the four locations for fish per meter (Table 4). This test is based on the linearly independent pairwise comparisons among the estimated marginal means. Statistical significant differences were noted for fish counts between the first data collection period (June 2011) and both second and third collections (January 2012 and June 2012). Data includes all transects completed during those specific times (Table 5).

Table 4: ANOVA Table of Effects for Three Data Collection Trips Over Four Locations. Data were collected on June 2011, January 2012, and June 2012.

Source	SS	df	MS	F	p	${}_{p}\eta^2$
Trip	55.955	2	27.978	31.299	<0.001	0.740
Location	85.017	3	28.339	31.703	<0.001	0.812
Trip * Location	76.245	5	15.249	17.059	<0.001	0.795
Error	19.665	22	0.894			
Total	394.663	33				

Table 5: Multiple Comparison Statistics for Significant Means Determined by Comparing Each Data Collection Trip Amongst One Another Using Fish per Meter Data. Statistically Significant Differences are annotated by an asterisk.

Trip	Data Collection Trip	Mean Difference	SE	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
First	Second Data Collection	0.872^{*}	0.399	<0.05	0.046	1.699
	Third Data Collection	3.717^{*}	0.446	<0.001	2.792	4.641
Second	Third Data Collection	2.845^{*}	0.399	<0.001	2.018	3.671

Statistical significant differences in fish counts were also noted between the second data collection trip and the third data collection trip. Additionally, a significant main effect was noted for location; $F(3, 22) = 31.70$, $p<.001$, ${}_{p}\eta^2 = 0.812$ (Table 4). There were statistically significant differences in mean number of fish per meter among the artificial reef and all sites (*M*=2.87, *M*=4.21, *M*=3.72), and between the Control Reef and Control Sandbed (*M*=1.34) (Table 6). There were no statistically significant differences in means for fish per meter discovered between the Control Reef and Moors Reef (*M*=0.846) or the Control Sandbed and Moors Reef (*M*= -0.49) (Table 6).

Table 6: Post hoc pairwise comparisons of four locations in Bluefields Bay, Jamaica. Comparisons were made among four locations to determine if differences in means are present. Asterisk indicates statistically significant differences.

Location	Comparison Location	Mean Difference	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Artificial Reef	Control Reef	2.87*	0.476	<0.001	1.88	3.86
	Control Sandbed	4.21*	0.446	<0.001	3.29	5.14
	Moors Reef	3.72*	0.459	<0.001	2.76	4.67
Control Reef	Control Sandbed	1.34*	0.476	<0.01	0.36	2.33
	Moors Reef	0.84	0.489	<0.10	-0.17	1.86
Control Sandbed	Moors Reef	-0.49	0.459	<0.50	-1.45	0.46

The Mean Square (Error) = .894.

Power is the ability to detect whether an effect is present within a data set. If the value is close to 1, then an effect should be distinguished. A power of *N*=1.00 was noted for the fish per meter at the four locations over the three time periods (Table 2). This suggests that there is an effect. Post hoc comparisons are then used to determine where the significances lie. These are indicated in Table 6 by an asterisk.

Power for overall fish per meter was *N*=0.916 as reported by GLM1 ANOVA (Table 3). Post hoc results showed the significances were present at the same locations as the 3X4 ANOVA. Finally, a statistically significant interaction was determined for fish per meter for each data collection trip between locations; $F(5, 22) = 15.25$, $p<.001$, ${}_{p}\eta^2 = 0.795$ (Table 4). Significant changes were noted at each location over the three distinct time periods.

The Artificial Reef

The fish per meter documented at the artificial reef site over time are shown in Figure 16. Calculations were determined as the number of fish documented in transects at the Artificial Reef site divided by distance traveled for each of the three data collection periods. The three data collection periods were the month preceding installation, six months after and finally, a year later. The mean fish per transect increased over time as well. Five, 10 and 40 species were documented on successive trips at the artificial reef site. Thus species richness increases over time even though Simpsons Diversity Indices decreased due to unevenness within the community structure.

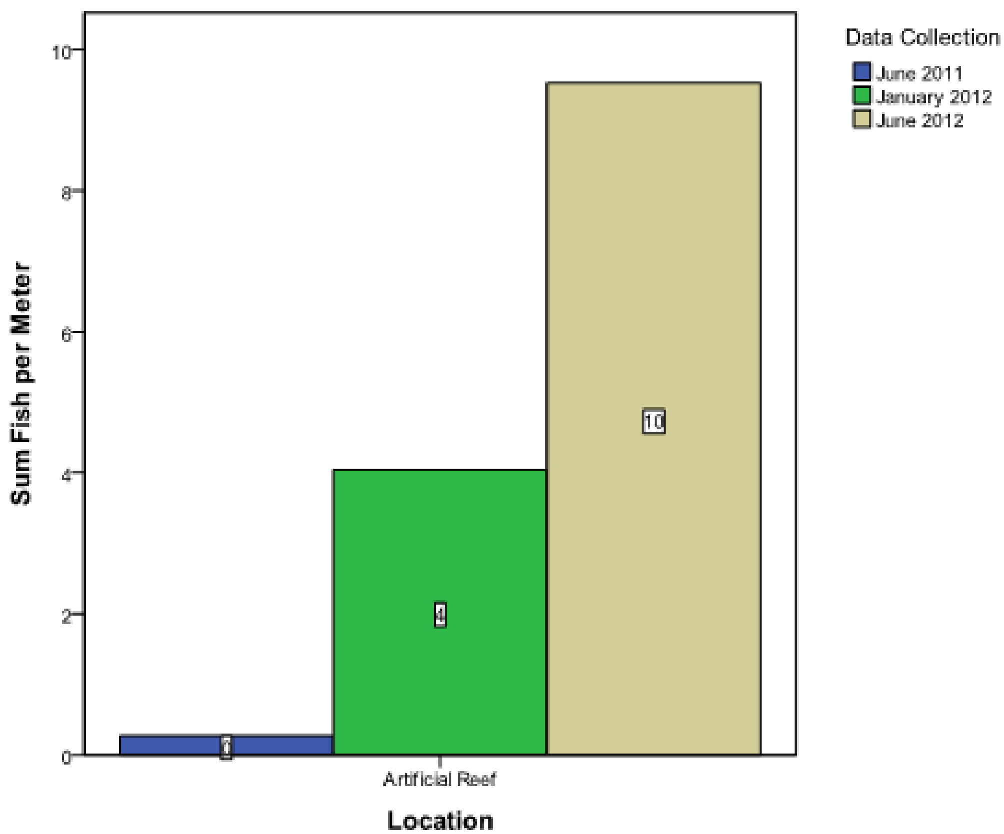

Figure 16: Fish per meter documented at the artificial reef site over time. Calculations were determined by number of fish counted divided by distance traveled for each of the three data collection periods.

Additional information from each collection trip is annotated in Table 7. Descriptive statistics are shown for the distance traveled and the number of fish counted during transects of each data collection period. The minimum and a maximum number of fish as well as the distance traveled per transects reflect the average number of fish in each transect. Table 8 shows the same information but compiles all data collection periods together for a cumulative total for each category.

Table 7: Artificial Reef - All Data Collection Periods. Descriptive statistics related to all transects completed during all collection periods and subsequent number of fish per transect documented at the artificial reef site. Data was collected June 2011, January 2012, and June 2012.

	First Data Collection		Second Data Collection		Third Data Collection	
	Distance (m)	Number of Fish	Distance (m)	Number of Fish	Distance (m)	Number of Fish
Mean	142.67	38.33	100.04	404.33	286.72	2732.33
Std. Dev	14.85	4.04	25.76	71.66	34.94	575.83
Minimum	125.54	34.00	81.85	348.0	259.27	2296.00
Maximum	151.77	42.00	129.51	485.0	326.05	3385.00
Transects	3		3		3	

Table 8: Comprehensive Descriptive Statistics Related to the Artificial Reef Over All Data Collection Periods. Data was collected June 2011, January 2012, and June 2012.

	All Trips	
	Distance (m)	Number of Fish
Mean	176.48	1058.33
Std. Dev	87.77	1298.30
Minimum	81.85	34.00
Maximum	326.05	3385.00
N (Transects)	9	

Artificial Reef versus Control Sandbed

Figure 17 shows the difference in total fish per meter noted between the Artificial Reef and the Control Sandbed for each data collection period. Means were calculated by taking the total number of fish documented at the site and dividing by the total distance traveled for all transects at that site. ANOVA test results are more important to consider since all time frames are considered (Table 1). The mean fish count at the artificial reef 4.72 fish per meter was statistically different from that of the Control Sandbed 0.51 fish per meter. There were significant differences in mean fish density among collection periods (Table 6). These means consider all time frames together. This suggests that the fish density per meter was greater at the artificial reef site than the Control Sandbed and increased over time. Fish counts at the Control Sandbed were relatively equal over time (Figure 17). The vast majority of the fish (8189) were located at the modules, or surrounding the modules. However, a total of 7 rosy razorfish (*Xyrichtys martinicensis*) were observed in the sandbed portion of the artificial reef site during the third data collection, along with one sanddiver (*Synodus intermedius*) which was noted buried in the sand close to the north edge where the sandbed and the surrounding seagrass meet. Almost all fish noted at the Control Sandbed were Rosy Razorfish.

The mean fish density for all time periods was 4.72/meter at the artificial reef site and 0.51/meter for the Control Sandbed. This difference is statistically significantly. The standard deviation for fish counts at the Control Sandbed (*SD*= 44.27) was lower than the artificial reef (*SD*= 1058.33) suggesting the fish within the sandbed remain within a certain area for extended periods and are more evenly distributed throughout the habitat.

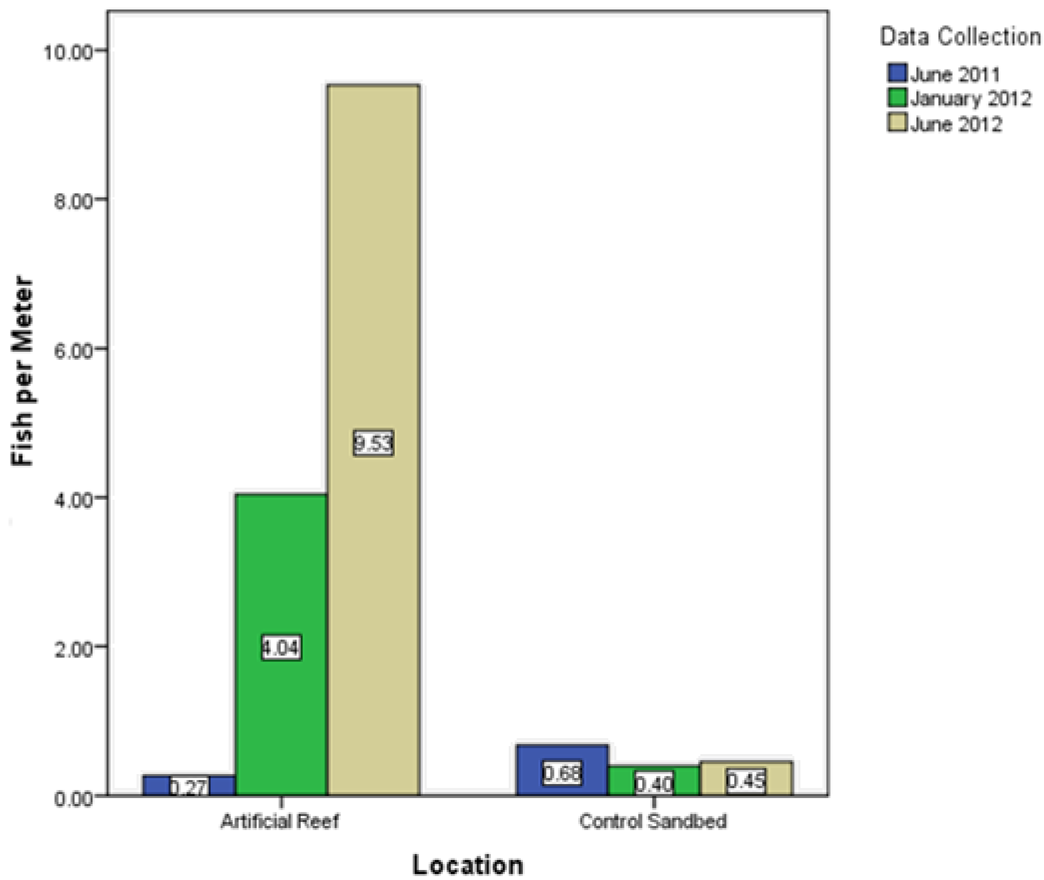

Figure 17: Fish per meter documented at the Artificial Reef site versus the Control Sandbed over all time periods. Calculations were determined as number of fish documented divided by total distance traveled for each site over the three data collection periods.

Tables 9 reflects the information collected in the Control Sandbed over all data collection periods individually and comprehensively (Table 10). When comparing individual results, mean fish per meter increased for the artificial reef site over each consecutive data collection trip. However, fish counts at the Control Sandbed decreased slightly over time. Differences in means are distinct between the two sites over time.

Table 9: Control Sandbed - All Data Collection Periods. Descriptive statistics related to transects completed during all collection periods and fish documented at the site. Data was collected June 2011, January 2012, and June 2012.

	First Data Collection		Second Data Collection		Third Data Collection	
	Distance (m)	Fish Count	Distance (m)	Fish Count	Distance (m)	Fish Count
Mean	126.71	85.67	78.63	31.33	187.96	85.33
Std. Dev	27.62	50.52	27.15	11.71	25.15	47.07
Minimum	96.49	29	54.86	18	159.7	51
Maximum	150.66	126	108.22	40	207.9	139
N (Transects)	3		3		3	

Table 10: Comprehensive descriptive statistics for the Control Sandbed including all data collection periods. Values reflect the number of fish, and distances traveled for all transects documented at the Control Sandbed location. Data was collected June 2011, January 2012, and June 2012.

	All Trips	
	Distance (m)	Number of Fish
Mean	131.1	67.44
Std. Dev	52.78	44.27
Minimum	54.86	18
Maximum	207.9	139
N (Transects)	9	

Artificial Reef versus Control Reef

Increases in the mean number of fish per meter documented at the Control Reef and artificial reef simultaneously suggests that sanctuary fish populations are increasing in size. (Figure 18). Both locations are within visual site of the warden's station and fishing was not observed at either location. However, the mean fish per meter was significantly different between the two sites when comprehensive analysis was performed (Table 6). Fish counts per meter at the artificial reef (*M*=4.72) was significantly higher than for the Control Reef (*M*=1.9). This indicates the Control Reef had a significant lower fish density present than at the artificial reef, or larger aggregations of fish are present at the Artificial Reef whereas at the Control Reef the fish are spread out. When these two sites were compared over time, statistically significant differences were noted between the two sites (*M*=2.87) (Table 6) and further substantiated by fish per meter for each location over all time periods individually (Figure 18). Differences in mean number of fish per meter occurred at the sites and over the three data collection periods.

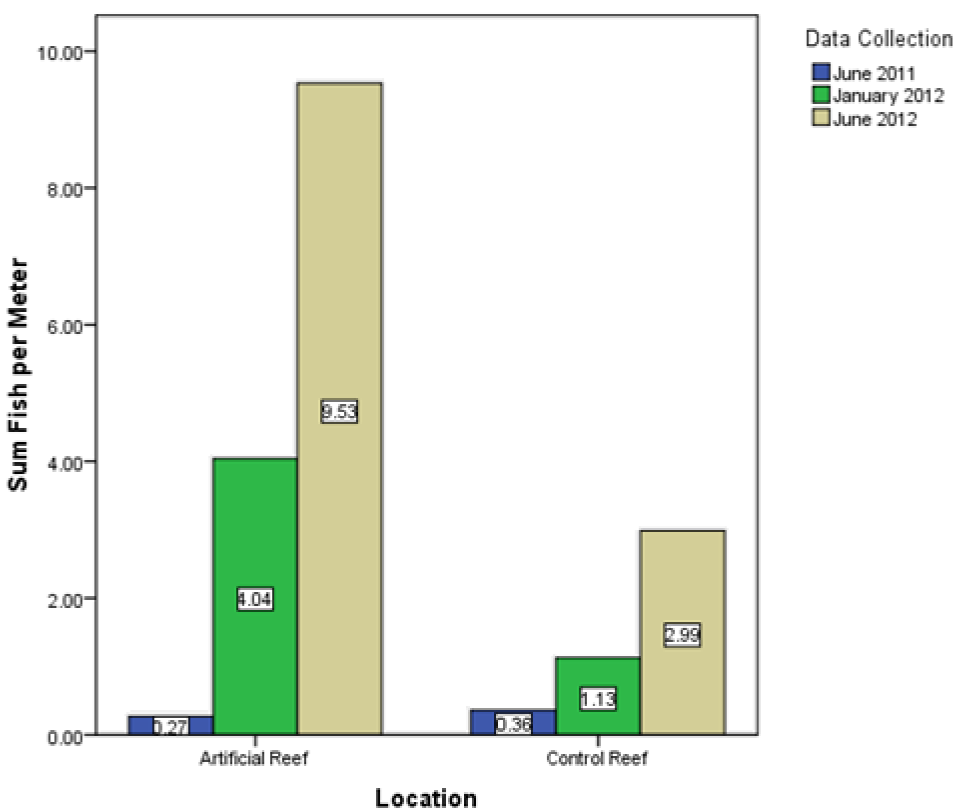

Figure 18: Mean number of fish per meter documented at the artificial reef site versus the Control Reef over the three data collection periods.

Only one transect was completed during the first data collection at the Control Reef site. Consequently, the mean and other statistics which involve an average cannot be determined. However the number of fish per meter was compared to other transects completed at this site.

Table 11: Comprehensive descriptive statistics for the Control Reef covering all data collection periods. Values reflect the number of fish per transect, and distances traveled for all transects documented at the Control Reef location. Data was collected June 2011, January 2012, and June 2012.

	Second Data Collection		Third Data Collection		All Trips	
	Distance (m)	Number of Fish	Distance (m)	Number of Fish	Distance (m)	Number of Fish
Mean	132.58	149.33	158.16	472.33	150.09	276
Std. Dev	35.18	23.86	7.76	148.51	27.42	205
Minimum	101.52	130	149.45	344	101.52	67
Maximum	170.79	176	164.32	635	178.37	635
N (Transects)	3		3		7	

Artificial Reef versus Surrounding Natural Reefs

Figure 19 shows the differences between the mean numbers of fish per meter documented at the artificial reef site versus all surveyed surrounding natural reef structures for each data collection period. A slight decrease in numbers was noted at the natural reef sites during the first two periods with a subsequent increase during the third data collection period.

ANOVA results show that the mean number of fish per meter for the artificial reef (M=4.72) was statistically higher than both the Control Reef (M=1.85) and Moors Reef (M=1.00). However, no statistical differences were noted between the Control Reef and

Moors Reef. There was a statistically significant difference for both mean values, fish per meter and fish per transect, for the artificial reef site versus natural reef locations. The artificial reef has more fish present then surrounding reefs regardless of fishermen influences on those reefs and is significantly different from natural reef structures within the bay.

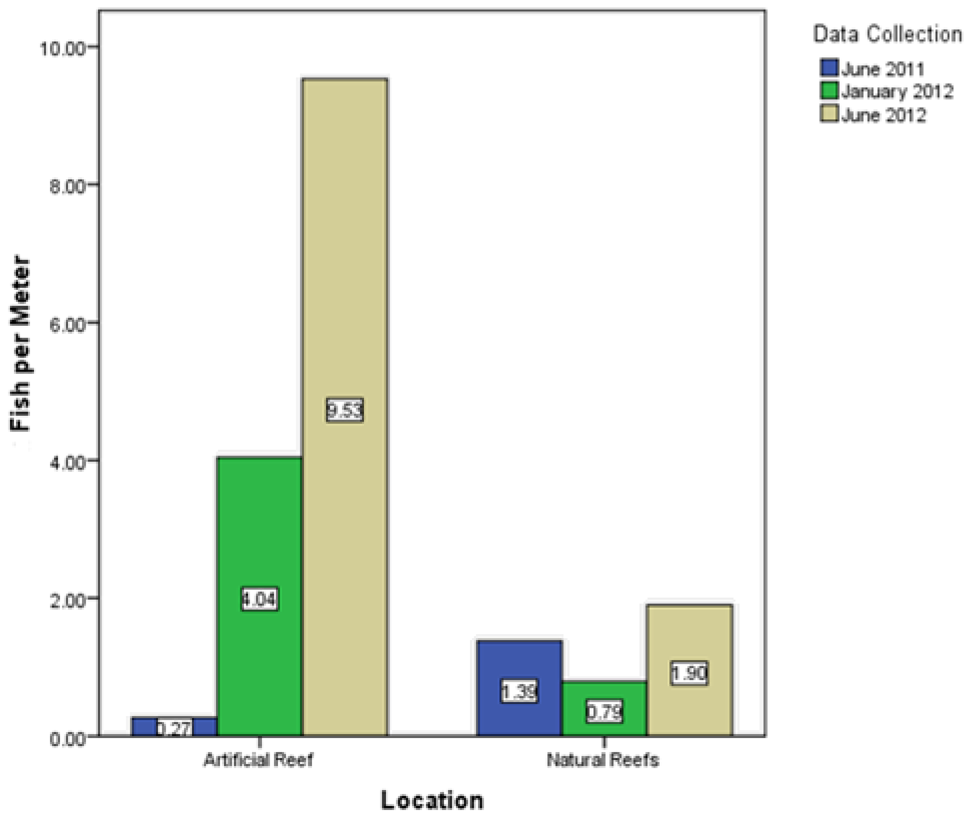

Figure 19: Sum number of fish per meter documented at the artificial reef site versus all natural reefs surveyed combined over the three data collection periods.

Simpsons Diversity Index

The Simpsons Diversity Index is a statistical analysis method used to determine changes in biodiversity by taking the frequency, abundance and dominance of all species into account. Table 12 relates the Diversity Index value at each site for each specific data collection period (June 2011, January 2012, and June 2012). Absolute and relative abundances and P values are provided in Appendix V.

Table 12: Simpsons Diversity Index and species richness values and for each location at each time period.

	Location				Species Richness			
Data Collection	AR	CR	CS	MR	AR	CR	CS	MR
Trip 1: June 2011	0.4	0.8	0.53	0.79	5	16	13	16
Trip 2: January 2012	0.13	0.87	0.54	0.81	10	28	5	30
Trip 3: June 2012	0.18	0.85	0.59		40	54	11	

Variances for diversity values were calculated for each location for each specific time as reflected in Table 13. Relative abundance values are provided in Appendix V. Using variables from each Table, locations can be compared in order to test the hypotheses. For example, the diversity for the artificial reef during the first data collection was 0.40 indicated as D_{Sa}. The second data collection was 0.13 and is denoted as D_{Sb}. Variances for each location at the same time are used for the calculation $S^2{}_a$ and $S^2{}_b$.

