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Red Lionfish (Pterois volitans) Invade San Salvador, Bahamas: Early Population Characteristics, and Comparisons of the Coral and Fish Communities on Shallow Patch Reefs in 2001 and 2007

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Red Lionfish (*Pterois volitans*) Invade San Salvador, Bahamas: Early Population Characteristics, and Comparisons of the Coral and Fish Communities on Shallow Patch Reefs in 2001 and 2007

By

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Abstract

Biological invaders are a leading contributor to global losses of biodiversity. A recent invader to the waters surrounding San Salvador, Bahamas, the red lionfish, *Pterois volitans*, was first reported in 2006; by 2009 they were common in waters 2-40 m deep around the island. Among the 5,078 fish observed on shallow patch reefs in 2007, only two were *P. volitans*; they were much more prevalent in deeper water along San Salvador's "wall." Captured *P. volitans* ranged in size from 19-32 cm, all longer than maturity length. Pallid goby (*Coryphopterus eidolon*), black cap basslet (*Gramma melacara*) and red night shrimp (*Rynchocienetes rigens*) were the most commonly identified stomach contents. My study in 2007 also collected data on coral communities and fish assemblages at three patch reef complexes (Rice Bay, Rocky Point, Lindsay Reef), during the initial phase of the invasion, and compared the results to a similar study done in 2001, before *P. volitans* colonized San Salvador. Scleractinian and, therefore, total coral species richness decreased significantly from 2001 to 2007; however, coral percentage cover increased significantly by ~50% from 2001 to 2007, probably due to a more precise estimation procedure rather than a real increase in coral cover. Significantly more fish species and numbers were observed in 2007 than in 2001, again probably due to a difference in counting procedures (2.25 more effort in 2007 than in 2001). The effects of the successful invasion and increasing population of *P. volitans* on San Salvador's reef ecosystem are uncertain at this time; future monitoring of lionfish and potential changes in coral and fish communities on the patch reefs of San Salvador is recommended.

Biography

The author completed her undergraduate studies at the SUNY College of Brockport in 2007 with a major in Environmental Science, a concentration in Aquatic Ecology and a minor in Chemistry. She continued her education at SUNY College of Brockport to complete her Master of Science in Biology in 2011. During her undergraduate and graduate studies she worked for SUNY College at Brockport as a field biologist for the Research Foundation and as a tutor and graduate assistant for the Environmental Science Department. She plans to pursue her PhD in Marine Biology and teach at the university level.

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Introduction

Biological invaders are one of the leading contributors to the loss of biodiversity in natural ecosystems, a loss that is considered by some to be a great risk to natural ecology and human well-being (Wilcove et al. 1998, Helfman 2007). Biological invaders enter an ecosystem through natural range extensions or from human-induced introductions, and are only considered invasive if they survive, reproduce and disperse into an ecosystem where their species did not previously exist (Carlton 1989).

In the past, marine invasions have been rare or rarely reported as compared to freshwater and terrestrial invasions. Yet, in the last two decades human-mediated invasions have become more prevalent and anthropogenic dispersals into the marine environment are increasing the rate at which marine invasions occur. Some believe that these invasions have the potential to modify ecosystems processes, food-web dynamics and community compositions (Ruiz et al. 1997, Wilcove et al. 1998, Cuddington and Hastings 2003, Semmens et al. 2004).

Although freshwater fish invasions have proven on many occasions to be devastating to native communities, limited research on the relatively small number of successful marine fish invasions has left the possible consequences arising from them uncertain (Ruiz et al. 1997, Whitfield et al. 2002, Albins and Hixon 2008). On top of this, characteristics of a species in one community can be a poor indicator of the consequences that species may have in its new community. Therefore, the effects of an invasive on its new environment are not easily predicted based upon the species life history in its native range (Ruiz et al. 1997).

One such marine invader, for which potential effects on native communities are of concern, is the red lionfish, *Pterois volitans*. It is a scorpionfish (family Scorpaenidae, order Scorpaeniformes, subclass Teleostei) which has a native range throughout the tropical and subtropical Indo-Pacific from southern Japan southward to Australia and eastward to the islands of the South Pacific (Schultz 1986, Meister et al. 2005). It is also a popular aquarium fish and one of the top ten most valuable marine fish imported to the United States (Ruiz-Carus et al. 2006).

How *P. volitans* was first released into the southwest Atlantic and Caribbean is unknown, but it is believed that it was introduced into Florida waters through anthropogenic dispersal via the aquarium trade (NOAA 2007). Whitfield et al. (2002) believed that both intentional and unintentional releases from aquaria have been the most likely mechanisms for the introduction of *P. volitans*. For example, one documented event occurred in1992 when Hurricane Andrew caused the release of several *P. volitans* from a private aquarium in Florida.

Regardless of the method of introduction, *P. volitans* has rapidly expanded its range. Since discovery in Florida waters in 1985, *P. volitans* has spread up the coast of the eastern United States as far north as Rhode Island, eastward to Bermuda, southward into the Caribbean, Turks and Caicos, Cayman Islands, Puerto Rico, Greater Antilles (Cuba, Jamaica, Haiti, Dominican Republic), and to Central and South America (Mexico, Belize, Honduras, Nicaragua, Costa Rica, Panama, Columbia, Venezuela) (Whitfield et al. 2002, Albins and Hixon 2008, Guerrero and Franco 2008, Schofield et al. 2011, USGS NAS Database 2011).

The first lionfish counts at 17 locations off North Carolina in 2004 averaged 21/ha. By 2008, mean counts rose to 150/ha with some sites having nearly 350 lionfish/ha. In the Bahamas there were similar reports of high densities of lionfish and results showing that the lionfish were thriving in both warm and subtropical reaches of the Atlantic. The data collected from the Bahamas shows that lionfish densities are orders of magnitude higher than what has been observed in their native range (Morris and Whitfield 2009).

Although it is not reported by USGS NAS (2011), the first documented lionfish sighting at the small island of San Salvador in the Bahamas was at Pigeon Creek, a tidal estuary and nursery habitat (Figure 1) in January of 2006 (pers. comm. to J.M. Haynes, The College at Brockport, SUNY, from B. Baldwin, St. Lawrence University). By January 2007, dozens of lionfish were observed at various patch reef locations around San Salvador (pers. comm., SUNY College at Brockport and Gerace Research Center students). This information suggested that *P. volitans* was in the early stages of a successful invasion and, therefore, collection of the initial invasion data within the patch reef ecosystems surrounding San Salvador was necessary to understand potential changes that may occur to these ecosystems due to the presumably larger populations of *P. volitans* to come.

In 2001, Walter and Haynes (2006) characterized coral and fish communities at three patch reef complexes near San Salvador: Rice Bay, Rocky Point and Lindsay

Reef. Since the first lionfish was not reported until 2006, the data collected by Walter and Haynes (Walter 2002) provide pre-lionfish invasion reef community characteristics. My study examined population characteristics (preferred habitat, prey selection, quantity of consumption) of *P. volitans* during the initial phase of colonization and replicated Walter's (2002) study. I did not expect to find major differences in the coral and fish communities between 2001 and 2007 because lionfish had only been observed at San Salvador for 18 months before my study, their population size was small, and any detectable changes in the native coral and fish communities due to lionfish were unlikely at this time.

Material and Methods

Study Area

Coral and fish communities were surveyed at three, shallow (< 5 m) patch reef complexes with contrasting physical characteristics: Rice Bay (RB), Rocky Point (RP) and Lindsay Reef (LR), at the small Bahamian island of San Salvador (Figure 1). Lionfish were also surveyed and collected along the "wall" of the western edge of the islands platform. San Salvador is located at 24° 3'N latitude and 74° 30'W longitude, 640 km east southeast of Miami, Florida.