Table 13: Variance for Simpson's Diversity Index values at values for each location at each specific time period.

	Location			
Data Collection	Artificial Reef	Control Reef	Control Sandbed	Moors Reef
Trip 1: June 2011	0.0021	0.00097	0.00084	0.00021
Trip 2: January 2012	0.00017	0.000045	0.0011	0.000060
Trip 3: June 2012	0.000033	0.000038	0.00081	

T calculated values are shown in Table 14 for each location at each time. Hypotheses are shown as a column in terms of location 1 versus location 2, etc. Calculations are in columns, for each specific site over time. The purpose was to determine if changes in diversity occurred over time at a location.

Table 14: Simpsons Diversity Index T calculated values for each specific location during each time period. Data Collections occurred June 2011(1), January 2012(2), and June 2012(3).

	Location			
Comparisons (Trip Number)	Artificial Reef	Control Reef	Control Sandbed	Moors Reef
1 vs 2	5.77*	-2.11	-0.32	-0.73
2 vs 3	-3.29	2.20*	-1.19	
1 vs 3	4.93*	-1.48	-1.63	

a. Asterisks indicate statistically significant values.

T calculated values were then compared against T critical (1.96) (Brower et. al. 1998). Table 14 illustrates whether the null hypothesis is accepted (A) or rejected (R) by annotation of asterisks.

Results indicate that diversity values were low for the Artificial Reef and the Control Sandbed over all data collection trips (Table 12). However, the Simpsons Diversity index takes into account the evenness between species. Both an increase in species richness and density were documented at the Artificial Reef site. However, values reflect the dominance of French grunts. The Diversity Index is thus depressed because the French Grunts are more abundant over all data collection trips at the site. There were significant differences in diversity between the first and second data collection and between the first and third data collection at the artificial reef site. However, the null hypothesis between the second and third data collection was rejected. The diversity was different before and after the artificial reef was put into place; i.e. both 2 and 3 are different from 1. The only other differences detected were between the Control Reef from data collection two versus data collection three. Calculations were re-run excluding French grunts from all sites during all time periods to look at how dominance would affect the outcome of the Diversity Index. The only noted differences were at the Artificial Reef between the second and third data collections, but not between the first and second. No other differences occurred at any other locations during any other time periods when French grunts were removed. The dominance shifted to the next most abundant species.

Trophic Comparison

The total number of individual fish documented is shown in Figure 20 according to the location in which they were noted. Eleven sites were surveyed in total, although the artificial reef sandbed is the same location as the artificial reef. However, before the artificial reef was installed, it was just a sandbed. The difficultly of identifying fish the seagrass is also noted in this figure.

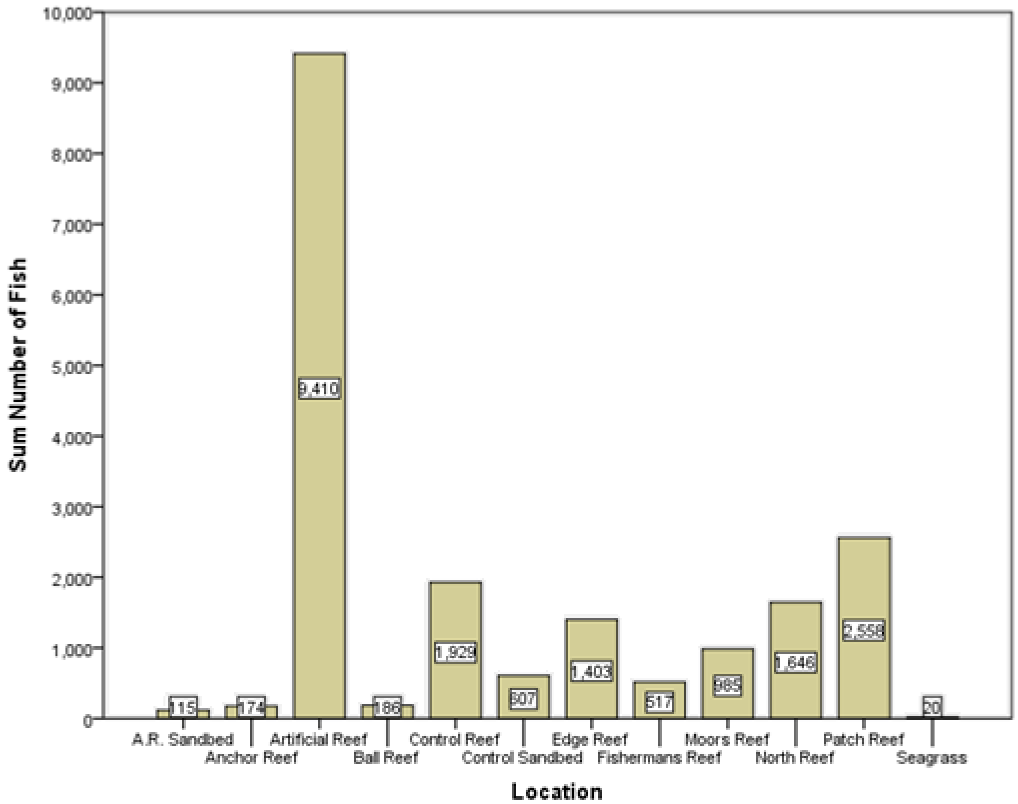

Figure 20: Total Number of individual fish documented at each unique location in Bluefields Bay, Jamaica. The artificial reef site before the artificial reef installation in June 2011 is annotated by A.R. sandbed (115).

Figure 21 shows the number of documented species present bay wide for the first data collection period, which reflects just a portion of Figure 20. Fish with groups less than five percent of the total were combined in order to present a distinct category and are labeled as "other". The total of these various species numbers 695 individuals. The cushion sea star was not added to this data either, as the information will be presented later. Finally, a number of fish were not identifiable as discussed previously and are noted as such.

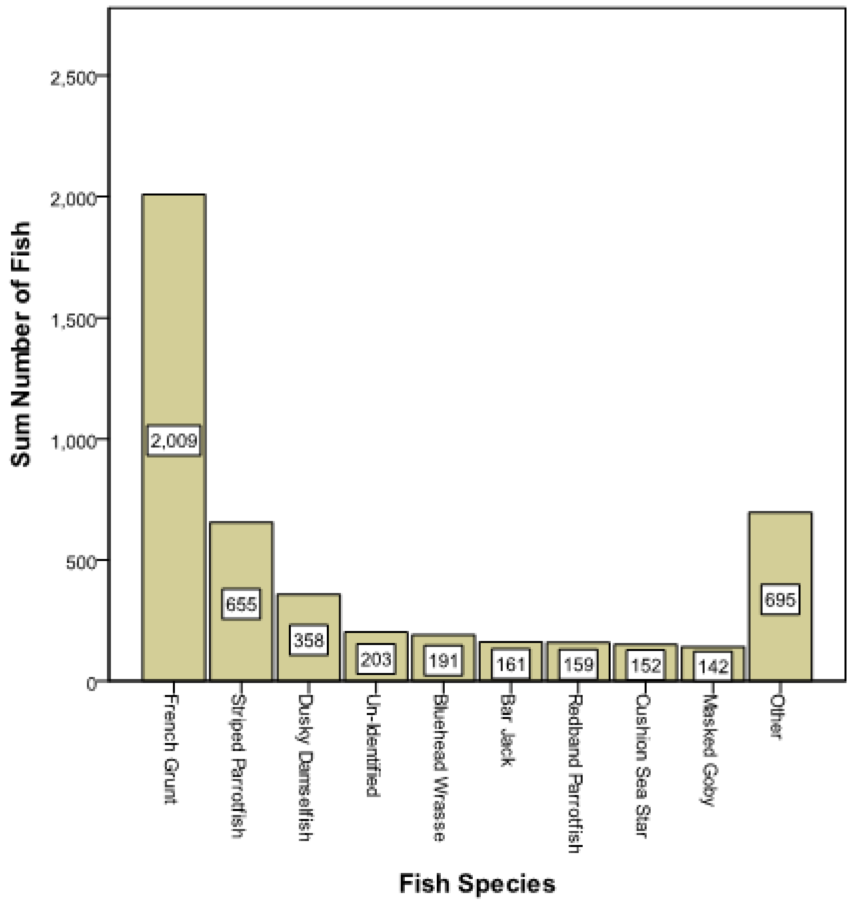

Figure 21: Total documented fish during the first data collection period with those less than 5% relevance combined as "other". UnIdentified reflects those which were unable to be distinguished during video analysis.

Figure 22 shows the number of species documented during the second data collection period and Figure 23 illustrates those from the third data collection period. Fish species less than five percent of the total number of individuals were condensed in order to present a distinct bin and are labeled as "other". The number of "others" includes 317 individual fish for the second data collection. However, like before the number of species which compose the "other category" are not shown. Figure 23 includes 1062 individuals which comprise the less than 5% category. French grunts are present in large numbers, more than any other fish. This is substantiated by the Simpsons Diversity Index which determined dominance was present within the bay.

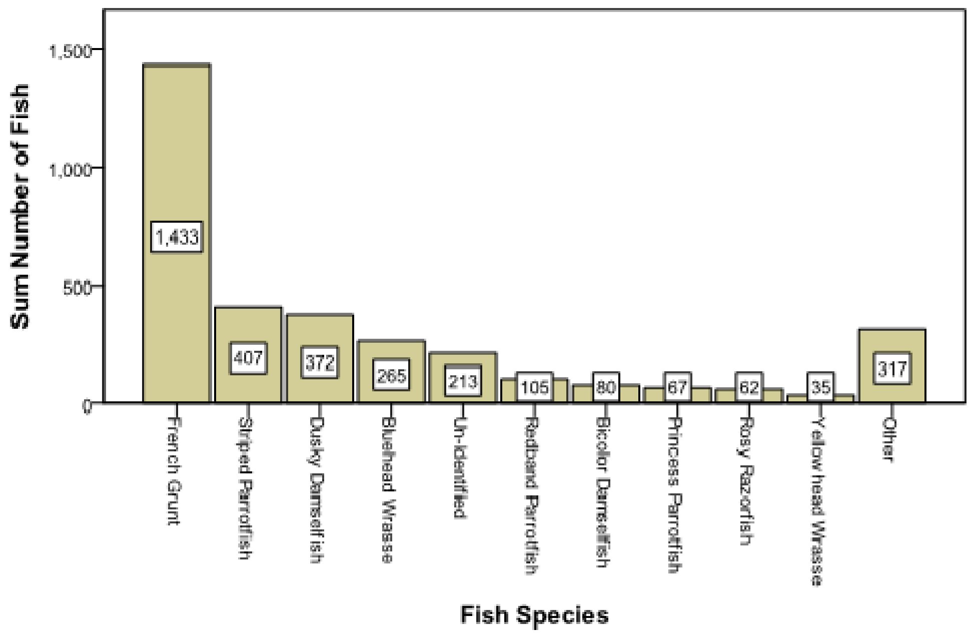

Figure 22: Total number of fish by species documented during the second data collection period. Those which comprise less than 5% were condensed to the bin "other". Unidentified fish totals are documented as well.

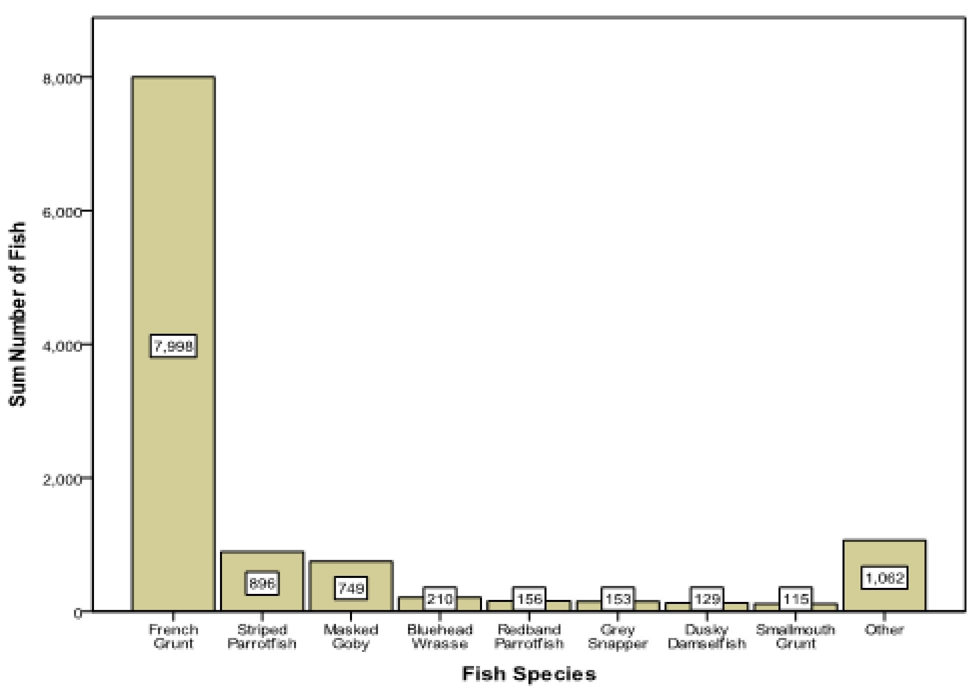

Figure 23: Total number of specific fish documented during the third data collection period. Species compromising less than 5% of the total were condensed to the bin "other". Unidentified fish were condensed in this calculation.

Taxonomic Comparison Bay Wide

A compilation of all documented fish species is noted in Appendix I. Taxonomic comparison is presented in Figure 36 as a percentage of the total. For example the number of fish present in the Serranidae family (groupers, hamlets, etc), comprise 9.86% of the total population percentage within Bluefields Bay, Jamaica. Corresponding frequency data is found in Appendix VII.

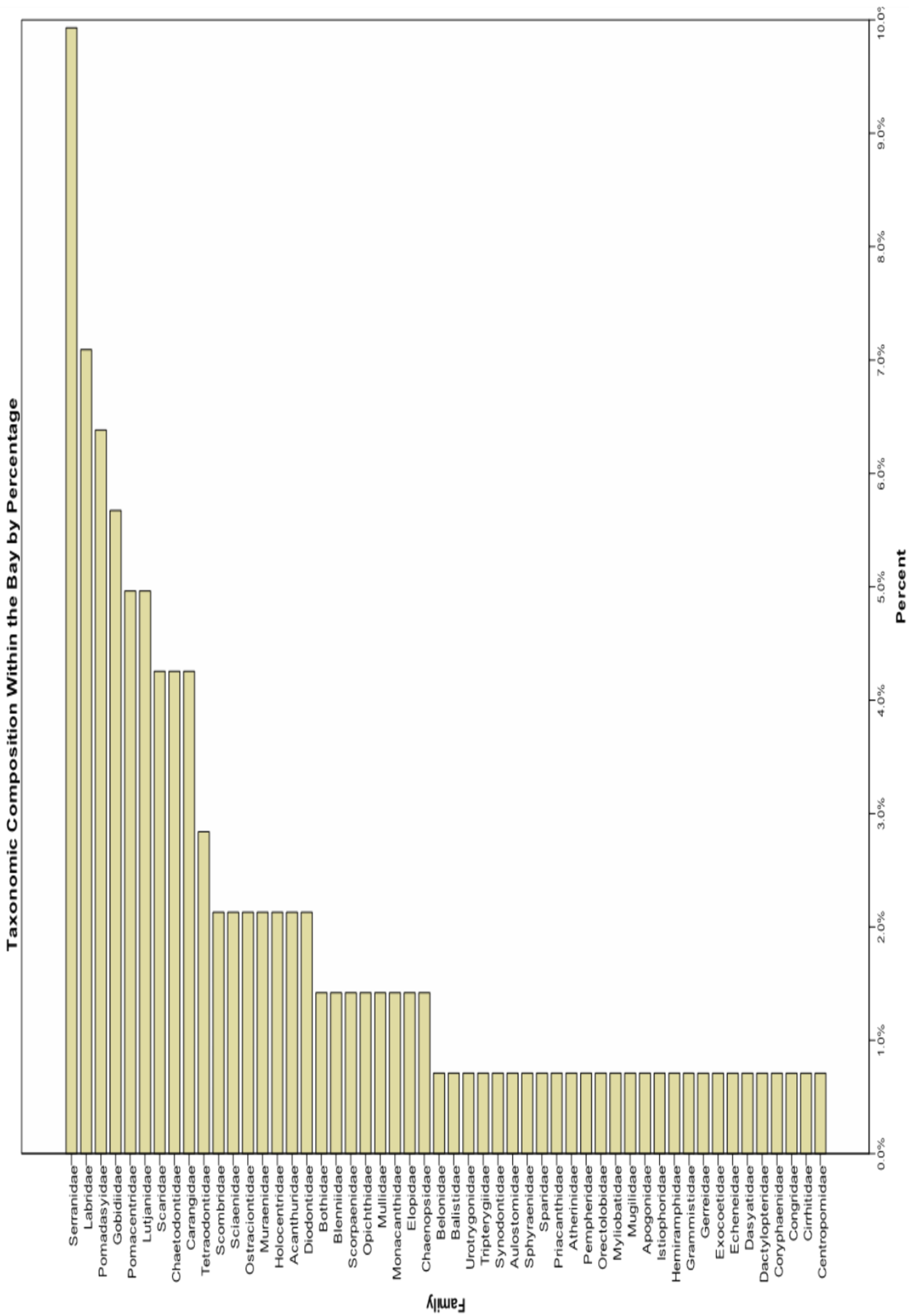

Figure 24: Taxonomic composition of all species documented according to family.

Fish species were documented to be within a certain zones when discovered and the information is compiled in Figure 25. Species were noted either in the sanctuary, outside the sanctuary, or in both locations and labeled as "both". Lastly, not all species were observed, but fishermen brought in harvests to the dock at the Fishermen's Friendly Society compound located on the beach in Bluefields Bay. They were noted to be "Fishermen caught". A comprehensive study of catch rates in the area was not carried out, however species which fishermen brought that were unique and not observed during sampling were noted. Most were pelagic predators like wahoo (*Acanthocybium solandri*) or dolphin (*Coryphaena hippurus*). Photographic evidence was presented for a striped marlin (*Tetrapturus audax*) and Red Grouper (*Epinephelus morio*) which were caught just west of the sanctuary boundary line, at the deep drop off. Corresponding frequency data for each location can be found in Table 15. A rather unique trend is notable in this figure. The majority of species were documented to be both within and outside of the sanctuary boundaries. A lower number of species is noted outside the boundary and could be attributed to various aspects such as lower effort, fishermen influence, depth of water column as it's deeper to the west, or is dependent on the species and its ecology or habitat preferences. Clear distinction of these trends cannot be determined with the given information. Further studies would need to be carried out to address this observation.

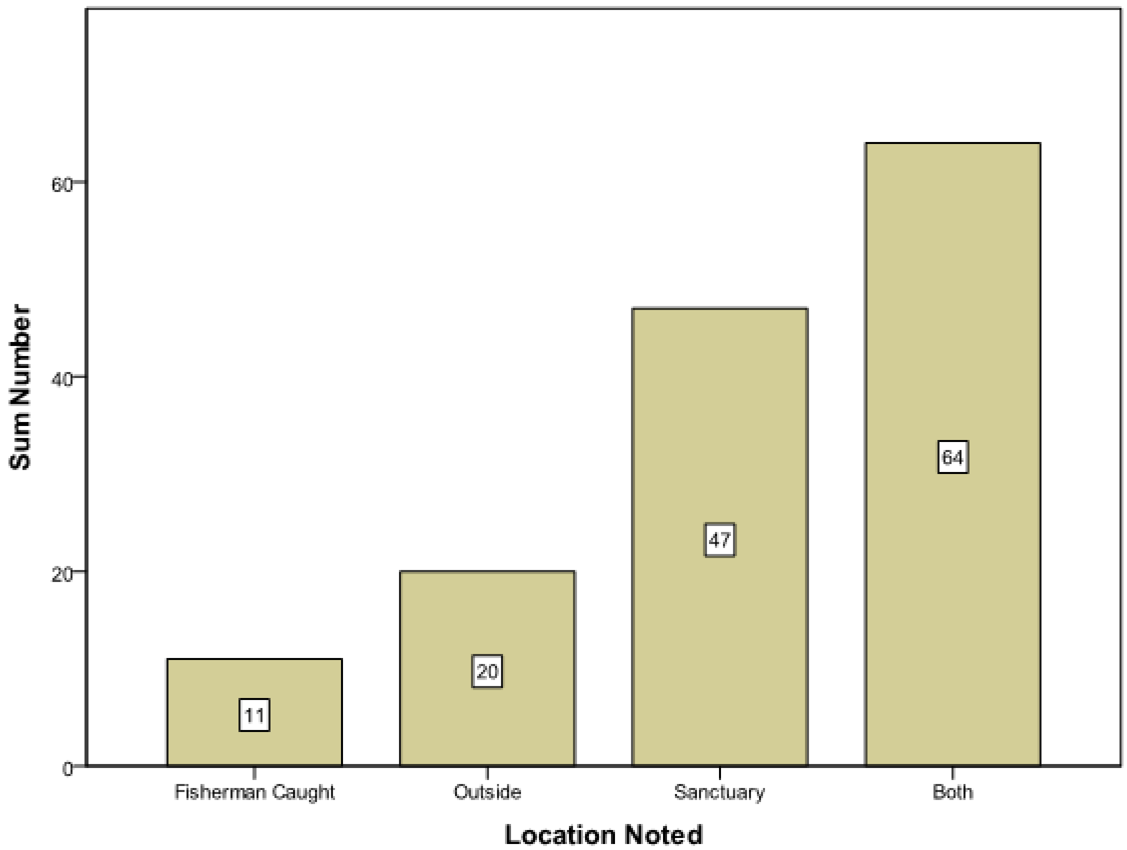

Figure 25: Total number of species documented according to location noted for all data collection periods.

Table 15: Frequency data of total fish species located at specific locations during all data collection periods.

	Frequency	Percent
Both (Outside/Inside)	64	45.1
Fishermen Caught	11	7.7
Outside	20	14.1
Sanctuary	47	33.1
Total	142	100.0

Habitat preferences were also delineated for selected species. Figure 26 shows where species were located for each habitat unit. A number of locations are a collection of various habitat types. Table 16 illustrates the frequency data of Figure 26. Fish may move between or prefer various habitats for different purposes.