Objectives

My first objective was to provide initial population characteristics of *P. volitans* in the waters surrounding San Salvador during the initial invasion phase: preferred habitat, food selection and quantity of consumption. The second and third objectives of my study were to compare the pre- (2001) and initial post-invasion (2007) coral and fish communities at each of the three selected patch reef complexes.

<u>Objective 1:</u> Determine prey selection, quantity of consumption and preferred habitat of *Pterois volitans* in the waters surrounding San Salvador during the initial invasion phase.

From May 24 to June 2, 2007 shallow shore dives and snorkels were conducted at artificial reefs, shallow patch reefs (other than the three study sites) and in the mangrove habitat at Pigeon Creek (Figure 2) in search of *P. volitans*. The date, time, search per unit effort (search time/# people), location, method of search (snorkeling, diving) and number of *P. volitans* observed were recorded.

From May 29 to June 15, 2007, a local diving company at the Riding Rock Inn recorded *P. volitans* sightings and collected 21 *P. volitans* via spearing during daily dives in waters 10-40 m deep, the safe depth range for recreational scuba diving. Location, depth, date, time and approximate size of fish were recorded for each *P. volitans* sighted. Speared *P. volitans* were brought to the surface, immediately put on ice and transported to my lab at the Gerace Research Center (GRC). On day of capture, data collected from the fish included total length (TL, cm), identification of stomach contents and volume of stomach contents. An analytical scale was not available at the GRC so water displacement was used as a surrogate for prey weight.

Objective 2: To describe differences, if any, in the coral communities between 2001 and 2007 on the three selected reefs. Transect lines were placed on each of the three reef complexes to create study plots. At RP and LR a 30-m baseline was run perpendicularly to the shore. From this baseline, four 40-m transect lines were laid out in various directions (Figure 2). Transect lines were laid at random but all transect lines needed to lie on the reef in their entirety and not overlap. If a transect line extended beyond the reef and onto the sandy benthos, it was moved to another location on the base line. This was repeated until the entire 40 meters of line was on top of the reef.

After placement, each of the 40-m transect lines were divided evenly into four 10-m by 5-m (50 m^2) box plots (N=16 per site) (Figure 3). The corners of each box plot were marked with a small nail and fluorescent flagging tape. Each nail was hammered into a dead part of the reef and removed at the end of the study to insure minimal disturbance.

Due to the small reef surface area at RB, a baseline transect could not be used. Therefore, 16, 10-m lines were placed entirely on top of the reef so they did not overlap (Figure 3). Each 10-m line became one box plot.

For the coral survey, 1-m^2 quadrats were constructed from four 1-m long, 37-mm diameter PVC pipes connected with elbows. Four evenly spaced holes were drilled into each 1-m pipe (20 cm apart), and string was used to make a box grid (N=25) in the quadrat frame (Figure 4).

The quadrat frame was haphazardly placed within each 50-m^2 box plot ten times (N=160 per reef) and coral species percentage cover was estimated by counting the number of 400 cm^2 boxes each coral species filled within the quadrat. My quadrat design differed slightly from Walter (2002) in that he did not put a string grid inside his frame but instead used the visual estimation technique employed by Ormond et al. (1996). Transparencies, china markers and a clip board were used to record the data in the water, and all observations were done by snorkeling. From the ten samples in each box plot, mean percentage coral cover (total, Scleractinia, Gorgonacea, Milleporidae) and species richness, diversity and equitability were calculated for each of the 16 box plots on each reef.

Objective 3: To describe differences, if any, in the fish communities between 2001 and 2007 on the three selected reefs.

Fish surveys were conducted in the same 50-m^2 box plots as the coral surveys. For each of the 16 plots I conducted two stationary point counts and one perimeter swim. Each stationary count was for 7.5 min or until no new fish was seen after 5 min, whichever came first. For stationary counts, each 50-m^2 box plot was visually divided into two, 5-m by 5-m plots. One stationary count was taken while hovering above the perimeter of the box plot on one of the 10-m sides ~2.5 m from the corner. Fish seen within that half of the box plot were counted. The second stationary point count was done diagonally on the opposite 10-m side of the box plot to get a representative count from both halves. After the point counts, one swimming (30 m) count was taken along the inside perimeter of the box plot to look for demersal, hiding and cryptic individuals. The three counts were summed to give a total fish count within each box plot. At the same time, a second observer was independently counting fish in the same box. The first and seconds observers counted fish in the opposite halves of the box plot and did their swimming counts in opposite directions.

Walter (2002) sampled in a slightly different way, so I adjusted his catch per unit effort (CPUE) to mine as follows. In most box plots I did two, 7.5-min stationary counts and 30 m of swimming counts. Walter observed each box plot twice and then took the average of the two counts: each count included two, 2.5-min stationary counts and two, 10 m swimming counts. Therefore, I had 1.5 times the stationary effort and 0.75 times the swimming effort of Walter (2002), so I multiplied his numbers by 2.25 (2 replicates*1.5*0.75) to achieve equivalent CPUE.

Data Analysis

Following Walter (2002), the mean percentage cover of each coral species was aggregated in total and by group: hard corals (order Scleractinia) soft corals, (order Gorgonacea) and hydrocorals (family Milleporidae). Coral community characteristics used to compare the reefs were species richness, Shannon's diversity and equitability. Fish abundance data were aggregated in total and by major family (Labridae, Acanthruidae, Pomacentridae, Scaridae) and feeding guild (herbivores, planktivores, invertivores, piscivores, detritivores) (Hiatt and Strasburg 1960, Humann and Deloach 2002). Biodiversity parameters for fish and coral communities were calculated using Microsoft Excel: species richness (S); species diversity using Shannon's Index ($H' = -\Sigma\ p_i \ln(p_i)$, where p_i is the proportion of individuals of the i^{th} species); and equitability (species evenness) ($E = H'/\ln S$).

To promote equal variances, coral percentage cover values received arcsine(x) transformations and fish abundance values received log(x+1) transformations (Excel) before statistical analysis (Statistix 2003). General Linear Models (GLM), followed by Tukey's Honest Significant Difference tests to provide experiment-wise error rates, were used to distinguish values of the coral and fish variables among the three reefs (RB, RP, LR) and between the two years/observers (2001/Walter and 2007/Alexander). The 16 box plots of coral and fish data per reef were replicates in the GLMs.

Walter (2002) deliberately chose to sample reefs with contrasting physical conditions and coral communities (McGrath and Smith 2003); as expected, the GLMs revealed many statistically significant differences among the three reefs. Since the primary interest of my study was to examine differences in coral and fish communities between 2001 and 2007, and not differences among reefs, differences in community characteristics among reefs will not be discussed.

Ecological changes or observer bias both could contribute to differences in the coral and fish communities observed in 2001 and 2007. To address the issue of inter-observer reliability, fish counts were taken independently by two observers in 2007.

Results and Discussion

Pterois volitans

Shallow water hunts—. From May 24 to June 2, 2007, no *P.* volitans were observed during 8.75 hours of snorkeling and diving (Table 1) at artificial reefs, shallow patch reefs (other than the three study sites) and a mangrove habitat at Pigeon Creek (Figure 1). By 2009 *P. volitans* were seen frequently at all shallow patch reefs near San Salvador (pers. comm., J.M. Haynes, The College at Brockport, SUNY).

Deep water hunts—. From May 29 to June 15, 2007, 46 *P. volitans* were observed during 22 deep water dives performed in collaboration with the local diving company (Table 2). Depths ranged from 30 feet to 140 feet (9-43 m), visually-approximated *P. volitans* lengths ranged from 5 to 10 inches (12.7 to 25.4 cm) and *P. volitans* were observed during 21 of the dives. *P. volitans* were much more prevalent in the deeper waters surrounding San Salvador than in the shallow reef systems in 2007.