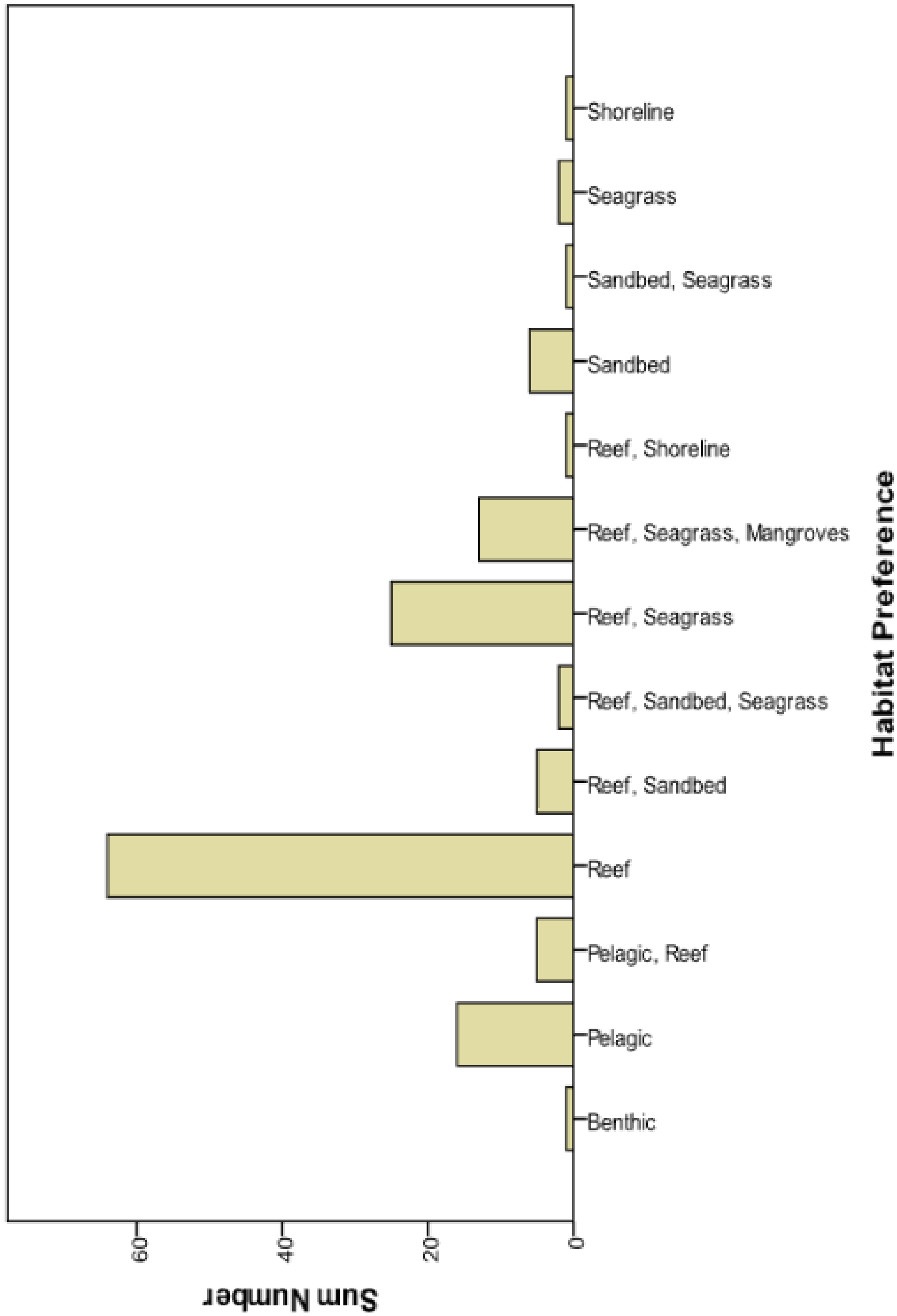

Figure 26: Number of fish species according to habitat categories during all periods combined.

Table 16: Habitat association frequency statistics for all species noted.

	Frequency	Percent
Reef	64	45.1
Shoreline	1	0.7
Reef, Sandbed, Seagrass	2	1.4
Reef, Sandbed	5	3.5
Sandbed, Seagrass	1	0.7
Sandbed	6	4.2
Seagrass	2	1.4
Pelagic	16	11.3
Benthic	1	0.7
Reef, Seagrass	25	17.6
Reef, Seagrass, Mangroves	13	9.2
Reef, Shoreline	1	0.7
Total	142	100.0

Species were further broken down into trophic categories as described previously in the Fish Populations section. Figure 27 shows the number of fish species which belong to each referenced category. Table 17 provides frequency data as pertaining to these classifications in Figure 27.

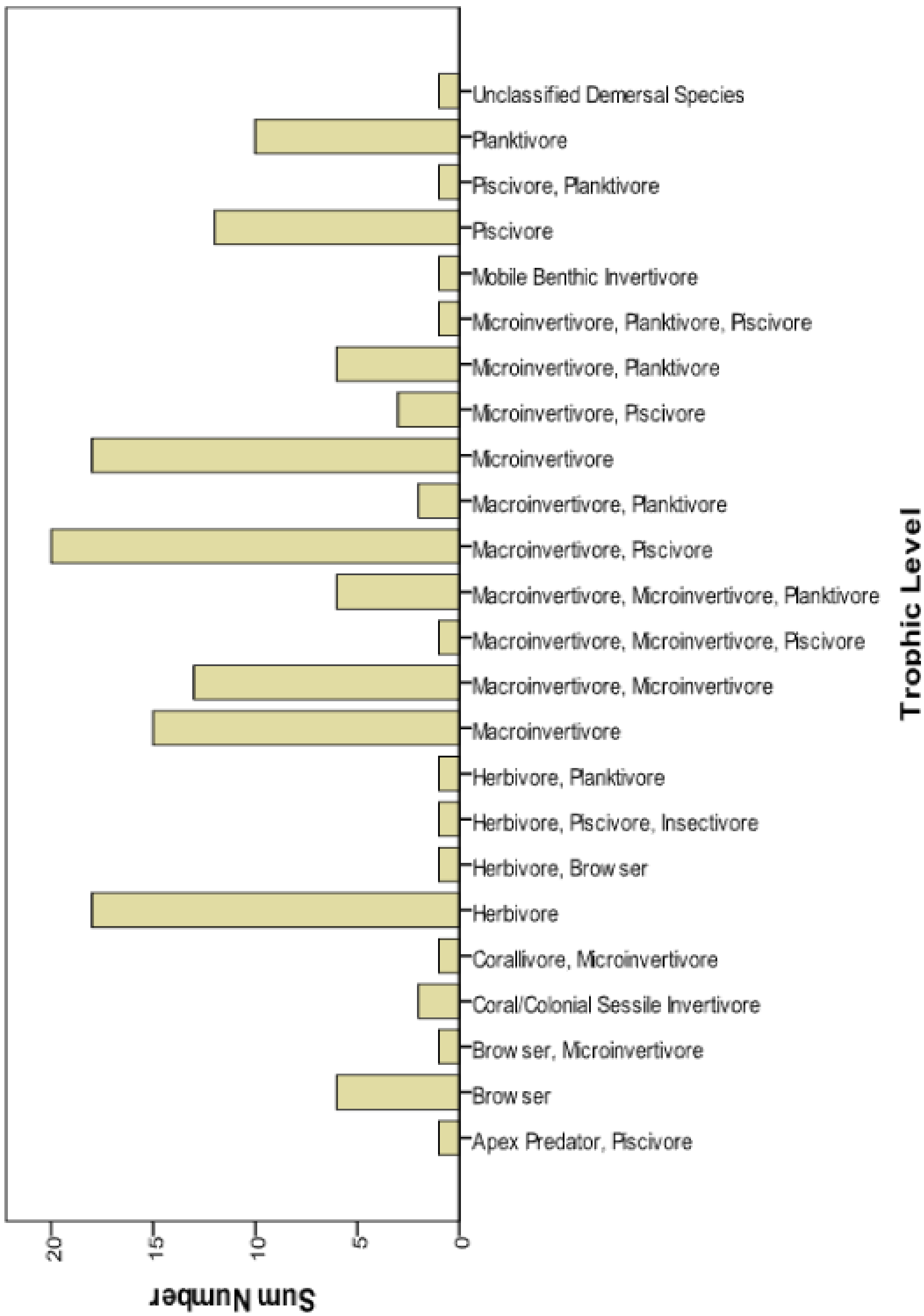

Figure 27: Sum of fish species according to referenced trophic levels.

Table 17: Frequency data for distinct trophic levels for all referenced fish species documented within Bluefields Bay, Jamaica.

	Number of fish per classification	Percent
Planktivore	10	7.0
Piscivore	12	8.5
Unclassified Demersal Species	1	0.7
Microinvertivore, Planktivore	6	4.2
Macroinvertivore, Piscivore	20	14.1
Macroinvertivore, Microinvertivore	13	9.2
Piscivore, Planktivore	1	0.7
Herbivore, Browser	1	0.7
Corallivore, Microinvertivore	1	0.7
Microinvertivore, Planktivore, Piscivore	1	0.7
Browser	6	4.2
Macroinvertivore, Microinvertivore, Planktivore	6	4.2
Herbivore, Piscivore, Insectivore	1	0.7
Microinvertivore, Piscivore	3	2.1
Macroinvertivore, Microinvertivore, Piscivore	1	0.7
Browser, Microinvertivore	1	0.7
Herbivore, Planktivore	1	0.7
Apex Predator, Piscivore	1	0.7
Macroinvertivore, Planktivore	2	1.4
Coral/Colonial Sessile Invertivore	2	1.4
Herbivore	18	12.7
Macroinvertivore	15	10.6
Microinvertivore	18	12.7
Mobile Benthic Invertivore	1	0.7
Total	142	100.0

Species were also classified depending on body shape classifications and are shown in Figure 28. Classifications are as follows and are presented in alphabetical order: Bottom Clinger, Bottom Hider, Bottom Rover, Deep Bodied, Eel-like, Flatfishes, Globiform, Lie-in-wait-Predators, Rattail, Rover-Predator, and finally Surface-Orientated. Frequency information for this data can be found in Table 18.

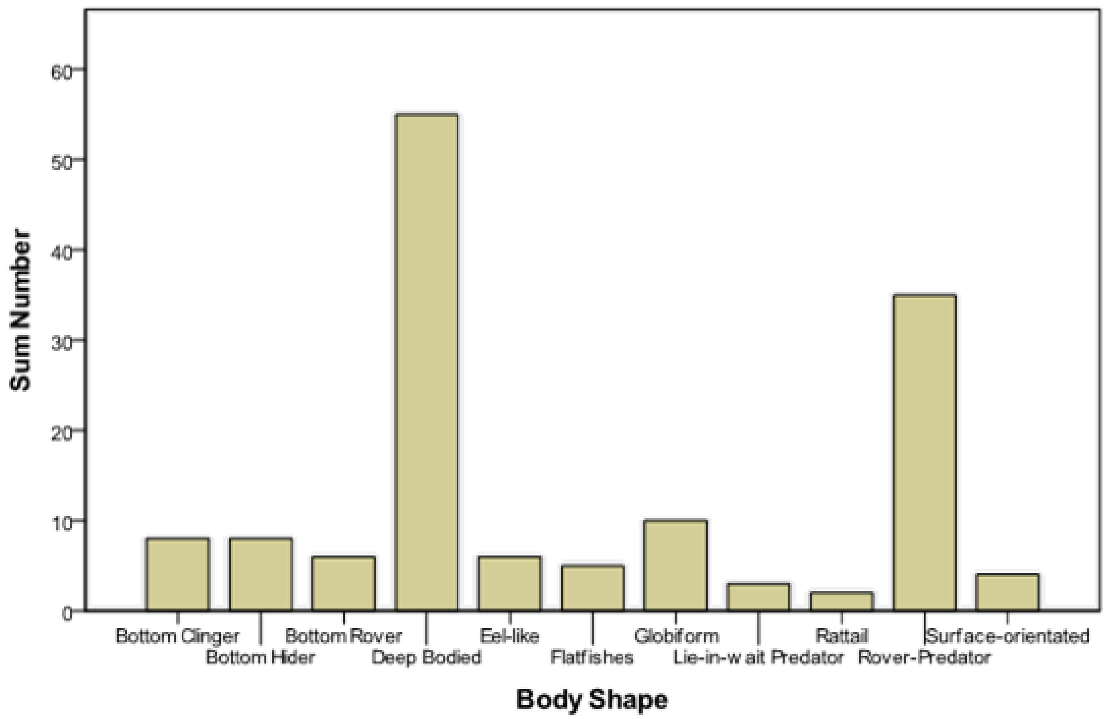

Figure 28: Sum of documented fish species according to body shape classifications. Classifications are based on morphometric features of an individual species.

Table 18: Frequency data with corresponding percentages for body shape classifications for all species noted.

	Number of species within category	Percent
Deep Bodied	55	38.7
Surface-orientated	4	2.8
Rattail	2	1.4
Bottom Hider	8	5.6
Rover-Predator	35	24.6
Flatfishes	5	3.5
Bottom Clinger	8	5.6
Lie-in-wait Predator	3	2.1
Globiform	10	7.0
Eel-like	6	4.2
Bottom Rover	6	4.2
Total	142	100.0

Selected Species Comparisons

A number of species were selected to emphasize the change in community structure within the boundaries of Bluefields Bay Marine Sanctuary. Figure 29 demonstrates selection from Hamulidae and Lutjanidae families. Information is shown for all data collection periods. Some species may not have been present beforehand, or present in low numbers. Increases in means over the three data collection periods were noted for all species concerned. Data does not include Moors Reef which was outside of MPA boundaries and subjected to normal fishermen influences. Figure 30 shows only the French grunt (*Haemulon flavolineatum)* mean fish per meter for all sites during all data collection periods. A distinct increase in the mean fish per meter is indicated for French grunts.

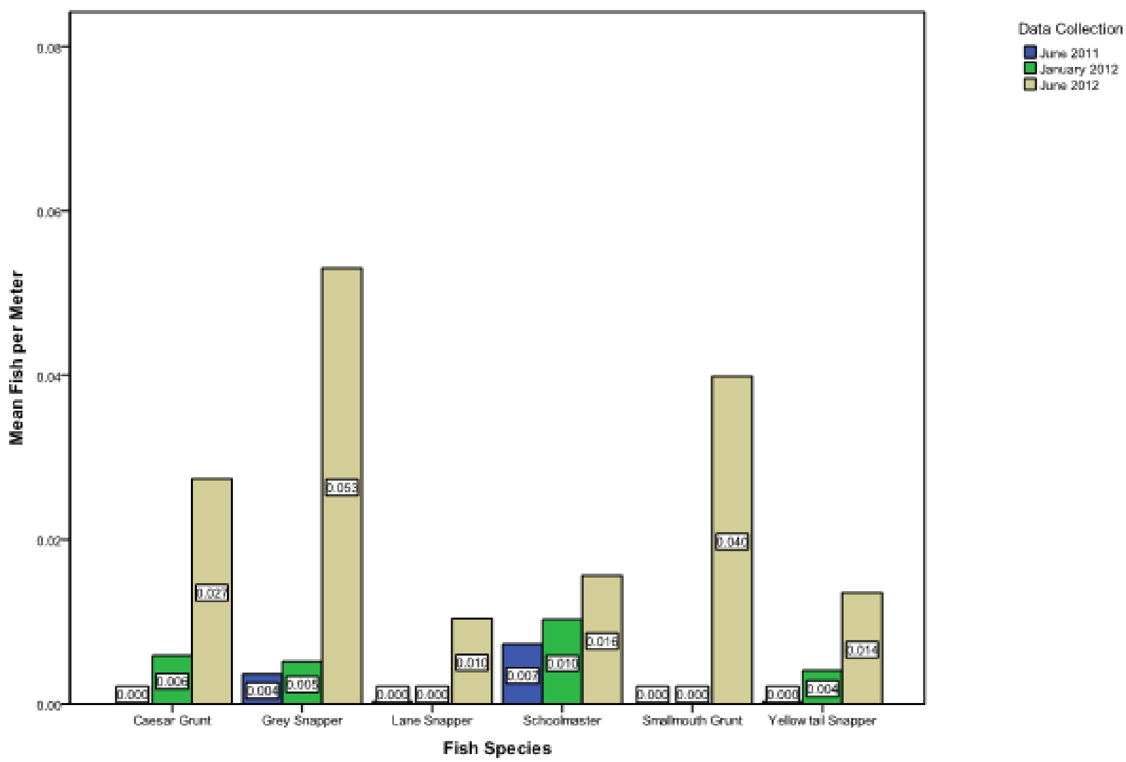

Figure 29: Selected species from Hamulidae and Lutjanidae. Number of fish present per meter over three data collection periods at all sites excluding Moors Reef (outside of sanctuary boundaries).

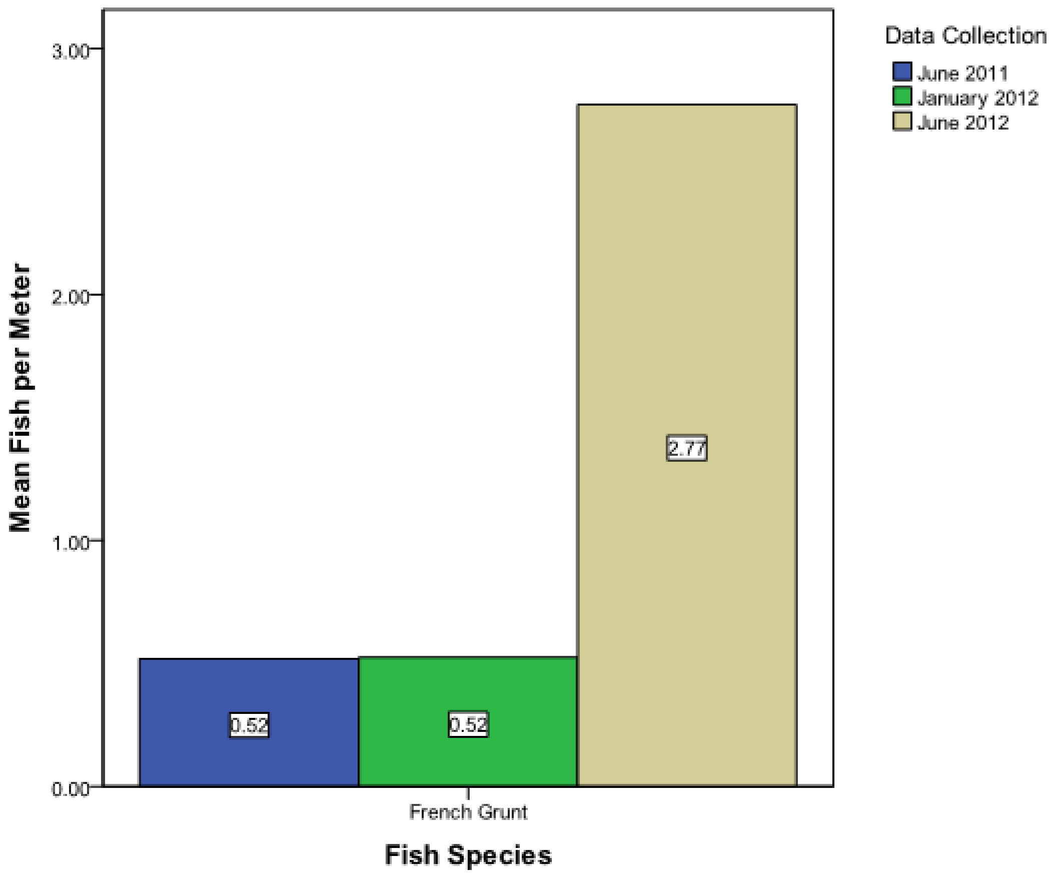

Figure 30: Mean number of French grunt (*Haemulon flavolineatum*) per meter traveled noted during each data collection period at all sites excluding Moors Reef.

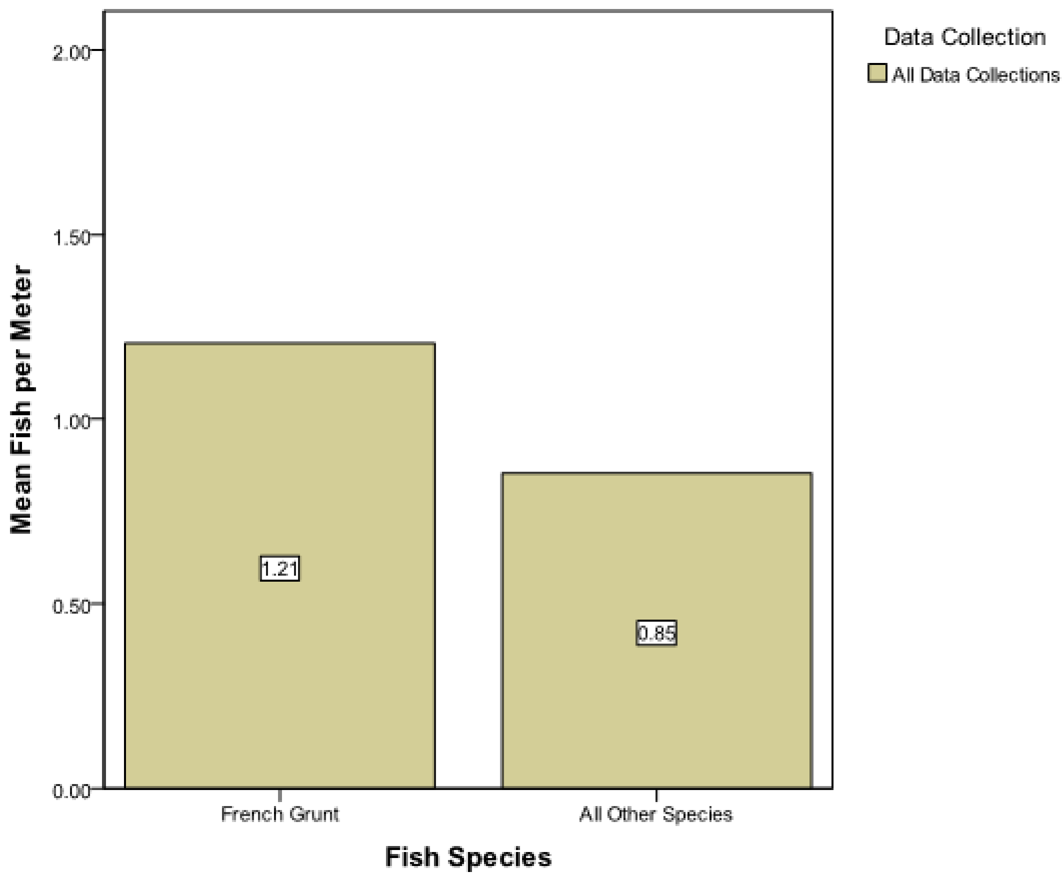

Figure 31: Mean number of French grunts (*Haemulon flavolineatum*) per meter traveled present for all data collection periods versus all other fish documented during same time periods combined. All locations are taken into consideration.