During nine of the deep water dives only single *P. volitans* were observed; during 12 dives they were observed in groups of 2 to 5. These groups of lionfish were prominent during the first two weeks of June. *P. volitans* are found in large groups as juveniles but adults are normally solitary, only congregating in groups of 3 to 8 during the initial stages of courtship (Whitfield et al. 2002, Schofield et al. 2011).

While on San Salvador, I spoke with several local fishermen who reported seeing large groups of *P. volitans* in early June. During the 3rd week of June, one of the fishermen took me to a site where he claimed to have seen a large group of *P. volitans* in early June. I searched the location but did not find any *P. volitans*.

In March of 2007, before my study began, a Master Diver from the local diving company started his own, informal log of *P. volitans* sightings during deep water dives. He was gracious enough to share this information with me (Table 3). During March, he observed *P. volitans* on 16 dives but only recorded three occurrences of more than one together.

Maturity—. Among the 46 *P. volitans* observed during deep water dives, 21 were speared; they ranged from 19-32 cm TL (24± 0.9 cm, Table 4). Female lionfish mature around 18 cm and males around 10 cm; therefore, all of the speared fish were adults (Morris and Whitfield 2009). According to recent research, lionfish spawn year round in the Bahamas, about every four days, with an annual fecundity of over two million eggs per female (Morris and Whitfield 2009). Yet my size and aggregation data suggest that *P. volitans* were engaged in courtship, and thus spawned, only in late May/early June. This inconsistency is a subject for further research.

Diet—. Small fish and shrimp were the foods of choice for the *P. volitans* I dissected; pallid goby (*Coryphopterus eidolon*), black cap basslet (*Gramma melacara*) and red night shrimp (*Rynchocienetes rigens*) were the most common identifiable stomach contents. Other research showed that adult lionfish in the

Bahamas feed on more than 40 species of fish, including many that are important in the diets of important species such as snappers and groupers (Morris and Whitfield 2009).

During dissections, I was often surprised by the large quantities of food found in stomachs relative to the size of the *P. volitans* (Table 4). This may be explained by the lionfish's ability to expand its stomach to over 30 times initial volume during consumption, an evolutionary adaptation thought to allow it to withstand long periods of fasting (Morris and Whitfield 2009).

Ecology—. Competition for prey between *P. volitans* and other predators may become an issue near San Salvador if the lionfish population continues to increase. Therefore, lionfish abundance and predation rates should be monitored in the future in areas that native fish rely on for nursery habitat, such as the extensive mangroves along Pigeon Creek at San Salvador (Conboy 2008; Figure 1).

Ablins and Hixon (2008) reported reduced recruitment of coral reef fishes after lionfish invasion. They hypothesized that lionfish decrease the abundance of ecologically important species such as parrot- and other herbivorous fishes that keep macroalgae from overgrowing corals. If this potential impact materializes, the currently high rates of macroalage overgrowth of coral at San Salvador could increase.

Shrimp populations could also suffer from increased predatory demands by *P. volitans*. Smaller shrimp populations may lead to adverse effects on both coral and reef fish communities. One very important niche that certain shrimp species fill in reef ecosystems is providing "cleaning stations," a place where the shrimp remove parasites from fish and other crustaceans on a regular basis. Some shrimp species also live in facultative or obligate partnerships with corals, anemones, mollusks and echinoderms. Others are detrital feeders that play an essential part in keeping the reef ecosystem in balance (Spalding et al. 2001).

Corals

Corals were surveyed in May-June and in January 2001 and May-June in 2007. In 2007, 39 coral species were identified: 24 Scleractinia, 12 Gorgonacea and three Milleporidae. In 2001, 36 coral species were identified: 22 Scleractinia, 12 Gorgonacea and two Milleporidae (Table 5).

Scleractinia—. Scleractinia observed in 2007 and not in 2001 were *Stephanocoenia intersepts* (blushing starlet), *Meandrina meandrites* (maze) and *Mycetophyllia aliciae* (knobby cactus). *Stephanocoenia intersepts* had low percentage cover at RB and LR (0.09% and 0.01% cover, respectively). *Meandriana meandrites* also had low abundances at RB and LR in 2007 (0.25% and 0.20%, respectively). *Mycetophyllia aliciae* was only found at LR at 0.10% relative abundance (Table 5). According to a study done in the Florida Keys, *M. aliciae* was rarely found and then only in low abundance (Rutten et al. 2008). Scleractinians observed in 2001 and not in 2007 were *Mussa angulosa* (spiny flower) and *Scolymia spp.* (disk). *M. angulosa* was only found at LR at 0.60%

relative abundance and *Scolymia spp.* was found at RP and LR, 0.11% and 2.15%, respectively (Table 5). These five rare scleractinians were likely present in both years but not consistently observed.

Gorgonacea—. All gorgonians observed in 2001 were observed in 2007. The only Gorgonacean species observed in 2007 but not in 2001 was *Muricea muricata* (spiny sea fan). Its percent cover was 0.15% at RB, 0.01% at RP and 0.02% at LR (Table 5).

Identifying Gorgonacea in the field is difficult; fewer than half of the 60-70 reef forms can be identified to species underwater; positive identification requires microscopic examination (Humann and Deloach 2002). Often I took small samples of Gorgonaceans back to the lab for further analysis, examining specimens under a microscope and using keys to identify them to species (Humann and Deloach 2002, Sanchez and Wirshing 2005, Janes and Wah 2005). I found that *M. muricata* could easily be misidentified as other Gorgonaceans in the field, such as *Eunicea succinea* (shelf-knob sea rod). I recommend collecting small samples from unknown gorgonaceans in future studies.

Milleporina—. Among fire corals (Milleporidae; Table 5), *Millepora alcicomis* and *M. complanata* were found both years and *M. squarrosa* only in 2007 (0.10% cover at LR). In both 2001 and 2007 the percentage cover of Milleporidae was very low. Glynn and Weerdt (1991) suggested that *Millepora* species are especially sensitive to higher than normal water temperatures, which have occurred twice at San Salvador since 2001 (pers. comm., J.M. Haynes, The

College at Brockport, SUNY). With rising concerns about global warming and its potential to increase the ocean temperatures enough to promote negative effects on reef ecosystems, such as coral bleaching (Toren et al. 1998), future research at San Salvador should explore changes in *Millepora* species cover in relation to temperature fluctuations in the shallow patch reef systems.

Changes from 2001 to 2007—. Mean total (P = 0.003, -15.4%) and scleractinian (P < 0.0001, -22.7%) coral species richness per box plot were significantly less in 2007 than in 2001. There were no significant differences for gorgonian species richness (P =0.239), Shannon's H (P = 0.934) and Equitability (P = 0.230) between years (Table 6). Except for lower scleractinian and, therefore, lower total coral cover, the coral communities at the three reef complexes studied near San Salvador had similar diversity in 2001 (Walter 2002) and 2007.

Percentage cover of total corals (P < 0.0001, +50%), scleractinians (P < 0.0001, +56.3%) and gorgonians (P = 0.009, +43.8%) was significantly greater in 2007 than in 2001. Milleporid cover did not differ significantly between years (P = 0.674) (Table 6). The 2007 coral community near San Salvador may have had a higher percentage of coral cover in 2007 than in 2001 but the differences observed were more likely related to the differing estimation techniques used by Walter (2002) and my study. Walter estimated percentage cover for each coral species within an entire 1-m^2 frame, while I estimated cover more precisely in each of the 25, 20 cm^2 panels within a 1-m^2 frame.

From the mid-1980s to 2000, scleractinian cover at reefs near San Salvador (including my study sites) suffered a massive decline from ~20% to 4-5% (McGrath and Smith 2003). The percentage cover of live coral observed in 2001 (3.2%, Walter 2002) and 2007 (5.0%, Table 6) was consistent with McGrath and Smith (2003). Due to its greater precision, I recommend that my method for sampling corals be used in future studies at the three study reef complexes.

Fishes

Seventy-one fish species were recorded in 2007 during the 48 belt transect/ perimeter surveys at RB, RP and LR (Table 7). Fifty species were recorded at RB, 45 at RP and 49 at LR in 2007; 37, 32 and 46 were recorded at the three reefs in 2001, respectively. Fifteen species observed in 2007 were not seen in 2001 (*Sargoncentron coruscum, Ocyurus chrysurus, Lutajanus mahogany, Haemulon flavolineatum, Haemulon chrysargyreum, Haemulon plumieri, Haemulon carbonarium, Holacanthus ciliaris, Stegastes partitus, Abudefduf saxatilis, Doratonotus megalepis, Sphyraena barracuda, Cathidermis sufflamen, Aluterus schoepfii, Urobatis jamaicensis*), and three species seen in 2001 were not seen in 2007 (*Chaetodon ocellatus, Acanthostracion polygonius, Rypticus saponaceus*). All 18 species were at densities <0.5/50 m^2, usually <0.2/50 m^2 (Table 7); therefore, they could easily have been present on the reefs in both years but not within the transect lines or could have been inadvertently overlooked during sampling. Of the 5,078 fish recorded on the three shallow patch reef complexes in 2007, only two were *P. volitans*, both at RP.

Changes from 2001 to 2007—. Total fish counts (P = 0.031, +17.0%), Shannon's H (P < 0.0001, +35.5%) and Equitability (P = 0.002, +14%), but not species richness (P = 0.393), were significantly greater in 2007 than in 2001 (Table 8). Among the major families and feeding guilds, Pomacentridae (damselfishes, P = 0.007, +28.6%), invertivores (P = 0.025, +26.6%) and piscivores (P = 0.037, +6.1%) were significantly more abundant in 2007 than in 2001. Only detritivores, the least abundant of the feeding guilds, were observed more often in 2001 than in 2007 (P = 0.030, -66.7%).

General fish discussion—. In the tropics, the May-July period is associated with high abundances of juveniles of many species. Fish were surveyed from mid-May to mid-June in 2001 and 2007, so I expected that the same species and age classes would be present. For example, the most abundant fish in both years was the bluehead, *Thalassoma bifasciatum*. However, bluehead counts were much higher in 2007 than in 2001 (reflected in both Labridae and invertivore counts; Table 8), and most of those observed in 2007 were juveniles. Observer counts of fish species in box plots in 2001 (N=1) and 2007 (N=2) and observer counts of total fish in box plots in 2007 (N=2) were nearly identical (Table 8). Walter in 2001, the second observer in 2007 and I had equivalent in-water training at San Salvador (prior undergraduate courses at SUNY College at Brockport) and demonstrated excellent observation and identification skills in the water (pers.

comm., J.M. Haynes, The College at Brockport, SUNY). Therefore, the increases in fish counts from 2001 to 2007 probably are real and due, in part, to higher numbers of juvenile blueheads in 2007. These results most likely reflect large natural variations in year class strength within fish populations.

Differences in the results between the 2001 and 2007 fish studies illustrate the importance of using precisely the same methods for comparative studies. With 2.25 times the sampling effort as Walter (2002), I observed a net of 12 more species (although not more species per box plot) and 17% more fish (Table 8). Although my methods required more time in the water, I recommend that they be used for future studies.

Conclusion

In 2007 *P. volitans* were predominantly in deep water, but by 2009 they were also common in shallow water. Among the 21 *P. volitans* captured in 2007, all were within the size range of mature adults, and small fishes and shrimps were their foods of choice. *P. volitans'* ability to eat large amounts of prey is a concern because of the potential for substantial reductions of fish and shrimp prey populations. Decreases in prey species could lead to increases in algal growth and competition for prey with native reef fishes, or disruptions of symbiotic relationships between some shrimps, fishes and other reef animals.

The coral communities at the three reef complexes studied at San Salvador had lower mean diversity in 2007 than in 2001 but percentage cover of total corals, scleractinians and gorgonians was significantly greater in 2007 than in 2001, changes most likely associated with somewhat different sampling methods between years. The percentage cover of live scleractinians observed in 2001 (Walter 2002) and 2007 was $\leq$5% and consistent with the ~75% decline from the mid-1980s to 2000 reported by McGrath and Smith (2003). Given rising concerns about global warming and other anthropogenic impacts on coral ecosystems and their global decline (Hughes et al. 2003), especially in the Caribbean (Gardner et al. 2003), changes in coral community characteristics at San Salvador from 1985 to 2007 likely reflect long-term impoverishment more than any other factor.

Although fish community parameters were generally more robust in 2007 than in 2001, these results likely reflect natural variations in year class strength (e.g., blueheads) and greater sampling effort in 2007 (2.25* 2001 effort). The results are not due to the recent invasion of *P. volitans*; only two were observed on the three study reef complexes in 2007.

In 2007 *P. volitans* was commonly observed in waters 10-40 m deep along San Salvador's "wall." By 2009 it was common on shallow patch reefs, including the three study reef complexes. It is evident that *P. volitans* has successfully invaded the waters surrounding San Salvador, Bahamas. The effects of its increasing population on Sal Salvador's reef ecosystem are uncertain at this time but research conducted elsewhere in the Bahamas (Morris and Whitfield 2009) does not suggest a positive outcome at San Salvador. Future monitoring will be needed to assess *P. volitans'* full impacts and to potentially execute population control measures at San Salvador.

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Table 1. Location, date, search per unit effort (SPUE = hours/# people searching) and method of search for *P. volitans* in shallow reef and non-reef habitats.

Shallow Habitat Hunts for *P. volitans*

Reef Habitat

Location	Date 2007	Time	SPUE	*P. volitans observed*	Survey Method
Telephone Pole Reef	24-May	10:30-11:30 am	0.25	0	Dive
Snapshot Reef	24-May	2:30-4:00 pm	0.37	0	Dive
Monument Reef	24-May	9:50-11:00 am	0.58	0	Snorkel
Tool Hole Reef	27-May	1:00-2:00 pm	0.50	0	Snorkel
Telephone Pole Reef	28-May	12:30-1:30 pm	0.33	0	Dive
Telephone Pole Reef	28-May	12:30-2:00 pm	0.75	0	Dive
Gaulin Reef	2-Jun	10:30-11:15 am	0.38	0	Snorkel

Artificial Reef Habitats

Location	Date	Time	SPUE	*P. volitans observed*	Survey Method
Navy Pier	27-May	3:00-3:30 pm	0.25	0	Snorkel
Sunken Motor Boat	27-May	3:40-4:00 pm	0.17	0	Snorkel

Mangrove Habitat

Location	Date	Time	SPEU	*P. volitans observed*	Survey Method
Pigeon Creek	26-May	Morning/low tide	0.25	0	Snorkel

Table 2. *P.volitans* observed on deep water dives with the Riding Rock diving group between May 29 and June 12, 2007.