In addition, the total mean fish per meter for all French grunts during all collection periods at all sites was greater than all other fish combined (Figure 31). The Simpsons Diversity Index showed the dominance of that species within the bay. French grunts are clearly the dominant species. Another selection of importance within the bay is the herbivores. During the second data collection, at Moors Reef, a huge school of Atlantic blue tang (500+ individuals) avoided the boat, a snorkeler, or possibly the camera. Typically, tangs were noted as singles or small groups in the videos. All data collection periods are shown for the herbivore mean fish per meter (Figure 32). Data does not include fish documented at Moors Reef as that specific location is outside of the boundaries of the sanctuary. Increases in means are noted for all species except for the stoplight parrotfish.

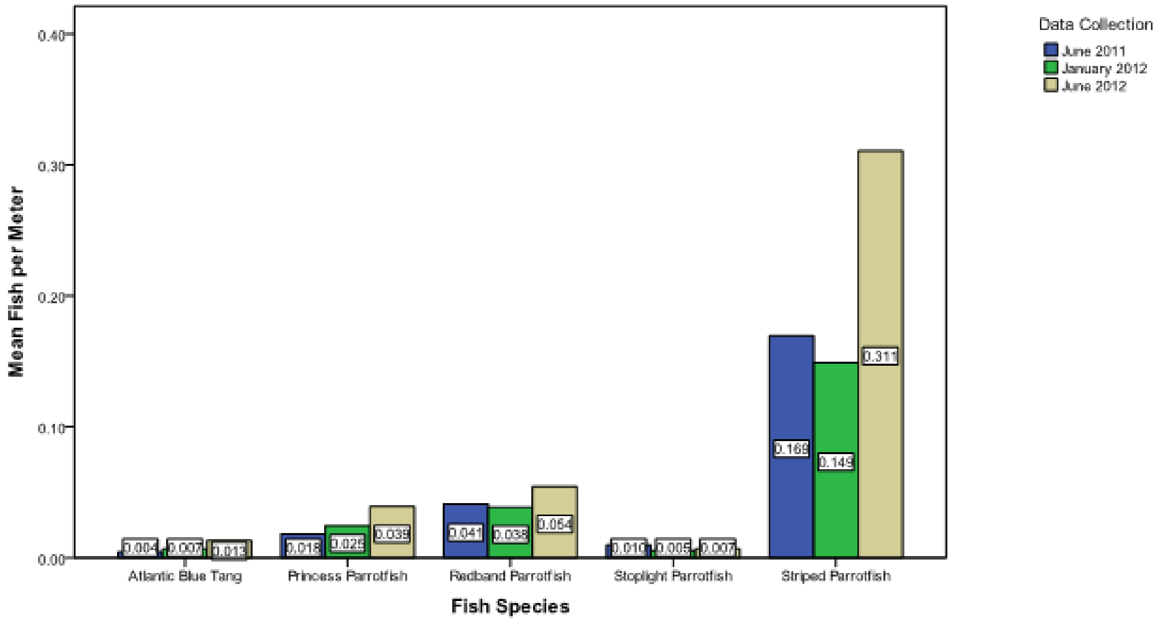

Figure 32: Comparison of selected herbivore species during all data collection periods at all sites excluding Moors Reef. Values reflect mean number of fish per meter traveled during each data collection regardless of location.

Finally, a selection of wrasses was isolated (Figure 33) for all data collection periods. Wrasses appeared to be a large component of the biomass within the bay. Although small, slender and cigar shaped, they traveled in harems with a unique community structure. Males were distinctly obvious due to the color pattern they adopt; juveniles were easy to distinguish as well. Some wrasses appeared to follow the camera, mostly the bluehead wrasse (*Thalassoma bifasciatum*). The figure shows the changes in mean number of fish per meter over time. These wrasse species increased from the first data collection to the third; however a depression in means is noted for the yellowheaded wrasse during the second data collection in January 2012 with a corresponding increase in bluehead wrasses at the same time. During the next transition from second data collection to the third, an increase is noted in yellowheaded wrasse with a decrease in bluehead wrasses. This possibly may be due to seasonality or competition of resources during those time frames within the bay. However, it does not account for other variables within the bay such as depredation or loss of individuals. Merely, a trend is noted.

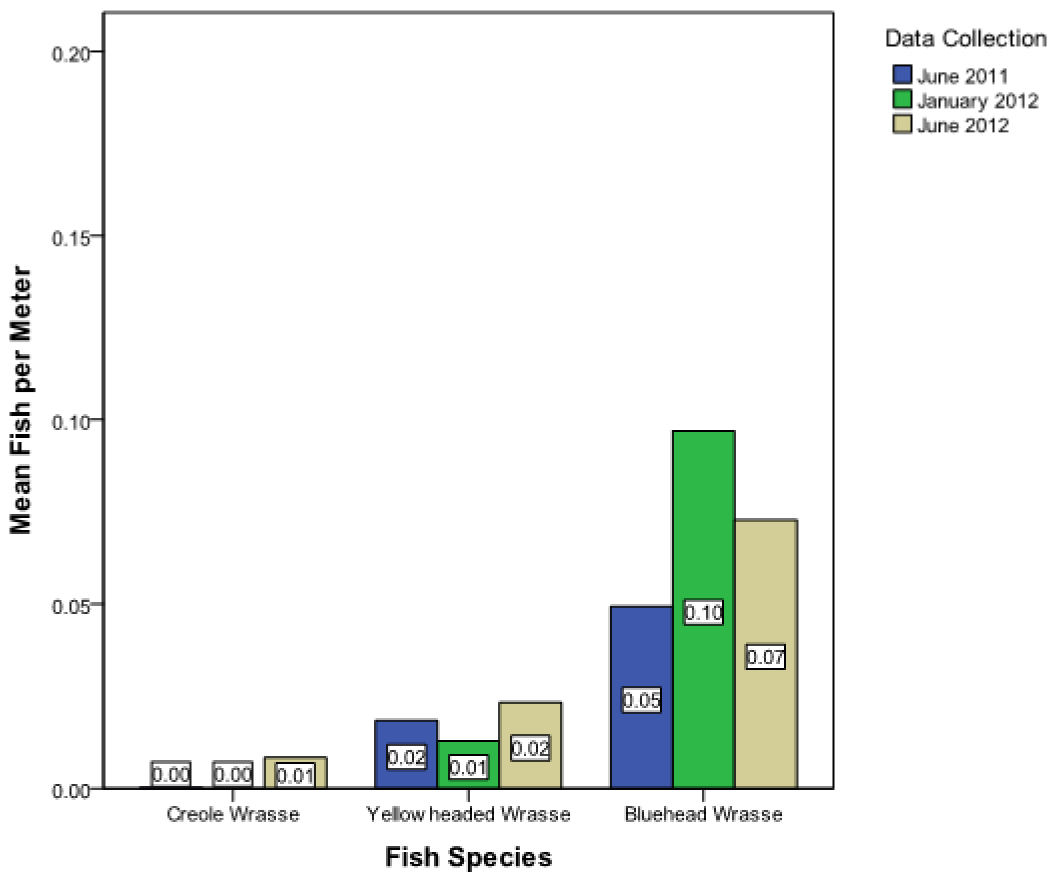

Figure 33: Mean fish per meter for selected wrasse species from all sites excluding Moors Reef and across all data collection periods.

Invertebrate Comparisons

Figure 34 is the resulting data showing habitat association of *Oreaster reticulates* within Bluefields Bay. Although the majority of sea stars were observed within sandbeds, they also occurred elsewhere. However, sampling effort was not even through different habitat units. Juveniles, typically green, spend most of their time within seagrasses (Scheilbling 1980). Seagrasses were only sampled during June 2011. However, some seagrass areas were present during video review for samples in January and June 2012. Those are indicated in the graph. Adult populations prefer sand patches which were surrounded by dense seagrass beds. Limitations in movement due to increased size, alters preference for sandbed locations over seagrass beds as they mature (Scheilbling 1980).

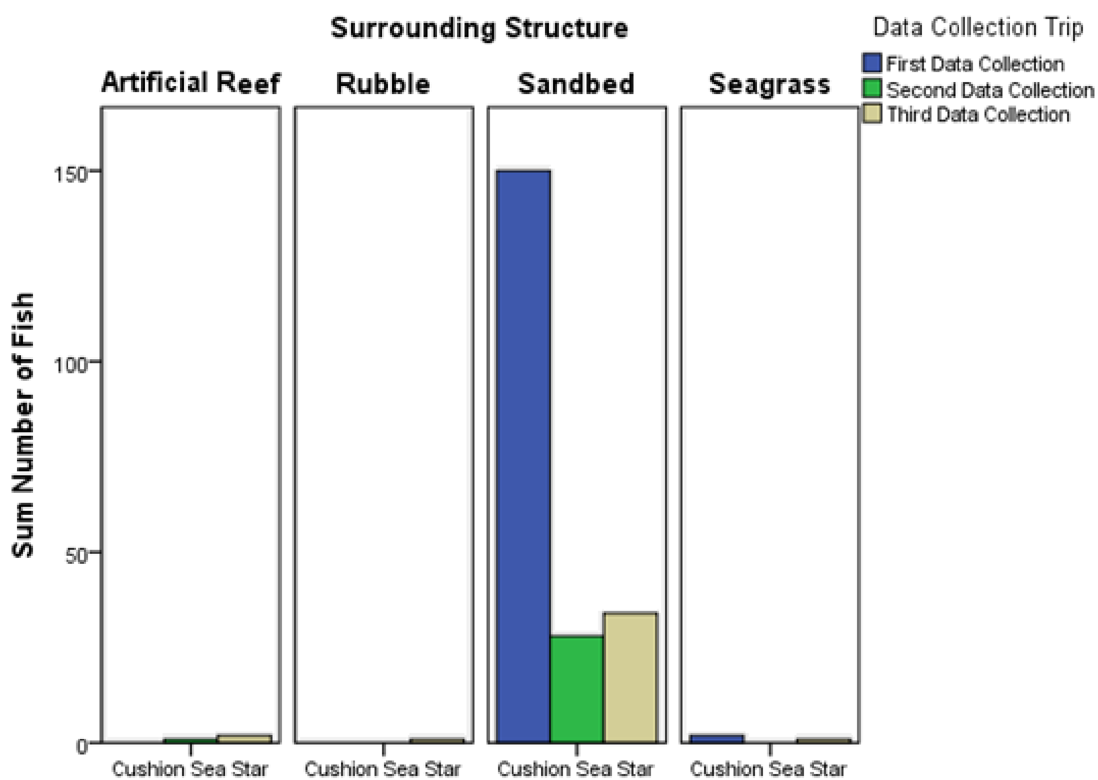

Figure 34: Documented habitat association of the cushion sea star within Bluefields Bay, Jamaica. Although present in different habitats, sandbeds are favored. Actual numbers presented. First data collection (June 2011), second data collection (January 2012), third data collection (June 2012).

The first data collection occurred before the artificial reef was implemented, the second 6 months after, and finally the third data collection occurred a year later. Figure 35 relates the changes in populations of cushion sea stars over the three data collection periods at the artificial reef site. Mean density is determine by number of individuals divided by the distance traveled at this site. Changes in population dynamics are shown over time. Decreases in density after artificial reef implementation are apparent.

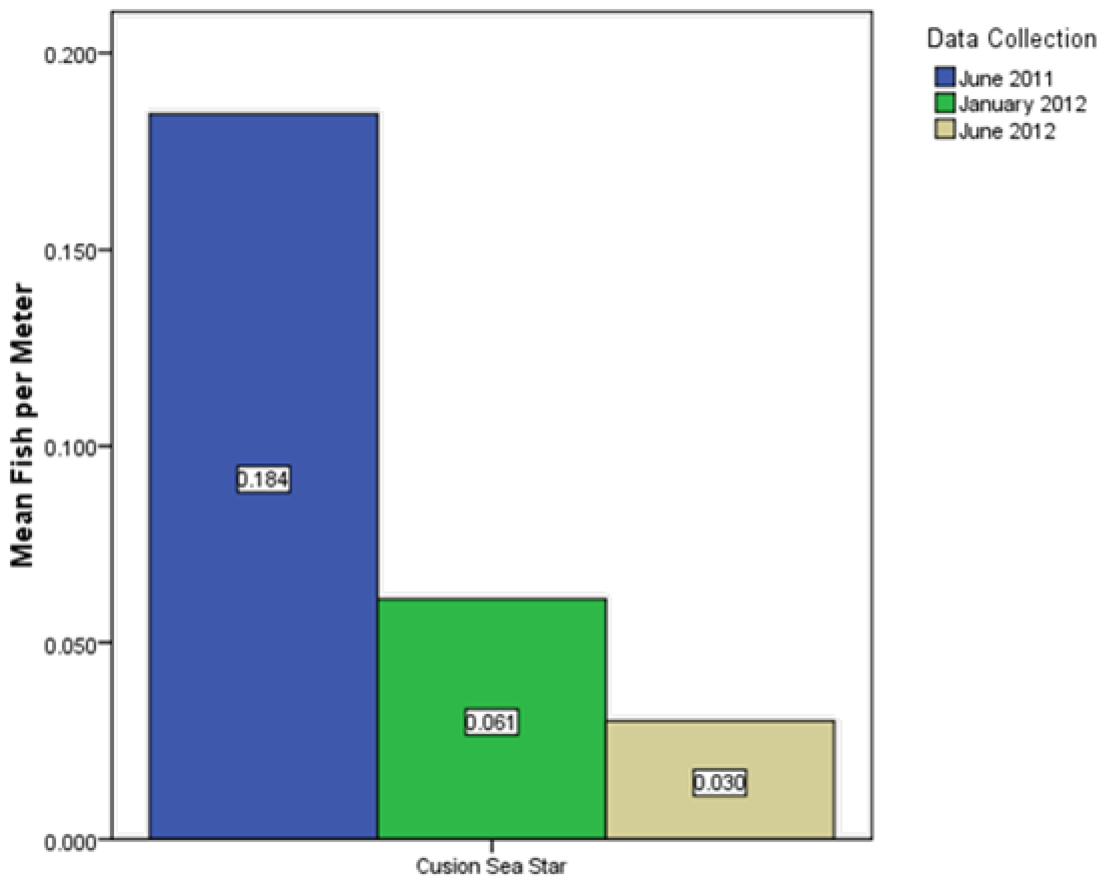

Figure 35: Mean density of Cushion Sea Stars documented at the Artificial Reef site with changes noted over time. The first data collection (June 2011) at the artificial reef site was a pure sandbed with no modules present.

DISCUSSION

A number of questions were addressed in this research project. Most importantly were the effects of the artificial reef implementation into a sandbed within Bluefields Bay Marine Sanctuary in Bluefields, Westmoreland, Jamaica. Fish abundance and diversity increased over time once the artificial reef modules were anchored to the sea floor. Initial sandbed analysis provided a clear picture of the fish population beforehand, composed almost entirely of Rosy Razorfish. Once modules were emplaced, colonization occurred quickly by a number of species. A year later, 8195 individuals were documented over three fifteen minute transects compared to the original 115 individual fish noted at the artificial reef site. Statistically significant differences occurred in mean fish per meter between the Artificial Reef and all controls: Control Reef, Control Sandbed and Moors Reef. Differences were noted between the Control Reef and Control Sandbed as well. No statistically significant differences were discovered between the Control Reef and Moors Reef, or between the Control Sandbed and Moors Reef. Both the fish per meter and fish per transect means were significantly different from the Control Reef, Control Sandbed and Moors Reef which is located outside of sanctuary boundaries. A statistical significance was not noted between locations outside the sanctuary compared to locations inside. However, a slight depression in mean fish density was seen. The slight depression might be attributed to fishermen influences outside, however more research would need to be conducted in order to verify those assumptions.

There were significant differences in Simpsons Diversity Indexes between the first and second data collection and between the first and third data collection. However, due to overwhelming abundance of French grunts, diversity values were depressed with findings of low diversity at the artificial reef site and the Control Sandbed. This is rather misleading as the number of species, or species richness, increased over time and the relative abundances increased over time at the artificial reef site. Finally, the Control Reef and Moors Reef were shown to have high diversity. The Simpsons Diversity variances values were low for the sandbed suggesting that populations were evenly distributed throughout the environment. Whereas the variance was high for the artificial reef suggesting aggregation is occurring at the location. The life history of the Rosy Razorfish could be attributed to this as well. Razorfish live in sandbeds where they create tunnels that they occupy. When disturbed they retreat into the sand to hide from predators. Variability on the artificial reef suggests fish may have more mobility, or aggregations occur. Obviously congregations of fish around the structure made them easier to find, however the variability just means that one sample might have a school of fish move through (or are present on the structure) while the other survey did not have this occurrence (Razorfish in the sandbed maintaining territories).

Species richness increased over time at the Artificial Reef, the Control Reef and Moors Reef across all data collections. Both the Artificial Reef and the Control Reef doubled (or more) in number of species over time. Differences in population dynamics can be found in Appendix V. The Control Sandbed decreased in species richness from 13 to 5 species when comparing the first and second survey periods. However, the number of species increased from the second survey to the final survey with 11 species documented. When the Artificial Reef site was a sandbed in June 2011, numbers reflected values consistent with the Control Sandbed.

The survey methodology used was a conceptual technique which proved successful in its ability to document fish through an area. Avoidance or attraction did not appear to be a significant issue except with bluehead wrasses and a large shoal of Atlantic blue tangs at Moors Reef as discussed previously. Ability of the researcher to recognize individuals and species is key to this method of analysis. Morphometric features and coloration play a pivotal role in determining species within the marine environment. Unfortunately, not all fish enter the view of the camera well enough to distinguish species. Depending on various aspects some areas may not be represented as well as a researcher might hope for, specifically seagrasses. However, this method worked well in areas that were rather open or uncongested with vegetation. Life history and ecology of some fish species are important to consider with this methodology. Some fish are cryptic, benthic, or nocturnal and prefer locations in which the camera would not provide satisfactory results as the camera could not properly survey certain locations. This method works well when limitations on specific areas to be sampled are in place like marine protected areas where collection of specimens may not be permitted. Devices should be meticulously scrutinized in order to determine where possible faults may occur. Improvision of a new technique due to camera malfunctions while on the ocean was not planned for, but was vastly important. Although different in some aspects (camera versus diver), the sites were already determined and coverage of the area was deemed more important. Issues that could bias the methodology by introducing a diver were addressed and avoided at all costs by the diver in order to provide the same types of samples to be collected. However some bias might still be present due to alterations in field of view or depth caused by the change in technique. At this time those aspects cannot be addressed as the camera system is still dysfunctional.

Unfortunately due to the circumstances a density value in the form of fish/m^2 cannot be determined. The height of the camera above the bottom could have influenced the outcome of the results. In order to estimate the potential relative error for density indexes, video was reviewed to determine differences between camera distance and field of view at a site over time. Depending on the depth of the camera the field of view could be potentially wider or narrower than other sampling efforts. The field of view appeared equal at the Artificial Reef between the first and third data collections. This was compared by watching videos in side by side and comparing natural features such as length of fish or seagrass, and patterns within the sand created by starfish. Size was relatively the same across the 6 transects. Camera depth was standardized by the diver during the third data collection. However, the second data collection appeared to have a greater field of view. The number of modules which were present laterally across the field of view in January 2012 was between 4 and 5 modules, whereas the number of units present during sampling in June 2012 was 3 modules. This suggests the height of the camera during January was greater than in June. However, the number of individual fish documented and the fish per meter were in January than in June. Potential biases resulting from variability in the field of view would not likely alter the outcome of the study; in fact it would possibly strengthen my conclusions. No juvenile fish were documented in January, whereas June 2012 the majority of fish documented were juveniles. The field of view appeared relatively equal across natural reef transects, although some variation may be present.

A number of various fish species were documented within particular habitat units in the bay. Twelve distinct natural habitat units were determined (Table 16). Natural reefs contained the largest portion of documentations (45%), followed by Reef-Seagrass (17.6%), Pelagic (11.3%), and finally Reef-Seagrass-Mangroves (9.2%). Habitat units were delineated by association of fish species where they were documented within the bay.

Analysis of seagrass video transects is difficult, as positively identifying fish species is complicated. Various challenges face the observer. Tides and currents move the blades of seagrasses in various fashions, in addition to the boat which samples a haphazard transect. Alternating currents may provide another challenge. Currents at the surface may not be the same as those 6m down in the water column. Seagrass movement adds distraction for the viewer when attempting to locate fish within the frame of the video. As the boat moves along with the camera above the bottom, the rate of speed can be too great to provide any viable data. One video (file #500) from the first data collection was an example of this scenario. Due to the rate of speed, the video could not be properly analyzed and was thrown out. During the second and third data collection trips, seagrass beds were not sampled.

Observation of some species like the bucktooth parrotfish (*Sparisoma radians*) is difficult due to the camouflage patterns they possess; even larger fish such as the hogfish (*Lachnolaimus maximus*) can disappear into the seagrass. Others like striped parrotfish (*Scarus iserti*), redband parrot (*Sparisoma aurofrenatum*), and princess parrots (*Scarus teaniopterus*) which have been noted in the area where difficult to distinguish within the framework of the study. Actual assemblage information will be provided in the following section. Difficulty in identification occurred due to smaller-sized cohorts of juveniles using the seagrasses for protection. Princess parrotfish were easy to distinguish if terminal color phase fish were present due to the blue and yellow colors which contrast to the seagrass beds. Stoplight parrotfish (*Sparisoma viride*) can be easily distinguished as unique phase colorations are present as they exhibit sexual dichromatism (Robertson &

Warner 1978, Bruggemann et al 1994, Humann & DeLoach 2002). Typically when one parrotfish is identified a small group can be located as they travel in foraging groups which can also include other fish taxa and migration patterns of these groups have been described by Odgen and Buckman (1973) for feeding purposes.

Taxonomic composition revealed that Serranidae were most abundant family in observations, followed by Labridae, Pomadasyidae, Gobiidae and finally Lutjanidae and Pomacentridae. These numbers are rather important as they comprise the families of fish which are of economical concern. However, diversity of species does not reflect potential biomass which could be produced within the bay. Although Serranidae (sea basses and groupers), are the most abundant in terms of species present, larger species of this family are lacking within the bay. The largest grouper species noted was a red grouper which was harvested just west of the sanctuary boundary. Species of Serranidae within the bay are mostly hamlets; with the next largest grouper species documented being the red hind (*Epinephelus guttatus*) or the coney (*Epinephelus fulvus*). Those two species are relatively small in size. The other families which were abundant include other important potentially economically valuable fish, Pomadasyidae (grunts) and Lutjanidaes (snappers). Gobiidae (gobies) although diverse in species, provide no economic value as they typically range from 1-3 cm in length and do not provide enough biomass to be edible. The same reasoning applies to the family Pomacentridae (damselfish) as well, although angelfish may be targets within Jamaican waters.