Riding Rock *P. volitans* Observations on Deep Water Dives

Date (2007)	Time	Location	# obs	Approx Size (in)	Approx. Depth (ft)	Dive Time (min)	Comments
29-May	10:00 AM	Sand Point	2	7	60	40	On surface of the wall with head slightly downward direction. Two banded coral shrimp close by.
29-May	11:50 AM	Telephone Pole	0	NA	NA	40	
30-May	9:45 AM	Great Cut	1	8	140	30	
30-May	4:00 PM	Sand Castles	1	7	59		Where sand castle meets cathedrals
31-May	10:15 AM	Orbit's Canyon	1	9	106		At left exit of swim through
31-May	11:40 AM	Stew Pot	2	6&8	84	40	Out on the wall, not hiding and together, within inches of each other.
31-May	4:15 PM	Grouper Gully	1	9	86		
2-Jun	11:51 AM	Doolittle's Grotto	3	8 to 10	2@105 and 1@85		After swim through on the left
3-Jun	9:45 AM	Shagrila	3	8 to 10	131 and 75	35	
4-Jun	10:30 AM	Doolittle's Grotto	5	7 to 10	1 @ 105 4 @ 125		One on the wall and 4 on coral head off in deep sand
4-Jun	3:45 PM	Hole in the Wall	1	6	95	30	
5-Jun	9:30 AM	Great Cut	1	8 to 10	85	35	
5-Jun	12:05 PM	Riding Rock Wall	3	6 to 8	70	35	
5-Jun	4:00 PM	Amplifier	3	8 to 10	60-80	40	
6-Jun	9:30 AM	North Pole Cave	1	9	126		At exit of chimminey
7-Jun	9:30 AM	Sandy Point	5	5 to 7	60 - 120	30	
8-Jun	3:30 PM	Cathedrals	2	7 to 8	95 and 60	45	At the base of the wall
10-Jun	12:20 PM	Riding Rock Wall	1	6to 7	78	45	
10-Jun	9:20 AM	Shagrila	2	8 to 5	90 - 120	36	
10-Jun	3:10 PM	Rillar's Reef	4	5 to 7	110, 85, 30	45	
11-Jun	10:00 AM	Doolittle's Grotto	3	6 to 7	30, 130	45	
12-Jun	10:15 AM	Black Forest	1	9	95		Over the wall

Table 3. ***P. volitans*** **sightings on deep water dives in March 2007, provided by the Riding Rock diving company.**

March 2007 *P. volitans Deep Water* Sittings		
Location	**Depth (ft)**	**# observed**
Shangrila	100	1
Riding Rock Wall	76	1
Telephone Pole	78	2
Devil's Claw	80	1
Telephone Pole	104	3
Cable Crossing	130	1
Double Caves	80	1
Runway	39	2
Sandcastles	59	1
Doolittle's Grotto	107	1
Pillar Reef	84	1
Vicki's Reef	39	1
Grouper Gully	38	1
Cathedrals	85	1
Snapshot Reef	17	1
Boat Launch	4	1

Table 4. Total length measurements, identification of stomach contents and volume of stomach contents for *P. volitans* that were collected and dissected.

P. volitans Dissections

Collection Date	Fish #	Total Length (cm)	Stomach Contents	Water Displacement of Contents (ml)	Egg Sacks
6/4/2007	1	21	Shrimp tail Fish scale	Too small Too small	No
6/4/2007	2	29	1 blenny (*Malacoctenus triangulatus*) 1 Pallid Goby (*Coryphopterus eidolon*)	2 0.5	No
6/6/2007	3	25	Unid. Flesh Shrimp pieces	1 Too small	No
6/7/2007	4	25	1 Black Cap Basslet (*Gramma melacara)* 2 Unid. Fish 1 snail shell	1.5 1.5	Yes
6/8/2007	5	26	2 Black Cap Basslet (Gramma melacara) 1 Unid. Fish	0.25 0.15	No
	6	28	1 Pallid Goby (*Coryphopterus eidolon*) 1 Unid Crustaceon 1 Red night Shrimp (*Rynchocienetes rigens*)	0.5 Too small	No
	7	22	1 Black Cap Basslet (Gramma melacara) 1 Unid. Flesh	3 0.5	No
	8	21	Empty		No
6/10/2007	9	21	Unid. Fish and Shrimp	1.5	No
	10	31	Unid. Fish	1.5	No
	11	19	Unid. Shrimp	0.4	No
6/10/2007	12	24	1 Pallid Goby (*Coryphopterus eidolon*)	1	Yes
	13	26	Empty		Yes

6/11/2007	14	22	3 Unid Shrimp Unid. Fish	0.5 0.5	No
	15	20	Empty		No
6/12/2007	16	30	1 Aarow Bleeny (*Lucayablennius zingaro*) Unid. Flesh	0.1 3.4	No
	17	20	Unid. Flesh	1	No
6/15/2007	18	19	1 Red night Shrimp (*Rynchocienetes rigens*)	0.5	No
	19	32	2 Unid. Fish and Flesh	1.5	No
	20	30	1 Pallid Goby (*Coryphopterus eidolon*) 1 Yellowhead Wrasse (*Halichoeres garnoti*) 1 Goby Unid. Flesh	Too small Too small 0.5 0.5	No
	21	28	Unid. Flesh	Too small	No

Table 5. Percent cover of coral species observed in 2001 and 2007 at Rice Bay, Rocky Point and Lindsay Reef.

Taxonomic name	Common name	Rice	Bay	Rocky	Point	Lindsay	Reef
Year		01	07	01	07	01	07
Hydrozoa							
Milleporidae							
Millepora alcicornis	branching fire	2.44	0.38	0.24	1.13	0.38	0.38
Millepora complanata	blade fire	1.33	0.52	3.06	0.28	2.82	0.49
Millepora squarrosa	encrusting fire	0.00	0.00	0.00	0.00	0.00	0.10
Anthozoa							
Zooantharia							
Scleractinia							
Astrocoeniia							
Acroporidae							
Acropora palmata	elkhorn	0.00	0.00	0.02	0.10	0.00	0.00
Fungiida							
Agariciidae							
Agaricia agarcites	lettuce	0.78	0.28	3.70	0.12	4.38	0.14
Poritidae							
Porites asteroides	mustard hill	6.04	1.64	22.4	24.9	14.0	7.30
Porites branneri	finger	0.28	0.34	0.25	1.17	0.00	0.00
Porites porites	finger	2.61	1.41	2.08	1.16	4.01	2.93
Porites porites divaricata	finger	0.00	0.00	0.11	0.00	0.29	0.35
Porites porites frucata	finger	0.00	0.10	0.11	0.30	0.08	0.00
Siderastreidae							
Siderastrea siderea	greater starlet	0.83	0.00	0.25	0.00	0.17	0.05
Siderastrea radians	lesser starlet	3.66	0.13	0.74	0.21	0.17	0.23
Astrocoeniidae							
Stephanocoenia intersepts	blushing starlet	0.00	0.09	0.00	0.00	0.00	0.01
Caryophylliida							
Caryophyllidae							
Eusmilia fastigiata	smooth flower	0.61	0.01	0.00	0.20	0.00	0.05
Faviida							
Faviidae							
Diploria clivosa	knobby brain	4.44	0.00	1.81	0.48	0.08	0.00
Diploria labyrinthiformes	grooved brain	0.00	0.01	2.82	0.00	0.42	0.23
Diploria strigosa	symmetrical brain	3.38	0.74	2.33	0.83	2.77	0.16
Favia fragrum	golfball	3.33	0.12	1.14	0.17	1.26	0.18
Manicina areolata	rose	5.10	0.45	0.00	0.00	0.86	0.08
Montastrea annularis	lobed star	3.99	0.33	4.37	1.16	24.8	6.44
Montastrea cavernosa	cavernous star	0.33	0.17	0.00	0.15	0.02	0.00
Montastrea faveolata	mountainous star	3.33	0.00	0.00	0.00	0.00	0.70

Meandrinidae							
Meandriana meandrites	maze	0.00	0.25	0.00	0.00	0.00	0.20
Dichocoenia stokesii	elliptical star	2.99	0.59	0.13	0.15	0.71	0.37
Mussidae							
Isophyllia sinuosa	sinuous cactus	0.00	0.00	0.00	0.00	0.54	0.02
Mussa angulosa	spiny flower	0.00	0.00	0.00	0.00	0.60	0.00
Scolymia spp.	disk	0.00	0.00	0.11	0.00	2.15	0.00
Mycetophyllia aliciae	knobby cactus	0.00	0.10	0.00	0.00	0.00	0.00
Octocorallia							
Gorgonacea							
Scleraxonia							
Briareidae							
Briareum asbestinum	corky sea finger	6.26	1.06	1.15	0.95	1.25	1.24
Anthothelidae							
E. caribaeorum	carpet gorgonian	0.67	1.28	0.47	0.37	2.57	0.11
Holaxonia							
Plexauridae							
Muricea muricata	spiny sea fan	0.00	0.15	0.00	0.01	0.00	0.20
Eunicea calyculata	warty sea rod	1.44	0.22	0.47	0.17	0.00	0.00
Eunicea mammosa	swollen-knob sea rod	2.16	2.18	4.61	3.02	2.27	0.34
Eunicea succinea	shelf-knob sea rod	2.16	1.23	4.61	0.77	2.27	0.72
Plexaura flexuosa	bent sea rod	0.00	0.14	0.38	3.39	0.00	0.00
Plexaura homomalla	black sea rod	8.20	2.82	12.61	5.00	13.02	6.40
Plexaurella spp.	slit-pore sea rod	1.72	0.14	0.11	0.20	4.01	0.00
Pseudoplexaura spp.	porous sea rod	16.0	1.75	7.84	2.16	2.19	0.05
Gorgoniidae							
Pseudopterogorgia spp.	sea plumes	4.55	0.73	6.14	0.79	0.67	0.00
Gorgonia flabellum	venus sea fan	0.78	0.96	7.94	2.95	8.52	6.25
Gorgonia ventalina	common sea fan	10.2	3.24	12.5	3.11	5.02	1.67

Table 6. Summary statistics for coral assemblages (Rice Bay, Rocky Point and Lindsay Reef combined) in 2001 and 2007 (N= 16 sample plots/reef/year; % Change = [(2007-2001)/2001]*100, where negative values indicate a decrease and positive values indicate an increase from 2001 to 2007; P-values from GLMs, includes arcsin[X] transformations).

	2001		**2007**		**% Change**	**P**
	Mean	SE	Mean	SE		
Species Richness	13.6	0.50	11.5	0.52	-15.4	0.003
Scleractinia	7.5	0.29	5.8	0.30	-22.7	<0.0001
Gorgonacea	5.4	0.29	5.9	0.34	9.3	0.239
Shannon's H'	1.824	0.067	1.832	0.068	0.4	0.934
Equitability E	0.801	0.041	0.747	0.027	-6.7	0.230
Percent Cover						
Total	6.6	0.006	9.9	0.007	50.0	<0.0001
Scleractinia	3.2	0.003	5.0	0.005	56.3	<0.0001
Gorgonacea	3.2	0.004	4.6	0.004	43.8	0.009
Milleporidae	0.002	0.0006	0.003	0.0006	50.0	0.674

Table 7. List of fish species observed in 2001 and 2007 with their relative percent abundances for each reef: Rice Bay, Rocky Point and Lindsay Reef.

Taxonomic name	Common name	Rice	Bay	Rocky	Point	Lindsay	Reef
Year		01	07	01	07	01	07
Actinopterygii							
Atheriniformes							
Atherinidae							
Atherinomorus stipes	hard-head silverside	0.0	0.0	2.2	0.8	0.0	3.9
Beryciformes							
Holocentridae							
Holocentrus rufus	longspine squirrelfish	0.5	0.4	0.0	0.0	0.3	0.1
Holocentrus coruscum	reef squirrelfish	0.0	0.1	0.0	0.2	0.0	0.1
Gasterosteiformes							
Aulostomidae							
Aulostomus maculatus	trumpetfish	0.3	0.1	0.0	0.2	0.1	0.1
Perciformes							
Percoidei							
Serranidae							
Cephalopholis cruentata	graysby	0.3	0.1	0.0	0.0	0.1	0.0
Cephalopholis fulvus	coney	0.0	0.8	0.9	1.2	2.1	2.5
Epinephelus guttatus	red hind	0.3	0.1	0.0	0.0	0.4	0.3
Epinephelus striatus	nassau grouper	0.0	0.2	0.0	0.1	0.0	0.1
Mycteroperca tigris	tiger grouper	0.3	0.0	0.0	0.1	0.1	0.3
Rypticus saponaceus	soapfish	0.3	0.0	0.0	0.0	0.0	0.0
Grammatidae							
Gramma loreto	fairy basslet	0.8	1.1	0.1	1.6	1.5	6.9
Priacanthidae							
Heteropriacanthus cruentatus	glasseye snapper	0.0	0.1	0.0	0.1	0.1	0.1
Malacanthidae							
Malacanthus plumieri	sand tilefish	0.3	0.0	0.0	0.0	0.0	0.1
Carangidae							
Caranx ruber	bar jack	1.1	1.4	0.0	0.4	1.5	5.3
Lutjanidae							
Lutjanus apodus	schoolmaster	0.3	1.0	0.1	0.2	0.1	0.0
Ocyurus chrysurus	yellowtail snapper	0.0	0.0	0.0	0.1	0.0	0.0
Lutjanus mahogoni	mahogany snapper	0.0	0.1	0.0	0.0	0.0	0.1
Gerreidae							
Gerres cinereus	yellowfin mojarra	0.3	0.0	0.0	0.4	0.4	0.9
Haemulidae							
Hemulon sciurus	bludstriped grunt	0.8	0.2	0.0	0.1	0.3	0.2
Haemulon flavolineatum	french grunt	0.0	1.1	0.0	0.0	0.0	0.0
Haemulon chrysargyreum	small mouth grunt	0.0	0.1	0.0	0.0	0.0	0.0
Haemulon plumierii	white grunt	0.0	0.1	0.0	0.0	0.0	0.0
Haemulon carbonarium	ceasar grunt	0.0	0.1	0.0	0.0	0.0	0.0
Mullidae							