Location of species was important to address to determine whether any bias might be present, if any possible trends might be present, or whether the sanctuary was possibly increasing in species richness. Results were encouraging as the majority (64) of species was noted to be both outside and inside the sanctuary, with 47 species noted only within the sanctuary and 20 species noted only outside the sanctuary. Larger number of species was observed within the bay (111) compared to outside of the boundaries of the sanctuary (84). However, it is important to note that sampling efforts were not the same outside of sanctuary boundaries. The majority of transects occurred within the MPA. The specific reasons for the trend may be due to a number of factors including depth, bottom morphometry or structure, anthropomorphic factors, or a number of other possible variables. Further research would need to be conducted to determine the specific reasons for this observation.

Trophic diversity appeared to be dominated by fish species which were Macroinvertivores/Piscivore (14.1%), followed closely by Herbivores and Microinvertivores both at 12.7%, and Microinvertivores (12.7%). More importantly, the percentage of sole Piscivores (8.5%) and apex predators (0.7%) was depressed. The bay, as with most of Jamaica, lacks predatory fish or those at the top of the food chain (Munro 1983, Hardt 2009). Evidence suggests that virtually all large predatory fish have been removed from Bluefields Bay except for one red grouper and one striped marlin, which were most likely vagrants. A top down cascade is definitely noted in Bluefields Bay. In order for larger predatory fish to be present, recruitment of juveniles has to occur before production can be a viable option within the bay. Fish would have to move into the area through colonization by adults or larval recruitment and establish territories. Some larger predatory fish are pelagic and may spillover into surrounding areas or require large tracks of ocean to complete their life cycles. Additionally, those specimens would have to avoid fishermen, and survive within the sanctuary with proper protection. This recovery of predators could take years in order to create a viable breeding population. Recruits are the most feasible option for Bluefields Bay at this point in time. More studies need to be conducted on the predator prey relationship within the bay to determine the re-establishment of a proper trophic chain.

While assessing trophic interactions within the bay, a trend was identified. Differences in fish morphology were noted (Table 18). The two most prolific forms present within Bluefields Bay were Deep Bodied (38.7%) and Rover Predators (24.6%). Deep Bodied fish are those that are flattened laterally and typically have long dorsal and anal fins. Those would include species like grunts, tangs, angelfish, etc. On the other hand, Rover Predators are streamline with pointed heads with a forked tail. Those include fish like tunas, barracudas, billfish etc. However this body shape is still highly represented within the marine fish community within Bluefields Bay. Species like the houndfish (*Tylosurus crocodilus*), laternbass (*Serranus baldwini*), tobaccofish (*Serranus tabacarius*), and others represent this grouping. Although not great in biomass, they represent smaller predators which occur in the bay. Results support Newman et al. (2006) who observed distinct proportions in fish functional groups within Jamaican waters.

An extensive review of literature provided by Bohnsack and Sutherland (1985) concluded that snappers and grunts have been documented to rapidly colonize artificial reefs. This particular study in Bluefields bay, Jamaica supports those findings. However, the discussion of attraction versus production is a difficult topic to consider. An increase in mean number of fish per meter was noted in Hamulidae (grunts) and Lutjanidae (snappers) bay wide over the three data collection periods for all selected species. Largest numbers were recorded during the third data collection in June 2012. The smallmouth grunt (*Haemulon chrysargyreum*) had the largest change as they were not noted in the first or second data collection. All documented smallmouth grunts were adults suggesting they were recruited to the artificial reef. All individuals observed were documented on the artificial reef modules, not in any other locations. The same occurred with the lane snapper (*Lutjanus synagris*) although a few were documented during the first data collection in June 2011 at the Control Reef. Caesar grunts (*Haemulon carbonarium*) were not noted during the first data collection at any location; however were present during the second and third data collection periods after the artificial reef was installed. Schoolmasters (*Lutjanus apodus*) and grey snappers (*Lutjanus griseus*) were present in relatively equal numbers during the first and second data collection throughout the bay, however remarkable gains were noted in June 2012 for both species. French grunts increased in mean fish per meter over all three data collection periods (Figure 30). When French grunts were compared to all other fish documented within the bay, they were by far the most abundant fish species (Figure 31).

Trends were noticed in a number of selected species throughout the bay. The majority of herbivores increased in mean number for fish per meter over time except for the stoplight parrotfish (*Sparisoma viride*). Exact reasons for these trends cannot be assessed properly without further research. However, this could possibly be a reflection on the success of the sanctuary.

Attraction by fish to the artificial reef in Bluefields Bay is definitely suggested by the data as individuals move from a natural habitat to an artificial one. However, it is too early to tell whether production influences the population dynamics at the artificial reef. Long term studies would need to be conducted at the site. Of important note, only adult fish were documented during the second data collection (January 2012) when the artificial reef was initially assessed. However huge numbers of juvenile French grunts were present during the third data collection. Juveniles maintained densities on the outer edges of the artificial reef while larger more mature fish were present in greater numbers within the interior of structure. A small open sand patch was present the very center of the artificial reef modules which provided more open areas for juveniles to congregate. To say whether these juveniles were produced on the artificial reef or whether they were attracted is unclear. Life histories and cycles would have to be taken into consideration as well as seasonality and biomass. Juveniles would need to be captured and morphometric measures or otoliths would need to be taken in order to assess the age of fish. Brothers and McFarland (1981) suggest counting the number of growth increments in the lapillus in order to determine the age of French grunts. McFarland (1985) further suggests that French grunts have a pelagic larval stage that lasts 15 days. With that information, it could be determined when the fish were produced. To determine if they were produced at the site would be more challenging and would take direct observation at the site. French grunts have not been observed spawning but spawning has been shown to be dependent on tides and moon cycles (McFarland et. al. 1985). However, grunts produce planktonic larvae. Settlement of postlarval juveniles would have to be assessed at the site to be certain. An additional factor relevant to this discussion is the use of surrounding seagrass and mangroves which grunts and snappers have been documented to use throughout their life cycle, especially juveniles (Mateo et. al. 2011). Bluefields Bay has extensive seagrass beds and to the north is lined by mangroves. These habitats have been documented to be instrumental as nursery areas (Johnson et al. 1999; Beck et al. 2001; Jackson et al. 2001; Kathiresan K and B.L. Bingham. 2001)

Although fishermen do target parrotfish for food outside the sanctuary, increases in density was noted over time except for the stoplight parrotfish. Bluefields bay is not affected by the algal dominance shift noted elsewhere on the island. Eutrophication of the bay is lower than other areas in Jamaica, as anthropomorphic factors have not influenced the area, yet (personal observations). Bluefields Bay provides a stark contrast in coral/algal dominance when compared to Discovery Bay. Observations within the area support Goreaus (1992b) findings of excellent reef growth and vital habitats were identified as a major national conservation priority.

Increases in density were noted with the bluehead (*Thalassoma bifasciatum*) and yellowhead wrasses (*Halichoeres garnoti*) over the three data collection periods. Additionally, an increase was noted with the pelagic species, creole wrasse (*Clepticus parrae*). Wrasses do not provide enough sustenance for fishermen to attempt to catch, yet decreases were noticed in overall abundance. Depression in numbers could be due to a number of factors; however dedicated research would need to be carried out in order to determine why these trends occurred. Finally cushion sea stars decreased in observed numbers once the artificial reef was installed at the artificial reef site.

An important consideration for MPA managers to take into account for proper implementation of management objectives within the bay is the incursion of the Indo-Pacific lionfish (*Pterois volitans/miles*). Although small numbers were discovered within the bay, the reproductive capacity of this species is outstanding as no natural predators exist in this particular ecosystem. Large predatory fish like groupers, eels and sharks have been shown to consume lionfish once they recognize them as a food source (Mumby et al. 2011). Typically these introductions are supported by spearfisherman harvest. However, there are no large predatory fish in Jamaican waters. Secondly, being a marine protected area, fish cannot be legally removed, including the lionfish. A draft for the management of lionfish within sanctuary boundaries has been developed by Dr. Dayne Buddo and the University of West Indies Discovery Bay Marine Laboratory in June 2012. The Jamaican government has to provide MPA managers the ability to harvest invasive species within the bay in a controlled manner. Permit regulations distinguished in the draft are supported by this author. Allowing artisanal fisherman to enter the sanctuary with spearfishing equipment to harvest this species would promote further non-compliance.

CONCLUSION

This study focused on the effects of artificial reef implementation into a marine protected area in Bluefields Bay, Jamaica. Alterations in fish population dynamics were substantial. Populations increased substantially in the area where the sandbed was converted to an artificial reef. Colonization of modules by fish populations was rapid and occurred within the first few months of implementation. Forty species were documented at the artificial reef site during June 2012. Some economically important species were noted within the area; however the colonization was disproportionate as vast majority of fish documented were French grunts. A number of fish species were shown to increase in population numbers over time throughout the bay. Surrounding artisanal fisheries might benefit once the populations increase enough to reach the carrying capacity of the artificial reef and surrounding structures. Unfortunately, estimates of that time period and capacity are beyond the scope of this study. The artificial reef had a greater number of fish per meter than a number of nearby reefs. Carrying capacity of the artificial reef would have to be reached first in order for fish to expand their territories. Some fish species appeared to be documented in greater numbers at the artificial reef modules than at natural reef structures in the area. This may be due to the lack of vertical relief provided by Acropora and staghorn corals which were once abundant in this area. Habitat association is given to a structure which imitates these native corals.

Trophic structure may return to a normal state within the boundaries if prey biomass can act as an attractant. Predator species would have to migrate from other waters and survive fishermen pressure to reach the sanctuary. Recruitment may be another factor which could influence the trophic diversity within the area. Larval fish can travel great distances and could move into the sanctuary, where they could mature. Fish populations appear to be increasing within the boundaries. Increases were noted on natural reef structures close to the warden's station within sanctuary boundaries.

Management goals need to be enforced in order to maintain the productivity of the bay in the absence of fishermen influences. The sanctuary however needs assistance from the Jamaican government to be successful, both in terms of financial support and implementation of laws related to enforcement. Demarcation of boundary markers is a high priority to properly announce the location of the Bluefields sanctuary and to decrease fishermen non-compliance. Findings support Goreaus (1992b) statement that Bluefields Bay should be considered a "major national conservation priority". The marine sanctuary needs to be protected by the government, in terms of anthropomorphic factors which affect the bay and from extensive development of the shoreline. Lastly, MPA managers need the authority to remove invasive species which affect the natural biodiversity within the bay. Caution will need to be taken in establishing these protocols so local fishermen do not feel discriminated against by MPA managers. Some fishermen believe the boundaries were established so that MPA managers will be the only fishers in the area (personal communication 2011). Public outreach and education could assist in these management goals. An effort to increase the consumption of lionfish island-wide has been successful thus far.

Buffer strips and protection of land resources vital to the influences on the bay need to be emplaced. Currently no buffer strips on either the ocean boundary or the land boundary are being practiced. Furthermore, vital mangrove habitat on the north shore to the west towards Savanna-la-mar should be included within the boundaries and protected by the laws of the marine sanctuary. Conflicts with artisanal fishermen over boundaries would be diminished and allow wardens to focus on other objectives within the bay if boundary markers were installed with heavy gauge wire. Additionally, if the warden force was increased, they could properly patrol the bay and reduce fishermen non compliance in the north portion of the sanctuary. The hillside provides expansive views where an outpost could be created to provide a visual over watch of the entire bay and radio communications could provide wardens with detailed information. Proficiency in the sanctuary monitoring could be enhanced. Discussion of an at sea monitoring station has been initiated as well (Kristos 2012).

Lastly, the most productive natural reef, known by locals as Moors Reef, should also be included within the sanctuary boundaries. Although this might create some conflict with local artisanal fishermen, the future of Jamaica's marine resources is endanger. Proper management goals need to be identified and established not only at a local scale, but also regionally. Bluefields Bay could be used a model for the remainder of the countries MPAs. Fish populations are under severe threat in Jamaican waters and this specific marine protected area provided an example of how conservation efforts can be productive.

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APPENDICES

Appendix 1

Comprehensive fish list of all species documented by snorkeling, fishermen harvest, or photographic evidence within Bluefields Bay, Jamaica.

Common Name	Species Name	Family	Ref. Pg.	Loc.	Hab. Code	Trophic Code	Body Shape
Sergeant Major	*Abudefduf saxatilus*	Pomacentridae	121	B	P, R	PL	DB
Papillose Blenny	*Acanthemblemaria chaplini*	Chaenopsidae	271	B	R	PL	BH
Spinyhead Blenny	*Acanthemblemaria spinosa*	Chaenopsidae	269	B	R	MI, PL	BH
Wahoo*	*Acanthocybium solandri*	Scombridae	57	S	P,R	MA,P	RP
Ocean Surgeonfish	*Acanthurus bahianus*	Acanthuridae	35	B	R,SG	H	DB
Doctorfish	*Acanthurus chirurgus*	Acanthuridae	35	B	R,SG	H	DB
Blue Tang	*Acanthurus coerulues*	Acanthuridae	33	FC	R,SG	H	DB
Spotted Eagle Ray	*Aetobatus narinari*	Myliobatidae	461	B	P	MA	FF
Redspotted Hawkfish	*Amblycirrhitus pinos*	Cirrhitidae	321	B	R	MI	BC
Porkfish	*Anisotremus virginicus*	Pomadasyidae	97	B	R,SG,M	MA	DB
Flamefish	*Apogon maculates*	Apogonidae	253	B	R	PL	DB
Silversides	*Atherinidae*	Atherinidae	81	S	P,R	PL	RP
Trumpetfish	*Aulostomus maculates*	Aulostomidae	325	S	R,SL	P	LIW
Queen triggerfish*	*Balistes vetula*	Balistidae	337	S	R	MA,MI	DB
Spanish Hogfish	*Bodianus rufus*	Labridae	191	B	R,SG	MA,MI	DB
Peacock Flounder	*Bothus lunatus*	Bothidae	293	S	SA	P	FF
Jolthead Porgy	*Calamus bajonado*	Sparidae	73	FC	R,SG,M	MA	DB
Whitespotted Filefish	*Cantherhines macrocerus*	Monacanthidae	401	S	R	MA	DB
Orangespotted Filefish	*Cantherhines pullus*	Monacanthidae	341	O	R,SG	H	DB
Gold Face Toby	*Canthigaster jamestyleri*	Tetraodontidae	383	O	R,SG	CSI	GL
Sharpnose Puffer	*Canthigaster rostrata*	Tetraodontidae	327	O	R,SG	H,B	GL
Blue Runner (Jack)	*Caranx crysos*	Carangidae	45	S	P	MA,P	RP

Common Name	Species Name	Family	Ref. Pg.	Loc.	Hab. Code	Trophic Code	Body Shape
Common Snook	*Centropomus undecimalis*	Centropomidae	65	S	R,SG,M	MA,P	RP
Atlantic Spadefish*	*Chaetodipterus faber*	Ephippidae	81	B	P	MA	DB
Foureye Butterflyfish	*Chaetodon capistratus*	Chaetodontidae	21	S	R	C,MI	DB
Spotfin Butterflyfish	*Chaetodon ocellatus*	Chaetodontidae		O	R	MI	DB
Banded Butterflyfish	*Chaetodon striatus*	Chaetodontidae	21	O	R	MI,PL	DB
Striped Burrfish	*Chilomycterus schoepfi*	Diodontidae	329	FC	R,SG	MA	GL
Atlantic Bumper	*Chloroscombrus chrysurus*	Carangidae	51	S	P	MI,PL,P	RP
Blue Chromis	*Chromis cyanea*	Pomacentridae	123	B	P,R	PL	DB
Brown Chromis	*Chromis multilineata*	Pomacentridae	125	B	P,R	PL	DB
Creole Wrasse	*Clepticus parrae*	Labridae	193	B	R,SG	PL	DB
Manytooth Conger	*Conger triporicpes*	Congridae	373	B	R	MA,P	EL
Dolphin (Mahi Mahi)*	*Coryphaena hippurus*	Coryphaenidae	41	S	P	MA,P	RP
Bridled Goby	*Coryphopterus glaucofraenum*	Gobiidae	249	O	R	H	BC
Masked Goby	*Coryphopterus personatus*	Gobiidae	251	FC	R	MI	BC
Dash Goby	*Ctenogobius saepepallens*	Gobiidae	275	O	SA	MI	BH
Flying Gurnard	*Dactylopterus volitans*	Dactylopteridae		O	B	MA,MI	BR
Southern Stingray	*Dasyatis Americana*	Dasyatidae	391	S	R,SA,SG	MA	FF
Balloonfish	*Diodon holocanthus*	Diodontidae	331	S	R,SG	MA	GL
Porcupinefish	*Diodon hystrix*	Diodontidae	331	B	R,SG	MA	GL
Sharksucker	*Echeneis naucrates*	Echeneidae	361	B	P	PL	SO
Chain Moray	*Echidna catenata*	Muraenidae	369	B	R	MA	EL
Rainbow Runner*	*Elagatis bipinnulata*	Carangidae	41	O	P	P	RP
Spiny Flounder	*Engyophrys senta*	Bothidae	337	B	SA	MA,P	FF
Rock Hind	*Epinephelus adscensionis*	Serranidae	153	S	R	MA,P	RP
Coney	*Epinephelus fulvus*	Serranidae	155	O	R	MA,P	RP
Red Hind	*Epinephelus guttatus*	Serranidae	153	B	R	MA,P	RP
Red Grouper*	*Epinephelus morio*	Serranidae	139	B	R	MA,P	RP
Highhat	*Equetus acuminatus*	Sciaenidae	353	B	R	MI	RT

Common Name	Species Name	Family	Ref. Pg.	Loc.	Hab. Code	Trophic Code	Body Shape
Spotted Drum	*Equetus punctatus*	Sciaenidae	411	FC	R	MI	RT
Tuna/Little Tuny*	*Euthynnus alletteratus*	Scombridae	59	S	P	P	RP
Yellowfin Mojarra	*Gerres cinereus*	Gerreidae	81	S	SL	MA,MI	RP
Nurse Shark	*Ginglymostoma cirratum*	Orectolobidae	379	B	R,SA	MA,P	BR
Sharknose Goby	*Gobiosoma evelynae*	Gobiidae	239	B	R	MI	BC
Rockcut Goby	*Gobiosoma grosvenori*	Gobiidae	273	B	R	MI	BC
Neon Goby	*Gobiosoma oceanops*	Gobiidae	235	S	R	MI	BC
Broadstripe Goby	*Gobiosoma prochilos*	Gobiidae	241	S	R	MI	BC
Green Moray	*Gymnothorax funebris*	Muraenidae	365	S	R	MA,P	EL
Spotted Moray	*Gymnothorax moringa*	Muraenidae	365	B	R	AP, P	EL
Tomate	*Haemulon aurolineatum*	Pomadasyidae	89	S	R,SG,M	MI,PL	DB
Caesar Grunt	*Haemulon carbonarium*	Pomadasyidae	95	B	R,SG,M	MA,MI,PL	DB
Smallmouth Grunt	*Haemulon chrysargyreum*	Pomadasyidae		B	R	MA,MI,PL	DB
French Grunt	*Haemulon flavolineatum*	Pomadasyidae	85	S	R,SG,M	MA,PL	DB
Spanish Grunt	*Haemulon macrostomum*	Pomadasyidae	91	S	R,SG	MA	DB
Cottonwick	*Haemulon melanurum*	Pomadasyidae		S	R	MA,MI,PL	DB
White Grunt	*Haemulon plumeri*	Pomadasyidae	95	S	R,SG,M	MA,MI,PL	DB
Bluestriped Grunt	*Haemulon sciurus*	Pomadasyidae	93	B	R	MA,MI,PL	DB
Yellowhead Wrasse	*Halichoeres garnoti*	Labridae	197	B	R,SG	MA,MI	RP
Clown Wrasse	*Halichoeres maculipinna*	Labridae	203	S	R,SG	MA,MI	RP
Blackear wrasse	*Halichoeres poeyi*	Labridae	205	B	R	MA,MI	RP
Puddingwife	*Halichoeres radiates*	Labridae	195	B	R	MA,MI	RP
Ballyhoo	*Hemiramphus brasiliensis*	Hemiramphidae	63	B	P	H,P,I	SO
Mirrorwing Flyingfish	*Hirundichthys speculiger*	Exocoetidae	63	O	P	PL	SO
Queen Angelfish	*Holacanthus ciliaris*	Chaetodontidae	27	O	R	B	DB
Rock Beauty	*Holacanthus tricolor*	Chaetodontidae	31	O	R	B	DB
Squirrelfish	*Holocentrus adcensionis*	Holocentridae	215	O	R	MA,MI	DB
Longjaw Squirrelfish	*Holocentrus marianus*	Holocentridae	217	O	R	MA,MI	DB

Common Name	Species Name	Family	Ref. Pg.	Loc.	Hab. Code	Trophic Code	Body Shape
Shy Hamlet	*Hypoplectrus guttavarius*	Serranidae	129	S	R	MI,P	RP
Indigo Hamlet	*Hypoplectrus indigo*	Serranidae	129	B	R	P	RP
Black Hamlet	*Hypoplectrus nigricans*	Serranidae	133	FC	R	MI,P	RP
Masked Hamlet	*Hypoplectrus providencianus*	Serranidae	133	B	R	MI,P	RP
Barred Hamlet	*Hypoplectrus puella*	Serranidae	129	S	R	MI	RP
Butter Hamlet	*Hypoplectrus unicolor*	Serranidae	127	B	R	MI	RP
Hogfish	*Lachnolaimus maximus*	Labridae	213	B	SG	MA	DB
Spotted Trunkfish	*Lactophrys bicaudalis*	Ostraciontidae	335	B	R,SG	B	GL
Honeycomb cowfish*	*Lactophrys polygonia*	Ostraciontidae	333	B	R	B	GL
Smooth Trunkfish	*Lactophrys triqueter*	Ostraciontidae	335	B	R,SG	B	GL
Mutton Snapper	*Lutjanus analis*	Lutjanidae	99	B	R,SG,M	MA,P	DB
Schoolmaster	*Lutjanus apodus*	Lutjanidae	105	B	R,SG,M	MA,P	DB
Red Snapper	*Lutjanus campechanus*	Lutjanidae	109	B	R	MA,MI,PL	DB
Grey Snapper	*Lutjanus griseus*	Lutjanidae	101	S	R,SG,M	MA,P	DB
Saddled Blenny	*Malacoctenus triangulatus*	Blenniidae	263	S	R	MI,PL	BH
Tarpon	*Megalops atlanticus*	Elopidae	79	S	R,SG,M	MA,P	RP
Seminole Goby	*Microgobius carri*	Gobidiidae	285	B	SA	H	BH
Yellowtail Damselfish	*Microspathodon chrysurus*	Pomacentridae	119	O	R	H	DB
White Mullet	*Mugil curema*	Mugilidae	65	B	SG	H	SO
Yellow Goatfish	*Mulloidichthys martinicus*	Mullidae	349	S	R,SA	MI	BR
Sharptail Eel	*Myrichthys breviceps*	Opichthidae	373	B	R,SA	MA	EL
Goldspotted Eel	*Myrichthys ocellatus*	Opichthidae	373	B	R,SA	MA	EL
Blackbar Soldierfish	*Myripristis jacobus*	Holocentridae	219	B	R	MA,MI	DB
Yellowtail Snapper	*Ocyurus chrysurus*	Lutjanidae	107	B	R,SG,M	MA,P	DB
Reef Croaker	*Odontoscion dentex*	Sciaenidae	357	S	R	MA,MI,P	DB
Redlip Blenny	*Ophioblennius atlanticus*	Blenniidae	281	S	R	H	BH
Glassy Sweeper	*Pempheris schomburgki*	Pempheridae	359	B	R	PL	DB
French Angelfish	*Pomacanthus paru*	Chaetodontidae	29	B	R	B	DB