Mulloidichthys martinicus	yellow goatfish	0.0	0.1	0.6	0.0	0.7	0.0
Psewdupeneus maculatus	spotted goatfish	2.7	3.6	0.1	0.2	1.5	0.6
Kyphosidae							
Kyphosus sectatrix	chub	1.1	0.0	1.8	10.4	2.1	0.1
Chaetodontidae							
Chaetodon capistratus	four-eye butterfly	0.3	0.2	0.0	0.0	0.4	0.7
Chaetodon ocellatus	spotfin butterfly	0.3	0.0	0.0	0.0	0.0	0.0
Chaetodon striatus	banded butterfly	1.1	1.0	0.6	0.2	0.5	0.4
Pomacanthidae							
Holocanthus tricolor	rock beauty	0.0	0.0	0.0	0.1	0.1	0.0
Holacanthus ciliaris	queen angelfish	0.0	0.0	0.0	0.0	0.0	0.1
Pomacentridae							
Chromis cyaneus	blue chromis	0.0	0.8	0.3	0.0	0.4	0.0
Microspathodon chrysurus	yellowtail damsel	0.0	0.0	1.3	1.5	0.0	0.0
Stegastes partitus	bicolor damsel	0.0	0.0	0.0	0.1	0.0	0.2
Stegastes dorsopunicans	dusky damsel	0.8	0.9	3.0	0.6	2.7	0.6
Stegastes leucostictus	beaugregory	4.1	1.4	0.3	0.6	0.4	1.1
Stegastes planifrons	threespot damsel	0.0	0.3	0.3	0.0	0.1	0.0
Stegastes diencaeus	longfin damsel	0.0	2.9	0.0	1.8	0.1	2.3
Stegastes variabilis	cocoa damsel	1.1	0.5	1.9	1.1	0.9	1.0
Abudefduf saxatilis	sergeant major	0.0	0.0	0.0	0.0	0.0	0.4
Labridae							
Bodianus rufus	spanish hogfish	0.3	0.1	0.3	0.2	0.1	0.1
Halichoeres bivattatus	slippery dick	10	1.6	2.4	2.1	0.3	0.0
Halichoeres garnoti	yellowhead wrasse	0.8	0.4	1.3	2.0	2.5	0.3
Halichoeres maculipinna	clown wrasse	0.8	1.4	1.2	7.2	0.0	0.0
Halichoeres radiatus	puddingwife	0.8	0.9	2.2	2.0	2.3	2.0
Thalassoma bifasciatum	bluehead	32	40	45	41	35	36
Doratonotus megalepis	dwarf wrasse	0.0	0.1	0.0	0.0	0.0	0.0
Scaridae							
Scaridae sp	UNID parrotfish	1.1	0.0	0.0	0.0	2.5	0.0
Scarus croicensis	striped parrotfish	4.6	4.4	3.7	0.1	10.4	3.0
Scarus taeniopterus	princess parrotfish	0.0	0.3	0.4	0.3	0.3	0.7
Scarus vetula	queen parrotfish	0.0	1.2	0.4	0.3	0.1	0.6
Sparisoma aurofrenatum	redband parrotfish	1.1	5.6	1.6	1.6	2.1	3.0
Sparisoma rubripinne	yellowtail parrotfish	0.0	1.2	0.3	0.5	0.1	0.2
Sparisoma viride	stoplight parrotfish	5.1	5.4	5.2	3.3	6.9	7.8
Clinidae							
Malacoctenus macropus	rosy blenny	0.3	1.0	0.0	0.0	0.0	0.2
Malacoctenus triangulatus	saddled blenny	2.4	1.6	0.3	1.5	3.3	2.1
Blenniidae							
Blenniidae sp.	UNID blenny	0.0	0.0	0.0	0.0	0.1	0.0
Ophioblennius atlanticus	red-lip blenny	0.0	0.0	1.5	0.3	0.0	0.0
Gobiidae							
Coryphopterus glaucofraenum	bridled goby	1.1	0.2	0.0	0.3	1.6	1.0
Gnatholepis thompsoni	goldspot goby	0.0	0.0	0.0	0.0	0.1	0.2
Gobiosoma genie	cleaning goby	0.0	0.1	0.0	0.0	2.8	0.3

Acanthuridae

Acanthurus bahianus	ocean surgeon	14	8.2	11	9.2	6.2	6.0
Acanthurus coeruleus	blue tang	6.0	5.5	9.2	5.9	5.0	7.9
Sphyraenidae							
Sphyraena barracuda	great barracuda	0.0	0.1	0.0	0.0	0.0	0.1
Pleuronectiformes							
Bothidae							
Bothus lunatus	peacock flounder	0.0	0.1	0.0	0.0	0.1	0.0
Scorpaeniformes							
Scorpaenidae							
Pterois volitans	red lionfish	0.0	0.0	0.0	0.1	0.0	0.0
Tetraodontiformes							
Balistidae							
Canthidermis sufflamen	ocean triggerfish	0.0	0.0	0.0	0.1	0.0	0.0
Monacanthidae							
Aluterus schoepfii	orange filefish	0.0	0.0	0.0	0.1	0.0	0.0
Ostraciidae							
Lactophrys bicaudalis	spotted trunkfish	0.0	0.1	0.0	0.0	0.1	0.1
Lactophrys trigonus	honeycomb cowfish	0.3	0.0	0.0	0.0	0.0	0.0
Lactophrys triqueter	smooth trunkfish	0.0	0.0	0.1	0.1	0.0	0.1
Tetraodontidae							
Canthigaster rostrata	sharp-nosed puffer	2.4	2.1	0.1	0.1	0.9	0.3
Elasmobranchii							
Rajiformes							
Dasyatidae							
Dasyatis americana	southern stingray	0.0	0.1	0.0	0.2	0.0	0.0
Urotrygonidae							
Urobatis jamaicensis	yellow stingray	0.0	0.0	0.0	0.0	0.0	0.2

Table 8. Summary statistics for fish assemblages (Rice Bay, Rocky Point and Lindsay Reef combined) in 2001 and 2007. (N = 16 sample plots/reef/year; % Change = [(2007-2001)/2001]*100, where negative values indicate a decrease and positive values indicate an increase from 2001 to 2007; P-values from GLMs using untransformed species counts and ln[N+1]-transformed fish counts. 2007a represents my data, 2007b represents fish data collected by the second observer in 2007.

	2001		**2007a**		**2007b**		**% Change**	**P**
	Mean	SE	Mean	SE	Mean	SE		
Species Richness	18.5	1.06	17.3	0.55	18.4	0.54	-6.5	0.393
Shannon's H'	1.786	0.059	2.438	0.0376	-	-	35.5	<0.0001
Equitability E	0.765	0.041	0.872	0.0009	-	-	14.0	0.002
Counts (50 m^{-2})								
Total	86.8	5.47	101.7	5.28	105.7	5.25	17.0	0.031
Major Families								
Acanthuridae	13.9	1.15	16.9	1.67	-	-	21.6	0.993
Labridae	38.5	2.69	48.3	3.42	-	-	25.5	0.660
Pomacentridae	4.9	0.66	6.3	0.53	-	-	28.6	0.007
Scaridae	13.7	1.55	13.4	0.99	-	-	-2.2	0.063
Feeding Guilds					-	-		
Herbivores	34.6	2.48	36.5	2.14	-	-	5.5	0.316
Planktivores	0.8	0.21	2.3	1.07	-	-	191.3	0.319
Detritivores	2.1	0.43	0.7	0.17	-	-	-66.7	0.030
Invertivores	53.7	4.04	68.0	4.16	-	-	26.6	0.025
Piscivores	5.3	0.77	7.0	1.03	-	-	6.1	0.037

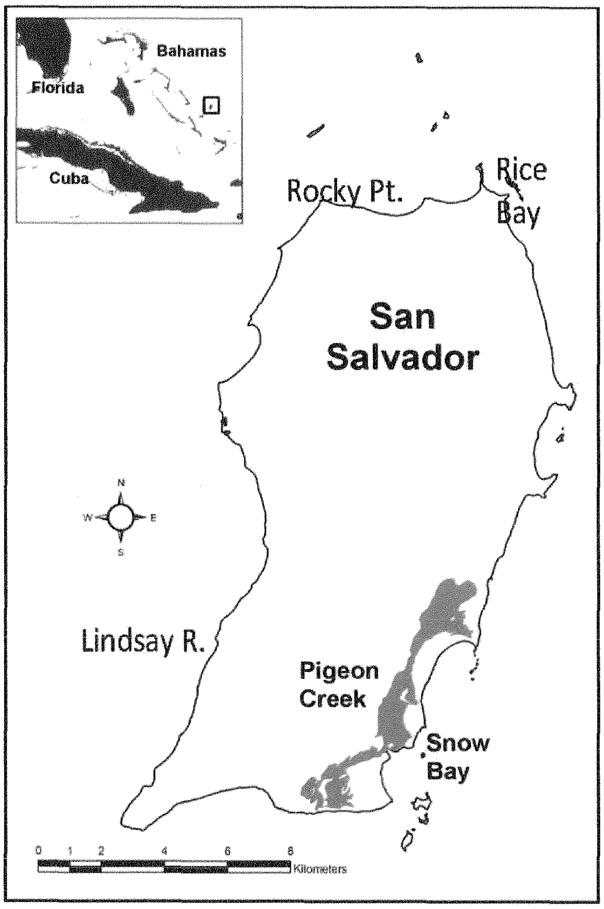

Figure 1. Map of San Salvador showing the three study reef complexes: Lindsay Reef, Rocky Point, Rice Bay and Pigeon Creek. Base map from Krumhansl et al. (2007).