Common Name	Species Name	Family	Ref. Pg.	Loc.	Hab. Code	Trophic Code	Body Shape
Glasseye Snapper	*Priacanthus cruentatus*	Priacanthidae	221	S	R	MA,PL	DB
Spotted Goatfish	*Pseudupenus maculatus*	Mullidae	349	B	R,SA	MI	BR
Lionfish	*Pterois volitans*	Scorpaenidae		FC	R	P	BR
Spotted Soapfish	*Rypticus subbifrenatus*	Grammistidae	169	S	R	UDS	DB
Striped Parrotfish	*Scarus croicensis*	Scaridae	181	FC	R,SG	H	DB
Princess Parrotfish	*Scarus taeniopterus*	Scaridae	179	B	R,SG	H	DB
King Mackerel*	*Scomberomorus cavalla*	Scombridae	55	FC	P	P	RP
Reef Scorpionfish*	*Scorpaenodes caribbaeus*	Scorpaenidae	303	B	R	P	BR
Greater Amberjack	*Seriola rivoliana*	Carangidae	49	S	P	P	RP
Tobaccofish	*Serranus tabacarius*	Serranidae	161	FC	R	MI	RP
Harlequin Bass	*Serranus tigrinus*	Serranidae	159	S	R	MI	RP
Chalk Bass	*Serranus tortugarum*	Serranidae	181	S	R	MI	RP
Redband Parrotfish	*Sparisoma aurofrenatum*	Scaridae	183	O	R,SG	H	DB
Bucktooth Parrotfish	*Sparisoma radians*	Scaridae	188	S	R,SG	H	DB
Yellowtail Parrotfish	*Sparisoma rubripinne*	Scaridae	205	B	R	H	DB
Stoplight Parrotfish	*Sparisoma viride*	Scaridae	179	S	R,SG	H	DB
Bandtail Puffer	*Sphoeroides spengleri*	Tetraodontidae	327	S	R,SG	B, MI	GL
Checkered Puffer	*Sphoeroides testudineus*	Tetraodontidae	327	S	R,SG	CSI	GL
Great Barracuda*	*Sphyraena barracuda*	Sphyraenidae	61	B	P	P	LIW
Dusky Damselfish	*Stegastes fuscus*	Pomacentridae	113	O	R	H	DB
Beaugregory	*Stegastes leucostrictus*	Pomacentridae	117	S	R	H	DB
Bicolor Damsel	*Stegastes partitus*	Pomacentridae	119	FC	R	H, PL	DB
Threespot Damselfish	*Stegastes planifrons*	Pomacentridae	115	B	R	H	DB
Sand Diver	*Synodus intermedius*	Synodontidae	313	B	SA	P	BC
Striped Marlin*	*Tetrapturus audax*	Istiophoridae		B	P	MA,P	RP
Bluehead Wrasse	*Thalassoma bifasciatum*	Labridae	199	S	R, SG	MI,PL	RP
Houndfish	*Tylosurus crocodiles*	Belonidae	59	S	P	MA,P	LIW
Yellow Stingray	*Urolophus jamaicensis*	Urotrygonidae	391	O	R,SA,SG	MA	FF

Common Name	Species Name	Family	Ref. Pg.	Loc.	Hab. Code	Trophic Code	Body Shape
Rosy Razorfish	*Xyrichtys martinicensis*	Labridae	235	B	SA	MA,MI	BH

a. Reference Page: Humann, P., & DeLoach, N. (1994). *Reef fish identification: Florida, Caribbean, Bahamas*. 2nd ed. Jacksonville, Fla.: New World Publications.

b. Location: Sanctuary (S), Outside Sanctuary (O), Both (B), Fishermen Caught (FC)

c. Habitat Code: Benthic (B), Mangroves (M), Pelagic (P), Reef (R), Sandbed (SA), Seagrass (SG), Shoreline (SL)

d. Trophic Code: Apex predator (AP), Browser (B), Corallivore (C), Coral/Colonial Sessile Invertivore (CSI), Herbivore (H), Insectivore (I), Macroinvertivore (MA), Microinvertivore (MI), Mobile Benthic Invertivore (MBI), Planktivore (PL), Piscivore (P), Unclassified Demersal Species (UDS).

e. Body Shape: Bottom Clinger (BC), Bottom Hider (BH), Bottom Rover (BR), Deep Bodied (DB), Eel-like (EL), Flatfishes (FF), Globiform (GL), Lie-in-wait-Predators (LIW), Rattail (RT), Rover-Predator (RP), Surface-Orientated (SO)

f. Asterisk indicates species harvested by fishermen or those in which photographic evidence was presented.

Appendix II

Pelagic species noted by fishermen harvest, snorkeling, scuba diving, and video recording within Bluefields Bay, Jamaica over all data collection periods.

Species	Common Name	Family
Abudefduf saxatilus	Sergeant Major	Pomacentridae
Acanthocybium solandri	Wahoo	Scombridae
Aetobatus narinari	Spotted Eagle Ray	Myliobatidae
Atherinidae/Clupeidae/Engraulididae	Silversides/Herrings/Anchovies	Atherinidae
Caranx crysos	Blue Runner	Carangidae
Caranx ruber	Bar Jack	Carangidae
Chaetodipterus faber	Altantic spadefish	Ephippidae
Chloroscombrus chrysurus	Atlantic Bumper	Carangidae
Chromis cyanea	Blue Chromis	Pomacentridae
Chromis multilineata	Brown Chromis	Pomacentridae
Coryphaena hippurus	Dolphin (Mahi Mahi)	Coryphaenidae
Echeneis naucrates	Sharksucker	Echeneidae
Elagatis bipinnulata	Rainbow Runner	Carangidae
Euthynnus alletteratus	Tuna/Bonita/Little Tuny	Scombridae
Hemiramphus brasiliensis	Ballyhoo	Hemiramphidae
Hirundichthys speculiger	Mirrorwing Flyingfish	Exocoetidae
Scomberomorus cavalla	King Mackerel	Scombridae
Seriola rivoliana	Greater Amberjack	Carangidae
Sphyraena barracuda	Great barracuda	Sphyraenidae
Tetrapturus audax	Striped Marlin	Istiophoridae
Tylosurus crocodilus	Houndfish	Belonidae

Appendix III

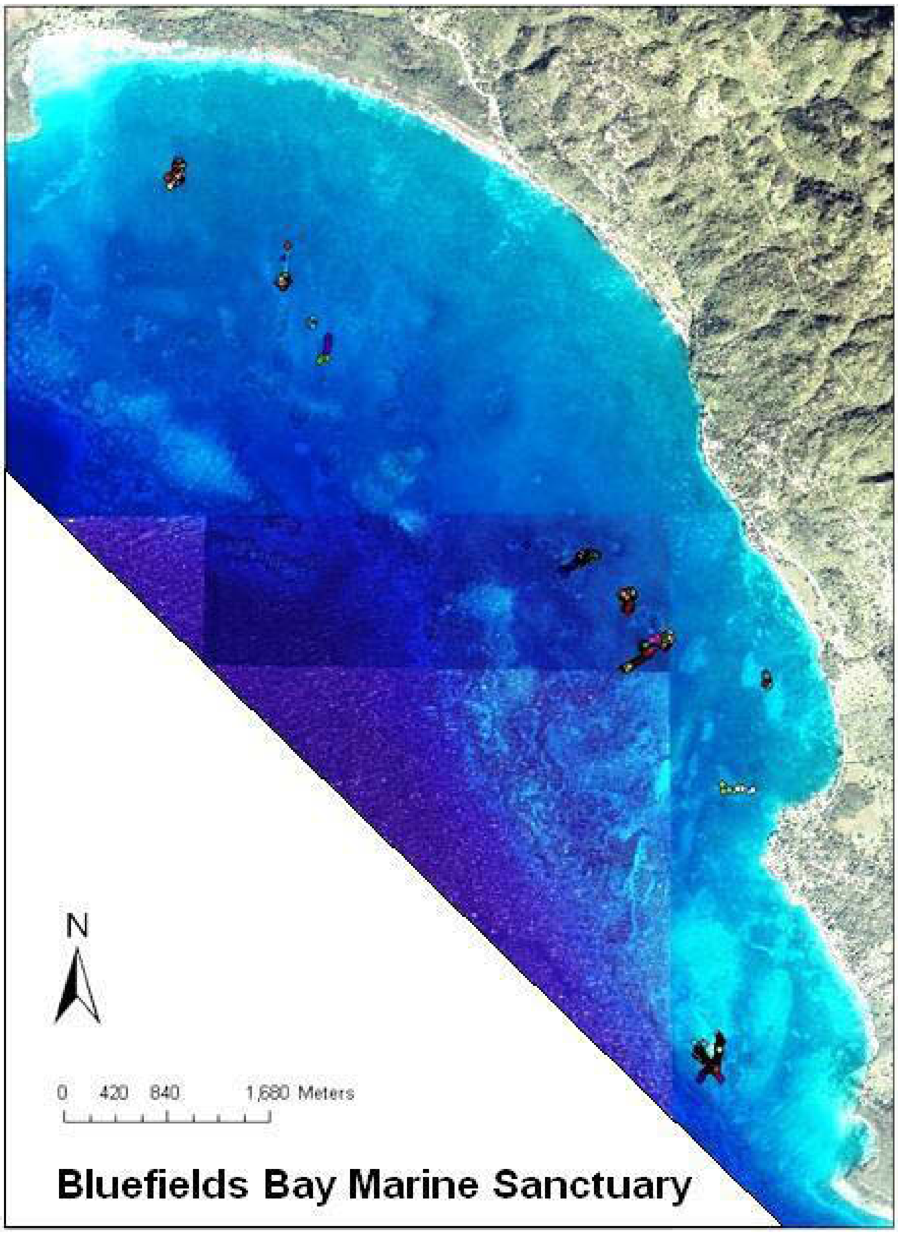
Transect Data as it pertains to specific video numbers.

Video Number	Location	Distance (m)	Distance (ft)
605	BR	20.04	65.73
405	PR	85.59	280.73
420	PR	100.05	328.16
442	SG	173.91	570.41
456	FR	168.25	551.86
500	SG	163.67	536.84
501	ARS	151.77	497.80
517	ARS	150.72	494.36
519	SG	137.88	452.23
534	ARS	125.54	411.75
536	PR	178.37	585.05
546	FR	108.65	356.37
602	PR	124.72	409.07
611	PR	27.27	89.43
624	CS	150.66	494.17
626	PR	198.64	651.55
640	CS	132.98	436.17
642	PR	162.49	532.98
643	BR	21.76	71.36
650	ANCHR	124.23	407.48
656	BR	79.98	262.32
657	CS	96.49	316.49
702	BR	52.72	172.92
717	ED	271.67	891.06
720	ANCHR	147.81	484.81
727	ED	23.20	76.09
736	ED	191.46	627.97
751	MR	82.73	271.34
801	ED	82.01	269.00
812	MR	96.78	317.42
816	ED	72.24	236.96
920	PR	7.51	24.63
937	PR	6.16	20.20
1214	MR	172.29	565.11
1231	MR	132.09	433.27
1249	MR	137.23	450.10
1310	MR	131.31	430.71
1326	MR	135.49	444.42
1346	MR	144.99	475.55

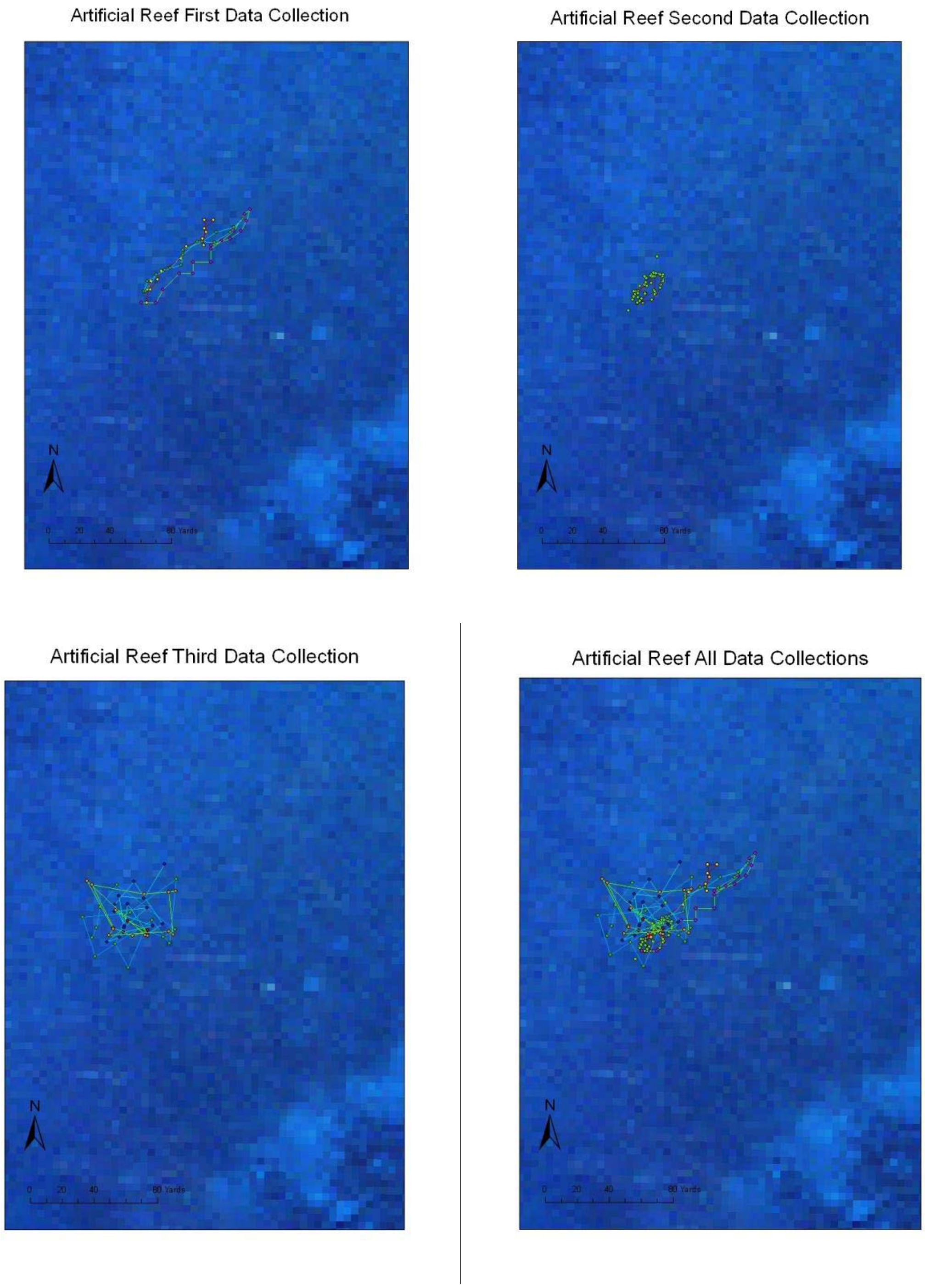
Video Number	Location	Distance (m)	Distance (ft)
1440	CR	125.43	411.40
1459	CR	170.79	560.17
1506	NR	176.16	577.80
1520	CR	101.52	333.00
1527	NR	194.67	638.51
1547	NR	201.53	661.01
1603	ED	104.87	343.99
1625	ED	165.36	542.37
1643	ED	102.89	337.47
1703	AR	129.51	424.80
1725	AR	81.85	268.46
1741	AR	88.76	291.12
2013	CS	54.86	179.93
2030	CS	108.22	354.96
2046	CS	72.80	238.79
AR1	AR	326.05	1069.44
AR2-1 and AR2-2	AR	259.27	850.41
AR3	AR	274.85	901.50
CR1	CR	160.73	527.19
CR2-1 and CR2-2	CR	149.45	490.19
CR3	CR	164.32	538.96
ED1	ED	151.78	497.83
NearReef1 and 1-1	NR	269.53	884.06
NearReef2	NR	243.58	798.95
NearReef3	NR	322.05	1056.33
SB1	CS	159.70	523.82
SB2	CS	196.28	643.81
SB3-1 and SB 3-2	CS	207.90	681.92

a. Locations: Anchor Reef (ANCHR), Artificial Reef (AR), Artificial Reef Sandbed (ARS), Ball Reef (BR), Control Reef (CR), Control Sandbed (CS), Edge Reef (ED), Fishermans Reef (FR), Near Reef (NR), Moors Reef (MR), Patch Reef (PR).

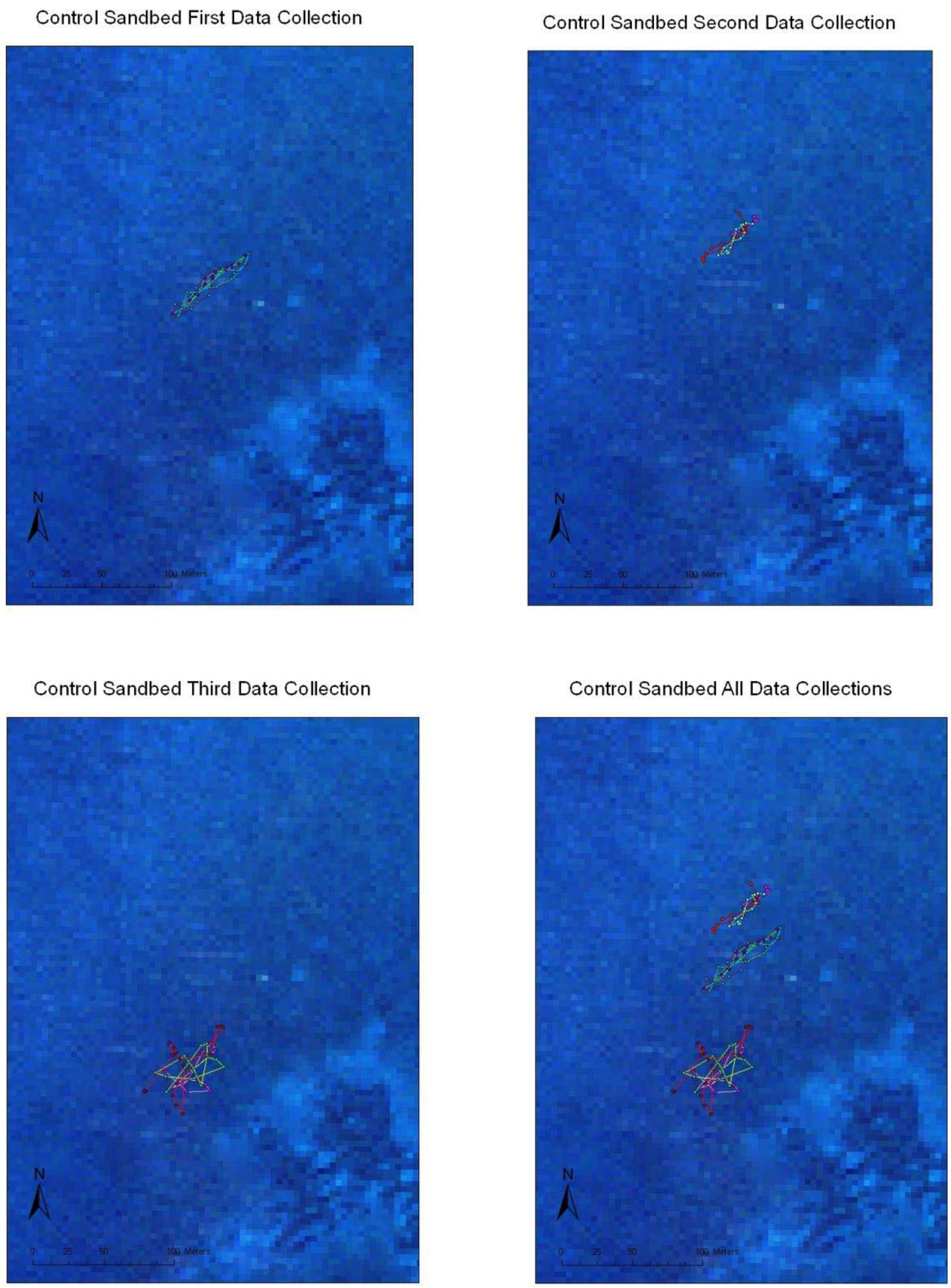
Appendix IV



All surveyed locations over all data collection periods throughout Bluefields Bay, Jamaica. Distortions in figure are due to associations of multiple images of the bay with some portions not present.

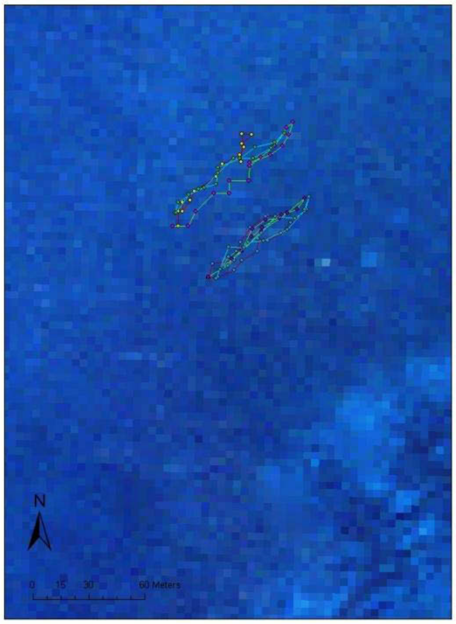


Artificial Reef Transects Over Time. Each map shows all transects at each individual data collection period and all transects at the site in the bottom right map.



Control Sandbed Transects Over Time. Data collection transects shown individually. Additionally comprehensive information is compiled in bottom right map. ArcGIS projection errors are present.

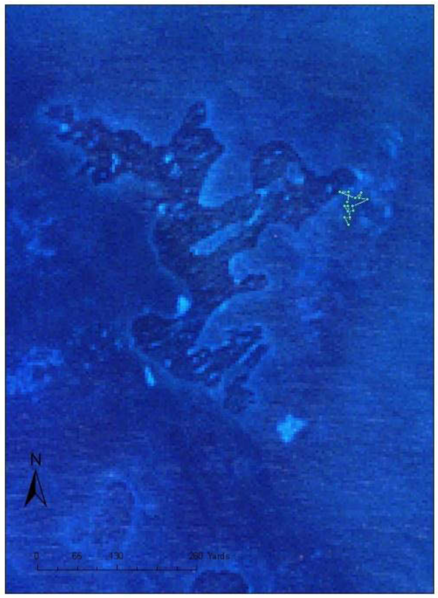
Proper Location Artificial Reef versus Control Sandbed



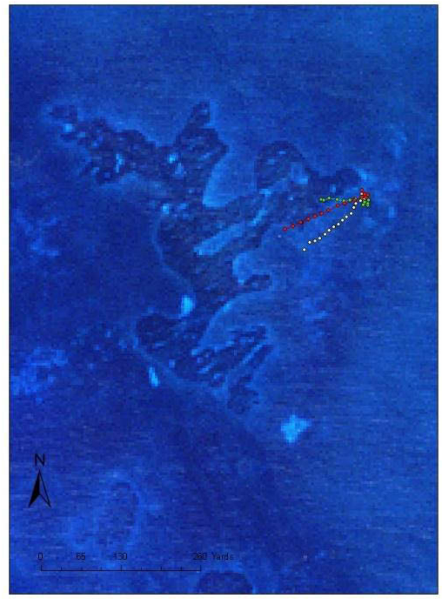
Proper Location Artificial Reef versus Control Sandbed

Artificial Reef versus Control Sandbed locations. First Map relates proper location of the two sandbeds in relation to each other. The second map shows similarities and differences in overlap of transect data.

Control Reef First Data Collection

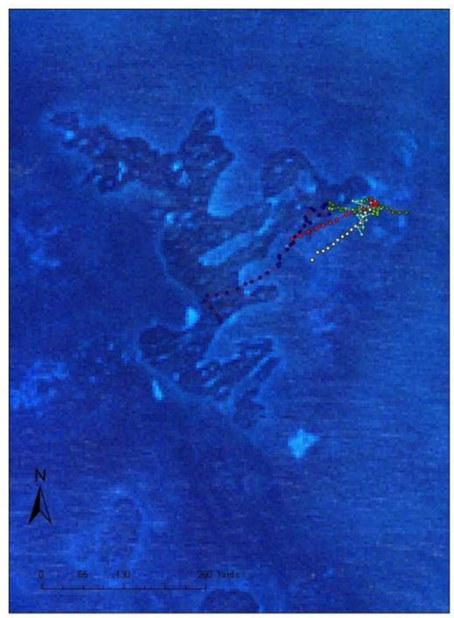


Control Reef Second Data Collection



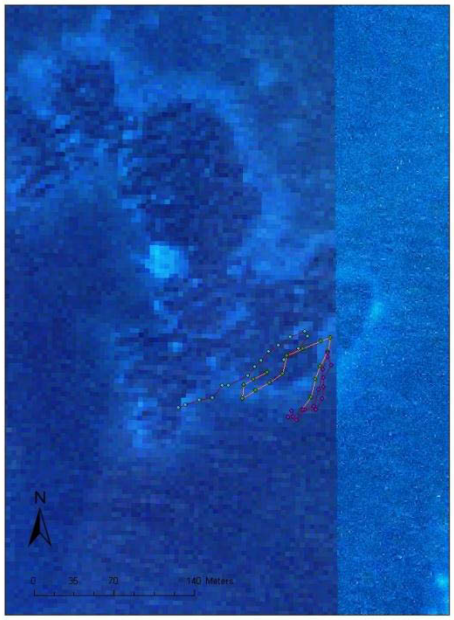
Control Reef Third Data Collection

Control Reef All Data Collections

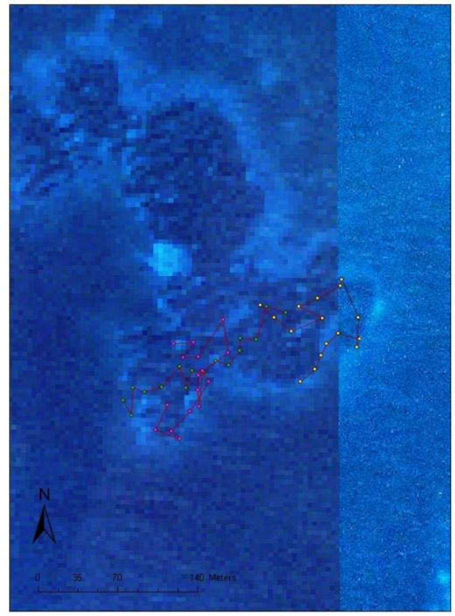


Control Reef Transects shown individually and comprehensively over time.

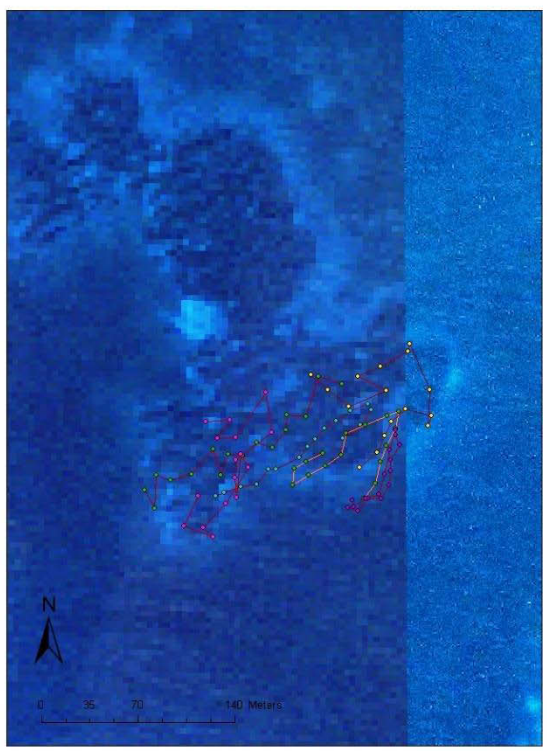
Near Reef First Data Collection



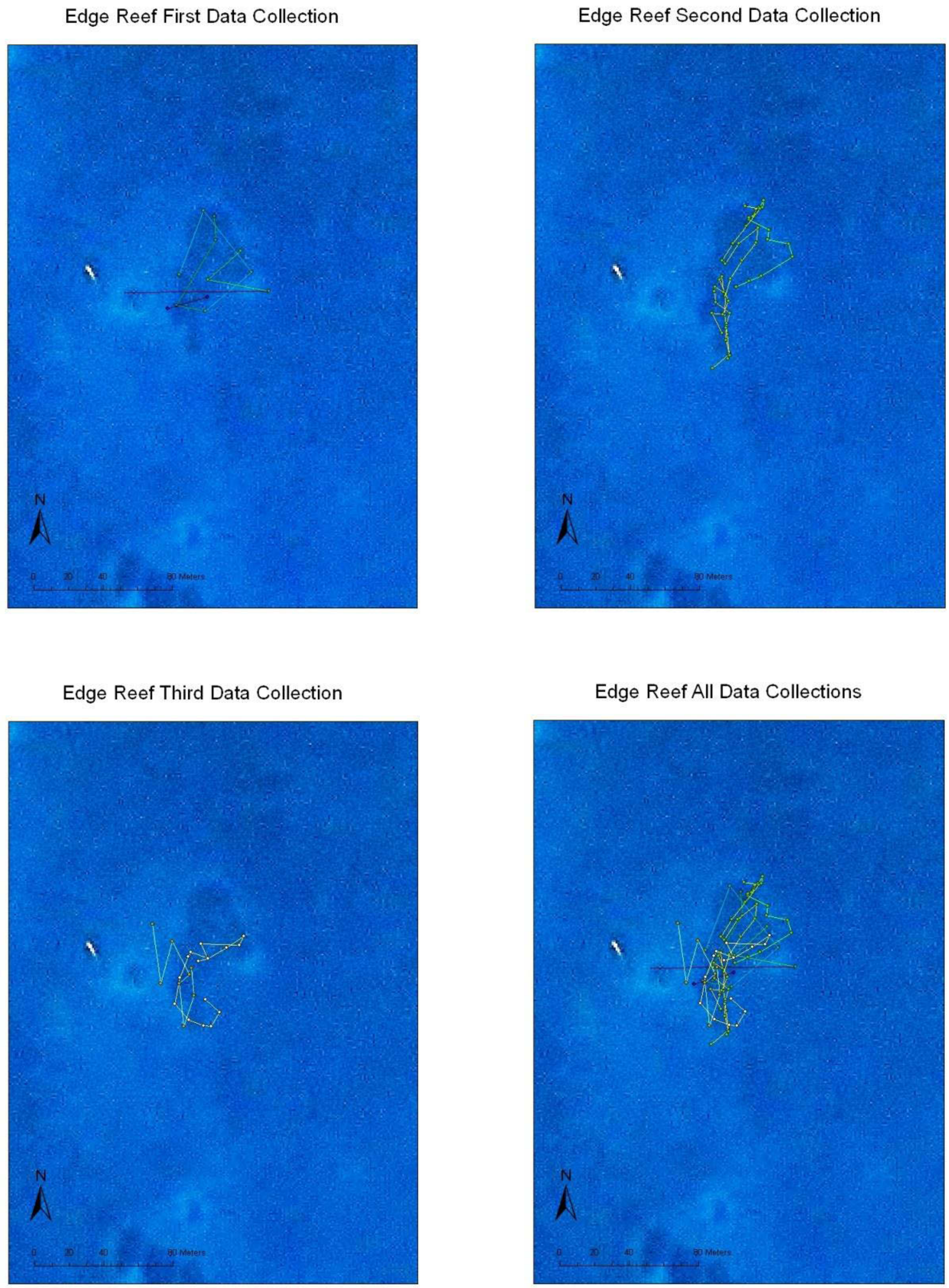
Near Reef Third Data Collection



Near Reef All Data Collections

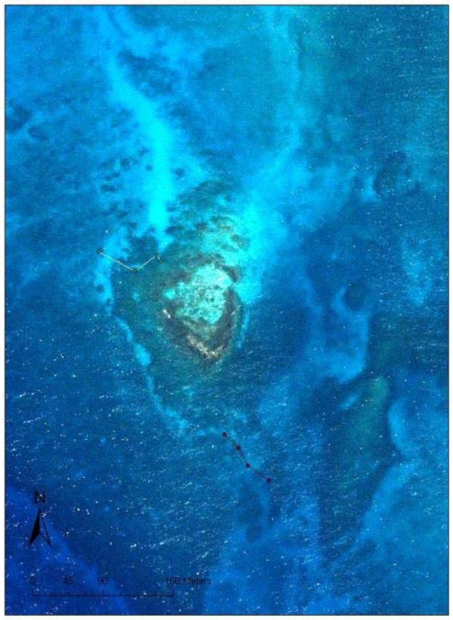


Near Reef Transect Data both individual and comprehensive. This site was not sampled during the second data collection period

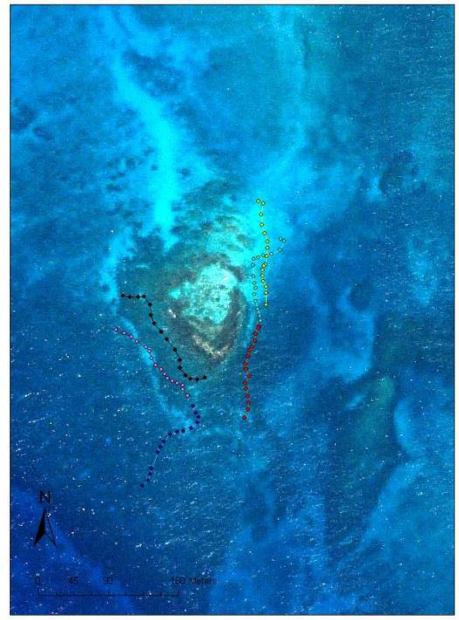


Edge Reef transect data both individual and comprehensive over time.

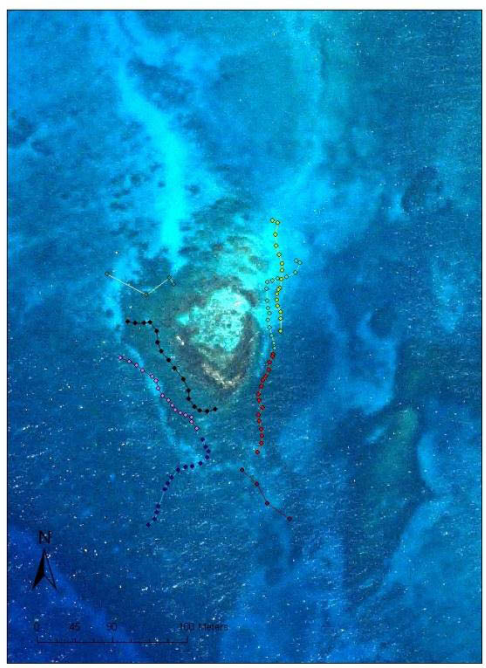
Moor Reef First Data Collection



Moor Reef Second Data Collection

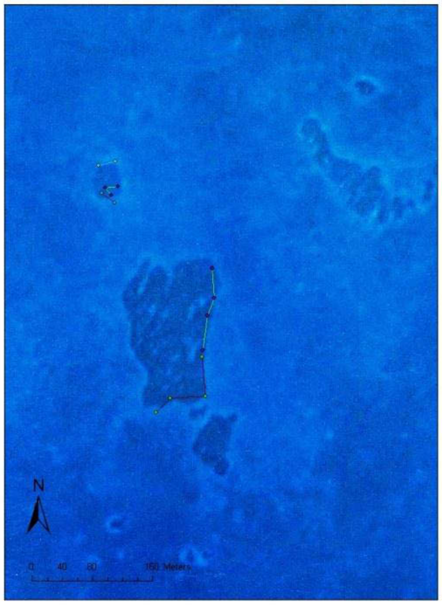


Moor Reef All Data Collections



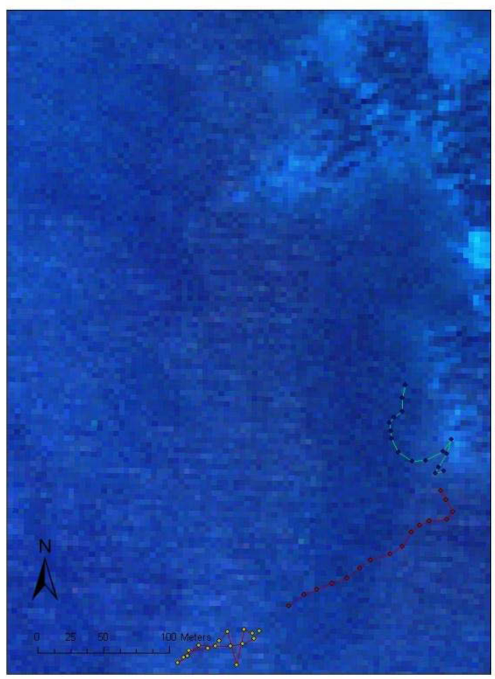
Moor Reef transects data individually and comprehensively over time.

Fishermans Reef and Ball Reef Transect Data



North Reef Transect Data

Seagrass Transect Data



Maps of various labeled locations in which information from only one survey trip was collected.

Appendix V

Simpsons Diversity Index: Absolute and Relative Abundances with associated variances for the Artificial Reef (AR) over three data collection periods. Absolute abundance is the number of individuals of each species whereas relative abundance (p_i) is the number of individuals of a species relative to the total number of individuals.

Fish Species	Trip	Number Fish	n-1	n*(n-1)	p_i	p_i^2	p_i^3
Peacock Flounder	1	1	0	0	8.70E-03	7.56E-05	6.58E-07
Sanddiver	1	1	0	0	8.70E-03	7.56E-05	6.58E-07
Rosy Razorfish	1	17	16	272	1.95E-01	3.82E-02	7.46E-03
Cushion Sea Star	1	87	86	7482	7.57E-01	5.72E-01	4.33E-01
Unidentified	1	9	8	72	7.83E-02	6.12E-03	4.79E-04
Blue Tang	2	1	0	0	8.24E-04	6.80E-07	5.60E-10
Caesar Grunt	2	11	10	110	9.07E-03	8.22E-05	7.46E-07
French Grunt	2	1132	1131	1280292	9.33E-01	8.71E-01	8.13E-01
Schoolmaster	2	1	0	0	8.24E-04	6.80E-07	5.60E-10
Grey Snapper	2	14	13	182	1.15E-02	1.33E-04	1.54E-06
Yellowtail Damselfish	2	1	0	0	8.24E-04	6.80E-07	5.60E-10
Redband Parrotfish	2	11	10	110	9.07E-03	8.22E-05	7.46E-07
Stoplight Parrotfish	2	1	0	0	8.24E-04	6.80E-07	5.60E-10
Cushion Sea Star	2	1	0	0	8.24E-04	6.80E-07	5.60E-10
Unidentified	2	40	39	1560	3.30E-02	1.09E-03	3.59E-05
Cottonwick	3	15	14	210	1.83E-03	3.35E-06	6.13E-09
Blue Tang	3	27	26	702	3.29E-03	1.08E-05	3.57E-08
Bar Jack	3	2	1	2	2.44E-04	5.95E-08	1.45E-11
Foureye Butterflyfish	3	4	3	12	4.88E-04	2.38E-07	1.16E-10
Spotfin Butterflyfish	3	1	0	0	1.22E-04	1.49E-08	1.82E-12
Dash Goby	3	8	7	56	9.76E-04	9.53E-07	9.30E-10
Porcupinefish	3	3	2	6	3.66E-04	1.34E-07	4.90E-11
Spiny Flounder	3	2	1	2	2.44E-04	5.95E-08	1.45E-11
Tomate	3	3	2	6	3.66E-04	1.34E-07	4.90E-11
Caesar Grunt	3	78	77	6006	9.52E-03	9.05E-05	8.62E-07

Fish Species	Trip	Number Fish	n-1	n*(n-1)	p_i	p_i^2	p_i^3
French Grunt	3	7440	7439	55346160	9.08E-01	8.24E-01	7.48E-01
Slippery Dick Wrasse	3	3	2	6	3.66E-04	1.34E-07	4.90E-11
Yellowhead Wrasse	3	2	1	2	2.44E-04	5.95E-08	1.45E-11
Rock Beauty	3	1	0	0	1.22E-04	1.49E-08	1.82E-12
Squirrelfish	3	9	8	72	1.10E-03	1.21E-06	1.32E-09
Masked Hamlet	3	5	4	20	6.10E-04	3.72E-07	2.27E-10
Schoolmaster	3	36	35	1260	4.39E-03	1.93E-05	8.47E-08
Grey Snapper	3	151	150	22650	1.84E-02	3.39E-04	6.25E-06
Lane Snapper	3	24	23	552	2.93E-03	8.57E-06	2.51E-08
Seminole Goby	3	3	2	6	3.66E-04	1.34E-07	4.90E-11
Yellow Goatfish	3	16	15	240	1.95E-03	3.81E-06	7.44E-09
Blackbar Soldierfish	3	1	0	0	1.22E-04	1.49E-08	1.82E-12
Yellowtail Snapper	3	3	2	6	3.66E-04	1.34E-07	4.90E-11
Striped Parrotfish	3	97	96	9312	1.18E-02	1.40E-04	1.66E-06
Princess Parrotfish	3	6	5	30	7.32E-04	5.36E-07	3.92E-10
Harlequin Bass	3	6	5	30	7.32E-04	5.36E-07	3.92E-10
Redband Parrotfish	3	49	48	2352	5.98E-03	3.57E-05	2.14E-07
Bucktooth Parrotfish	3	1	0	0	1.22E-04	1.49E-08	1.82E-12
Yellowtail Parrotfish	3	27	26	702	3.29E-03	1.08E-05	3.57E-08
Stoplight Parrotfish	3	3	2	6	3.66E-04	1.34E-07	4.90E-11
Bandtail Puffer	3	7	6	42	8.54E-04	7.29E-07	6.23E-10
Dusky Damselfish	3	1	0	0	1.22E-04	1.49E-08	1.82E-12
Beaugregory	3	9	8	72	1.10E-03	1.21E-06	1.32E-09
Bicolor Damselfish	3	1	0	0	1.22E-04	1.49E-08	1.82E-12
Sanddiver	3	2	1	2	2.44E-04	5.95E-08	1.45E-11
Bluehead Wrasse	3	17	16	272	2.07E-03	4.30E-06	8.92E-09
Rosy Razorfish	3	9	8	72	1.10E-03	1.21E-06	1.32E-09
Cushion Sea Star	3	6	5	30	7.32E-04	5.36E-07	3.92E-10
Unidentified	3	5	4	20	6.10E-04	3.72E-07	2.27E-10

Simpsons Diversity Index: Absolute and Relative Abundances with associated variances for the Control Reef (CR) over three data collection periods. Absolute abundance is the number of individuals of each species whereas relative abundance (p_i) is the number of individuals of a species relative to the total number of individuals.

Fish Species	Trip	Number Fish	n-1	n*(n-1)	p_i	p_i^2	p_i^3
Atlantic Blue Tang	1	1	0	0	1.47E-02	2.16E-04	3.18E-06
Foureye Butterflyfish	1	1	0	0	1.47E-02	2.16E-04	3.18E-06
Masked Goby	1	9	8	72	1.32E-01	1.75E-02	2.32E-03
Yellowhead Wrasse	1	2	1	2	2.94E-02	8.65E-04	2.54E-05
Squirrelfish	1	1	0	0	1.47E-02	2.16E-04	3.18E-06
Barred Hamlet	1	1	0	0	1.47E-02	2.16E-04	3.18E-06
Schoolmaster	1	3	2	6	4.41E-02	1.95E-03	8.59E-05
Reef Croaker	1	2	1	2	2.94E-02	8.65E-04	2.54E-05
Spotted Goatfish	1	2	1	2	2.94E-02	8.65E-04	2.54E-05
Striped Parrotfish	1	23	22	506	3.38E-01	1.14E-01	3.87E-02
Princess Parrotfish	1	2	1	2	2.94E-02	8.65E-04	2.54E-05
Redband Parrotfish	1	5	4	20	7.35E-02	5.41E-03	3.98E-04
Dusky Damselfish	1	5	4	20	7.35E-02	5.41E-03	3.98E-04
Bicolor Damselfish	1	1	0	0	1.47E-02	2.16E-04	3.18E-06
Threespot Damselfish	1	1	0	0	1.47E-02	2.16E-04	3.18E-06
Unidentified	1	9	8	72	1.32E-01	1.75E-02	2.32E-03
Sergeant Major	2	1	0	0	2.23E-03	4.98E-06	1.11E-08
Atlantic Blue Tang	2	2	1	2	4.46E-03	1.99E-05	8.90E-08
Bar Jack	2	4	3	12	8.93E-03	7.97E-05	7.12E-07
Foureye Butterflyfish	2	1	0	0	2.23E-03	4.98E-06	1.11E-08
Atlantic Blue Chromis	2	5	4	20	1.12E-02	1.25E-04	1.39E-06
Masked Goby	2	5	4	20	1.12E-02	1.25E-04	1.39E-06
Rock Hind	2	2	1	2	4.46E-03	1.99E-05	8.90E-08
Red Hind	2	1	0	0	2.23E-03	4.98E-06	1.11E-08
Caesar Grunt	2	1	0	0	2.23E-03	4.98E-06	1.11E-08
French Grunt	2	55	54	2970	1.23E-01	1.51E-02	1.85E-03
Yellowhead Wrasse	2	4	3	12	8.93E-03	7.97E-05	7.12E-07

Fish Species	Trip	Number Fish	n-1	n*(n-1)	p_i	p_i^2	p_i^3
Rock Beauty	2	1	0	0	2.23E-03	4.98E-06	1.11E-08
Squirrelfish	2	10	9	90	2.23E-02	4.98E-04	1.11E-05
Barred Hamlet	2	5	4	20	1.12E-02	1.25E-04	1.39E-06
Schoolmaster	2	6	5	30	1.34E-02	1.79E-04	2.40E-06
Yellowtail Damselfish	2	3	2	6	6.70E-03	4.48E-05	3.00E-07
Reef Croaker	2	1	0	0	2.23E-03	4.98E-06	1.11E-08
Spotted Goatfish	2	1	0	0	2.23E-03	4.98E-06	1.11E-08
Striped Parrotfish	2	50	49	2450	1.12E-01	1.25E-02	1.39E-03
Princess Parrotfish	2	7	6	42	1.56E-02	2.44E-04	3.81E-06
Redband Parrotfish	2	21	20	420	4.69E-02	2.20E-03	1.03E-04
Yellowtail Parrotfish	2	5	4	20	1.12E-02	1.25E-04	1.39E-06
Stoplight Parrotfish	2	2	1	2	4.46E-03	1.99E-05	8.90E-08
Dusky Damselfish	2	89	88	7832	1.99E-01	3.95E-02	7.84E-03
Bicolor Damselfish	2	44	43	1892	9.82E-02	9.65E-03	9.47E-04
Threespot Damselfish	2	1	0	0	2.23E-03	4.98E-06	1.11E-08
Bluehead Wrasse	2	27	26	702	6.03E-02	3.63E-03	2.19E-04
Unidentified	2	91	90	8190	2.03E-01	4.13E-02	8.38E-03
Sergeant Major	3	2	1	2	1.41E-03	2.00E-06	2.83E-09
Ocean Surgeonfish	3	1	0	0	7.07E-04	5.00E-07	3.54E-10
Doctorfish	3	1	0	0	7.07E-04	5.00E-07	3.54E-10
Atlantic Blue Tang	3	5	4	20	3.54E-03	1.25E-05	4.42E-08
Porkfish	3	1	0	0	7.07E-04	5.00E-07	3.54E-10
Spanish Hogfish	3	4	3	12	2.83E-03	8.00E-06	2.26E-08
Foureye Butterflyfish	3	2	1	2	1.41E-03	2.00E-06	2.83E-09
Banded Butterflyfish	3	1	0	0	7.07E-04	5.00E-07	3.54E-10
Brown Chromis	3	4	3	12	2.83E-03	8.00E-06	2.26E-08
Creole Wrasse	3	20	19	380	1.41E-02	2.00E-04	2.83E-06
Masked Goby	3	190	189	35910	1.34E-01	1.81E-02	2.43E-03
Red Hind	3	2	1	2	1.41E-03	2.00E-06	2.83E-09
Sharknose Goby	3	2	1	2	1.41E-03	2.00E-06	2.83E-09

Fish Species	Trip	Number Fish	n-1	n*(n-1)	p_i	p_i^2	p_i^3
Neon Goby	3	5	4	20	3.54E-03	1.25E-05	4.42E-08
Caesar Grunt	3	1	0	0	7.07E-04	5.00E-07	3.54E-10
French Grunt	3	213	212	45156	1.51E-01	2.27E-02	3.42E-03
White Grunt	3	1	0	0	7.07E-04	5.00E-07	3.54E-10
Yellowhead Wrasse	3	45	44	1980	3.18E-02	1.01E-03	3.22E-05
Queen Angelfish	3	1	0	0	7.07E-04	5.00E-07	3.54E-10
Rock Beauty	3	2	1	2	1.41E-03	2.00E-06	2.83E-09
Squirrelfish	3	19	18	342	1.34E-02	1.81E-04	2.43E-06
Longjaw Squirrelfish	3	3	2	6	2.12E-03	4.50E-06	9.55E-09
Shy Hamlet	3	2	1	2	1.41E-03	2.00E-06	2.83E-09
Indigo Hamlet	3	1	0	0	7.07E-04	5.00E-07	3.54E-10
Masked Hamlet	3	1	0	0	7.07E-04	5.00E-07	3.54E-10
Barred Hamlet	3	4	3	12	2.83E-03	8.00E-06	2.26E-08
Butter Hamlet	3	1	0	0	7.07E-04	5.00E-07	3.54E-10
Schoolmaster	3	6	5	30	4.24E-03	1.80E-05	7.64E-08
Grey Snapper	3	2	1	2	1.41E-03	2.00E-06	2.83E-09
Lane Snapper	3	2	1	2	1.41E-03	2.00E-06	2.83E-09
Seminole Goby	3	3	2	6	2.12E-03	4.50E-06	9.55E-09
Yellowtail Damselfish	3	3	2	6	2.12E-03	4.50E-06	9.55E-09
Yellow Goatfish	3	8	7	56	5.66E-03	3.20E-05	1.81E-07
Blackbar Soldierfish	3	4	3	12	2.83E-03	8.00E-06	2.26E-08
Yellowtail Snapper	3	8	7	56	5.66E-03	3.20E-05	1.81E-07
Spotted Goatfish	3	18	17	306	1.27E-02	1.62E-04	2.06E-06
Lionfish	3	1	0	0	7.07E-04	5.00E-07	3.54E-10
Whitespotted Soapfish	3	1	0	0	7.07E-04	5.00E-07	3.54E-10
Striped Parrotfish	3	433	432	187056	3.06E-01	9.38E-02	2.87E-02
Princess Parrotfish	3	45	44	1980	3.18E-02	1.01E-03	3.22E-05
Redband Parrotfish	3	49	48	2352	3.47E-02	1.20E-03	4.16E-05
Bucktooth Parrotfish	3	2	1	2	1.41E-03	2.00E-06	2.83E-09
Stoplight Parrotfish	3	10	9	90	7.07E-03	5.00E-05	3.54E-07

Fish Species	Trip	Number Fish	n-1	n*(n-1)	p_i	p_i^2	p_i^3
Bandtail Puffer	3	13	12	156	9.19E-03	8.45E-05	7.77E-07
Dusky Damselfish	3	80	79	6320	5.66E-02	3.20E-03	1.81E-04
Beaugregory	3	15	14	210	1.06E-02	1.13E-04	1.19E-06
Bicolor Damselfish	3	43	42	1806	3.04E-02	9.25E-04	2.81E-05
Threespot Damselfish	3	10	9	90	7.07E-03	5.00E-05	3.54E-07
Bluehead Wrasse	3	91	90	8190	6.44E-02	4.14E-03	2.67E-04
Fairy Basslet	3	8	7	56	5.66E-03	3.20E-05	1.81E-07
Unidentified	3	18	17	306	1.27E-02	1.62E-04	2.06E-06

a. Data Collections occurred June 2011, January 2012, and June 2012.

b. Values were used to determine Simpsons Diversity Index and variance of diversity.

Simpsons Diversity Index: Absolute and Relative Abundances with associated variances for the Control Sandbed (CS) over three data collection periods. Absolute abundance is the number of individuals of each species whereas relative abundance (p_i) is the number of individuals of a species relative to the total number of individuals.

Fish Species	Trip	Number Fish	n-1	n*(n-1)	p_i	p_i^2	p_i^3
Peacock Flounder	1	1	0	0	3.89E-03	1.51E-05	5.89E-08
Bar Jack	1	161	160	25760	6.26E-01	3.92E-01	2.46E-01
Bridled Goby	1	1	0	0	3.89E-03	1.51E-05	5.89E-08
Flying Gurnard	1	2	1	2	7.78E-03	6.06E-05	4.71E-07
Slippery Dick Wrasse	1	2	1	2	7.78E-03	6.06E-05	4.71E-07
Yellowhead Wrasse	1	11	10	110	4.28E-02	1.83E-03	7.84E-05
Spotted Goatfish	1	1	0	0	3.89E-03	1.51E-05	5.89E-08
Redband Parrotfish	1	1	0	0	3.89E-03	1.51E-05	5.89E-08
Yellow Stingray	1	2	1	2	7.78E-03	6.06E-05	4.71E-07
Rosy Razorfish	1	2	1	2	7.78E-03	6.06E-05	4.71E-07
Caribbean Spiny Lobster	1	1	0	0	3.89E-03	1.51E-05	5.89E-08
Cushion Sea Star	1	62	61	3782	2.41E-01	5.82E-02	1.40E-02
Unidentified	1	10	9	90	3.89E-02	1.51E-03	5.89E-05
Spanish Hogfish	2	1	0	0	1.82E-02	3.31E-04	6.01E-06
Yellow Stingray	2	1	0	0	1.82E-02	3.31E-04	6.01E-06
Rosy Razorfish	2	28	27	756	5.09E-01	2.59E-01	1.32E-01
Cushion Sea Star	2	23	22	506	4.18E-01	1.75E-01	7.31E-02
Unidentified	2	2	1	2	3.64E-02	1.32E-03	4.81E-05
Trumpetfish	3	1	0	0	3.91E-03	1.53E-05	5.96E-08
Dash Goby	3	10	9	90	3.91E-02	1.53E-03	5.96E-05
Spiny Flounder	3	1	0	0	3.91E-03	1.53E-05	5.96E-08
French Grunt	3	149	148	22052	5.82E-01	3.39E-01	1.97E-01
Lantern Bass	3	3	2	6	1.17E-02	1.37E-04	1.61E-06

Fish Species	Trip	Number Fish	n-1	n*(n-1)	p_i	p_i^2	p_i^3
Redband Parrotfish	3	6	5	30	2.34E-02	5.49E-04	1.29E-05
Rosy Razorfish	3	50	49	2450	1.95E-01	3.81E-02	7.45E-03
Cushion Sea Star	3	1	0	0	3.91E-03	1.53E-05	5.96E-08
Cushion Sea Star	3	30	29	870	1.17E-01	1.37E-02	1.61E-03
Cushion Sea Star	3	1	0	0	3.91E-03	1.53E-05	5.96E-08
Unidentified	3	1	0	0	3.91E-03	1.53E-05	5.96E-08

a. Data Collections occurred June 2011, January 2012, and June 2012.
b. Values were used to determine Simpsons Diversity Index and variance of diversity.

Simpsons Diversity Index: Absolute and Relative Abundances with associated variances for Moors Reef (MR) over three data collection periods. Absolute abundance is the number of individuals of each species whereas relative abundance (p_i) is the number of individuals of a species relative to the total number of individuals.

Fish Species	Trip	Number Fish	n-1	n*(n-1)	p_i	p_i^2	p_i^3
Atlantic Blue Tang	1	4	3	12	1.59E-02	2.54E-04	4.05E-06
Brown Chromis	1	7	6	42	2.79E-02	7.78E-04	2.17E-05
French Grunt	1	1	0	0	3.98E-03	1.59E-05	6.32E-08
Yellowhead Wrasse	1	3	2	6	1.20E-02	1.43E-04	1.71E-06
Rock Beauty	1	1	0	0	3.98E-03	1.59E-05	6.32E-08
Squirrelfish	1	2	1	2	7.97E-03	6.35E-05	5.06E-07
Yellowtail Damselfish	1	6	5	30	2.39E-02	5.71E-04	1.37E-05
Redlip Blenny	1	1	0	0	3.98E-03	1.59E-05	6.32E-08

Fish Species	Trip	Number Fish	n-1	n*(n-1)	p_i	p_i^2	p_i^3
Striped Parrotfish	1	79	78	6162	3.15E-01	9.91E-02	3.12E-02
Harlequin Bass	1	3	2	6	1.20E-02	1.43E-04	1.71E-06
Redband Parrotfish	1	17	16	272	6.77E-02	4.59E-03	3.11E-04
Stoplight Parrotfish	1	2	1	2	7.97E-03	6.35E-05	5.06E-07
Dusky Damselfish	1	64	63	4032	2.55E-01	6.50E-02	1.66E-02
Bicolor Damselfish	1	15	14	210	5.98E-02	3.57E-03	2.13E-04
Bluehead Wrasse	1	33	32	1056	1.31E-01	1.73E-02	2.27E-03
Unidentified	1	12	11	132	4.78E-02	2.29E-03	1.09E-04
Sergeant Major	2	13	12	156	1.77E-02	3.15E-04	5.58E-06
Doctorfish	2	1	0	0	1.36E-03	1.86E-06	2.54E-09
Atlantic Blue Tang	2	4	3	12	5.46E-03	2.98E-05	1.63E-07
Trumpetfish	2	1	0	0	1.36E-03	1.86E-06	2.54E-09
Brown Chromis	2	5	4	20	6.82E-03	4.65E-05	3.17E-07
Dash Goby	2	2	1	2	2.73E-03	7.44E-06	2.03E-08
French Grunt	2	34	33	1122	4.64E-02	2.15E-03	9.98E-05
Bluestriped Grunt	2	1	0	0	1.36E-03	1.86E-06	2.54E-09
Yellowhead Wrasse	2	8	7	56	1.09E-02	1.19E-04	1.30E-06
Squirrelfish	2	3	2	6	4.09E-03	1.68E-05	6.86E-08
Longjaw Squirrelfish	2	1	0	0	1.36E-03	1.86E-06	2.54E-09
Indigo Hamlet	2	3	2	6	4.09E-03	1.68E-05	6.86E-08
Black Hamlet	2	1	0	0	1.36E-03	1.86E-06	2.54E-09
Butter Hamlet	2	1	0	0	1.36E-03	1.86E-06	2.54E-09
Seminole Goby	2	4	3	12	5.46E-03	2.98E-05	1.63E-07
Yellowtail Damselfish	2	6	5	30	8.19E-03	6.70E-05	5.48E-07
Reef Croaker	2	5	4	20	6.82E-03	4.65E-05	3.17E-07
Striped Parrotfish	2	202	201	40602	2.76E-01	7.59E-02	2.09E-02

Fish Species	Trip	Number Fish	n-1	n*(n-1)	p_i	p_i^2	p_i^3
Harlequin Bass	2	3	2	6	4.09E-03	1.68E-05	6.86E-08
Redband Parrotfish	2	39	38	1482	5.32E-02	2.83E-03	1.51E-04
Yellowtail Parrotfish	2	3	2	6	4.09E-03	1.68E-05	6.86E-08
Stoplight Parrotfish	2	1	0	0	1.36E-03	1.86E-06	2.54E-09
Dusky Damselfish	2	195	194	37830	2.66E-01	7.08E-02	1.88E-02
Beaugregory	2	6	5	30	8.19E-03	6.70E-05	5.48E-07
Bicolor Damselfish	2	27	26	702	3.68E-02	1.36E-03	5.00E-05
Threespot Damselfish	2	3	2	6	4.09E-03	1.68E-05	6.86E-08
Bluehead Wrasse	2	126	125	15750	1.72E-01	2.95E-02	5.08E-03
Caribbean Spiny Lobster	2	1	0	0	1.36E-03	1.86E-06	2.54E-09
Unidentified	2	3	2	6	4.09E-03	1.68E-05	6.86E-08
Red Hind	2	1	0	0	1.36E-03	1.86E-06	2.54E-09

a. Data Collections occurred June 2011 and January 2012. Moors Reef was not sampled during June 2012.
b. Values were used to determine Simpsons Diversity Index and variance of diversity.

APPENDIX VI

First Data Collection Number of Fish Documented and Unidentified. Corresponding percentages are presented.

Data Collection #	Video #	Location	Number of fish	Number Unidentified	Percent UnID (%)
1	643	Ball Reef	38	1	2.63
1	656	Ball Reef	25	4	16.00
1	702	Ball Reef	67	1	1.49
1	717	Edge Reef	23	0	0.00
1	727	Edge Reef	25	0	0.00
1	736	Edge Reef	52	2	3.85
1	801	Edge Reef	215	19	8.84
1	816	Edge Reef	267	11	4.12
1	501	Artificial Reef Sandbed	39	0	0.00
1	517	Artificial Reef Sandbed	42	0	0.00
1	534	Artificial Reef Sandbed	34	0	0.00
1	624	Control Sandbed	126	1	0.79
1	640	Control Sandbed	102	0	0.00
1	657	Control Sandbed	29	7	24.14
1	741	Seagrass Bed	1	0	0.00
1	442	Seagrass Bed	15	1	6.67
1	500	Seagrass Bed	1	0	0.00
1	519	Seagrass Bed	5	2	40.00
1	611	Patch Reef	146	20	13.70
1	626	Patch Reef	224	26	11.61
1	642	Patch Reef	234	8	3.42
1	605	Ball Reef	56	2	3.57
1	536	Patch Reef	67	8	11.94
1	405	Patch Reef	176	2	1.14
1	420	Patch Reef	89	7	7.87
1	456	Fisherman's Reef	64	15	23.44
1	546	Fisherman's Reef	213	8	3.76
1	602	Fisherman's Reef	240	0	0.00
1	650	Anchor Reef	69	11	15.94
1	720	Anchor Reef	105	22	20.95
1	751	Moor Reef	96	4	4.17
1	812	Moor Reef	156	7	4.49
1	937	Patch Reef	1495	0	0.00
1	920	Patch Reef	257	0	0.00
Totals	34		4793	189	3.94

Second Data Collection Number of Fish Documented and Unidentified. Corresponding percentages are presented.

Data Collection #	Video #	Location	Number of fish	Number Unidentified	Percent UnID
2	1506	North Reef 1	164	10	6.10
2	1527	North Reef 2	144	15	10.42
2	1547	North Reef 3	170	3	1.76
2	1703	Artificial Reef	380	19	5.00
2	1725	Artificial Reef	485	11	2.27
2	1741	Artificial Reef	348	10	2.87
2	2013	Sandbed 1	18	1	5.56
2	2030	Sandbed 1	36	1	2.78
2	2046	Sandbed 1	40	0	0.00
2	1214	MoorWest1	91	0	0.00
2	1231	MoorWest2	157	0	0.00
2	1249	MoorWest3	171	1	0.58
2	1310	MoorEast1	68	0	0.00
2	1326	MoorEast2	177	0	0.00
2	1346	MoorEast3	68	2	2.94
2	1440	ControlReef1	130	23	17.60
2	1459	ControlReef2	142	29	20.42
2	1520	ControlReef3	176	38	21.59
2	1603	EdgeReef1	59	17	28.81
2	1625	EdgeReef2	171	15	8.77
2	1643	EdgeReef3	161	15	9.32
Totals	21		3356	210	6.26

Third Data Collection Number of Fish documented with corresponding percentage of unidentified.

Data Collection #	Video #	Location	Number of fish	Number Unidentified	Percent UnID (%)
3	0002	ControlSandbed1	139	1	0.72
3	0003	ControlSandbed2	51	0	0.00
3	0004	ControlSandbed3	16	0	0.00
3	0005	Controlsandbed3-2	50	0	0.00
3	0006	ControlReef1	635	15	2.36
3	0007	ControlReef2-1	241	0	0.00
3	0008	ControlReef2-2	197	2	1.02
3	0009	ControlReef3	344	2	0.58
3	0021	EdgeReef1	430	0	0.00
3	NearReef1-1	NearReef1-1	162	0	0.00
3	NearReef1-2	NearReef1-2	256	0	0.00
3	NearReef2	NearReef2	423	0	0.00
3	NearReef3	NearReef3	327	0	0.00
3	AR1	AR1	2516	1	0.04
3	AR2-1	AR2-1	1405	0	0.00
3	AR2-2	AR2-2	891	1	0.11
3	AR3	AR3	3385	4	0.12
Totals	17		11468	26	0.23

Total number of fish documented with number and percent of unidentified fish noted.

Collection trip	Total Number Counted	Total Number Unidentified	Percentage (%)
1	4793	189	3.94
2	3356	210	6.26
3	11468	26	0.23
Totals	19617	425	2.17

APPENDIX VII

Number of species per family pertaining to Taxonomic Composition within Bluefields Bay, Jamaica.

Family	Number per Category	Percentage
Pomacentridae	1	0.7
Acanthuridae	3	2.1
Apogonidae	1	0.7
Atherinidae	1	0.7
Aulostomidae	1	0.7
Balistidae	1	0.7
Belonidae	1	0.7
Blenniidae	2	1.4
Bothidae	2	1.4
Carangidae	6	4.2
Centropomidae	1	0.7
Chaenopsidae	2	1.4
Chaetodontidae	6	4.2
Cirrhitidae	1	0.7
Congridae	1	0.7
Coryphaenidae	1	0.7
Dactylopteridae	1	0.7
Dasyatidae	1	0.7
Diodontidae	3	2.1
Echeneidae	1	0.7
Elopidae	2	1.4
Exocoetidae	1	0.7
Gerreidae	1	0.7
Gobidiidae	8	5.6
Grammistidae	1	0.7
Hemiramphidae	1	0.7
Holocentridae	3	2.1
Istiophoridae	1	0.7
Labridae	10	7.0
Lutjanidae	7	4.9
Monacanthidae	2	1.4
Mugilidae	1	0.7
Mullidae	2	1.4
Muraenidae	3	2.1

Family	Number per Category	Percentage
Opichthidae	2	1.4
Orectolobidae	1	0.7
Ostraciontidae	3	2.1
Pempheridae	1	0.7
Pomacentridae	7	4.9
Pomadasyidae	9	6.3
Priacanthidae	1	0.7
Scaridae	6	4.2
Sciaenidae	3	2.1
Scombridae	3	2.1
Scorpaenidae	2	1.4
Serranidae	14	9.9
Sparidae	1	0.7
Sphyraenidae	1	0.7
Synodontidae	1	0.7
Tetraodontidae	4	2.8
Tripterygiidae	1	0.7
Urotrygonidae	1	0.7
Total	142	100.0