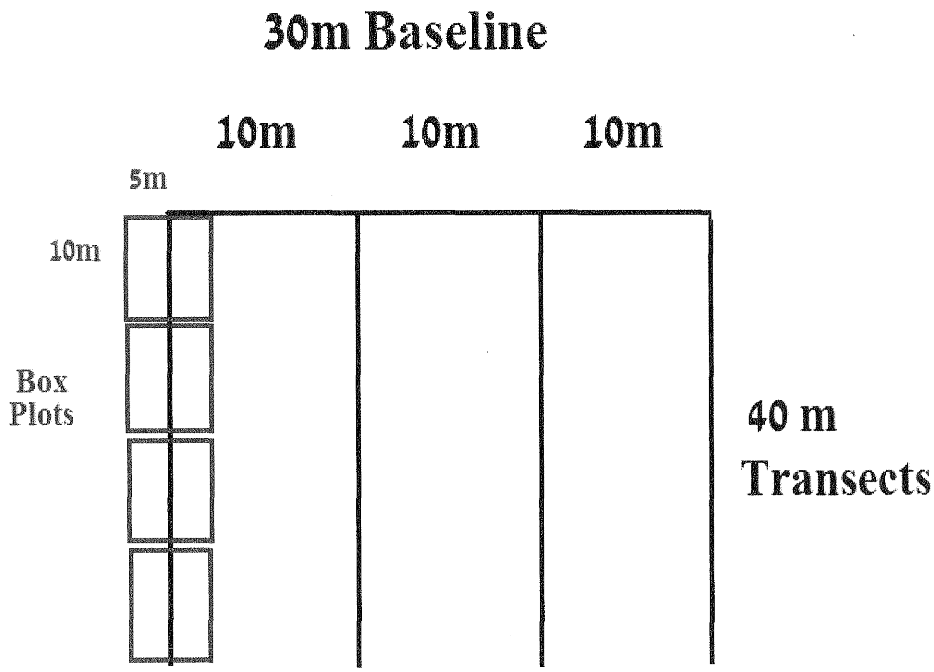

Figure 2. Diagram of how the 50 m^2 box plots were created. Transect lines were not always set up evenly spaced and in the same direction off of the baseline as shown in this example.

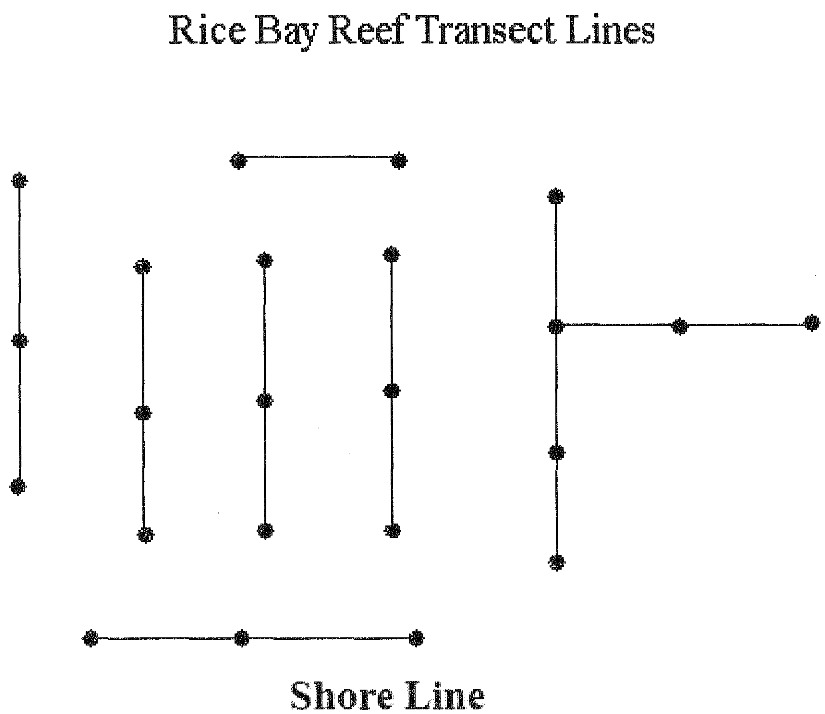

Figure 3. Diagram showing the set up of transect lines at Rice Bay (N = 16). Each line segment between two dots represents a 10-m transect.

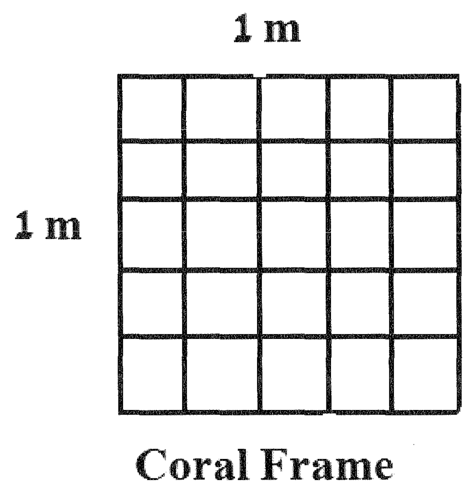

Figure 4. Diagram of the quadrat frame with box grid inside used for the coral percent cover surveys.

Appendix A. Total Fish and Fish Family Raw Data for 2001.

Reef 1 Rice Bay — **Year** 2001 = 1
Reef 2 Rocky Point
Reef 3 Lindsay Reef

Box Plot	Reef	Year	Total	Labridae	Acanthuri	Scaridae	Pomacentri
1	1	1	47.25	6.75	15.75	15.75	4.5
2	1	1	58.5	31.5	11.25	4.5	9
3	1	1	60.75	36	2.25	9	4.5
4	1	1	87.75	38.25	20.25	4.5	2.25
5	1	1	38.25	29.25	9	0	0
6	1	1	24.75	6.75	13.5	2.25	0
7	1	1	22.5	6.75	2.25	13.5	0
8	1	1	119.25	49.5	22.5	2.25	6.75
9	1	1	36	31.5	4.5	0	0
10	1	1	29.25	22.5	6.75	0	0
11	1	1	56.25	22.5	11.25	11.25	0
12	1	1	58.5	11.25	13.5	13.5	2.25
13	1	1	38.25	13.5	6.75	9	6.75
14	1	1	29.25	13.5	6.75	0	4.5
15	1	1	99	38.25	18	13.5	6.75
16	1	1	22.5	11.25	4.5	0	2.25
1	2	1	103.5	65.25	9	13.5	11.25
2	2	1	103.5	56.25	24.75	6.75	11.25
3	2	1	121.5	58.5	38.25	18	2.25
4	2	1	128.25	38.25	18	13.5	4.5
5	2	1	99	42.75	9	40.5	4.5
6	2	1	117	54	18	4.5	4.5
7	2	1	108	63	22.5	13.5	6.75
8	2	1	99	54	22.5	6.75	13.5
9	2	1	94.5	38.25	11.25	9	9
10	2	1	78.75	31.5	27	11.25	9
11	2	1	81	47.25	18	2.25	4.5
12	2	1	78.75	27	24.75	9	11.25
13	2	1	119.25	58.5	13.5	13.5	2.25
14	2	1	119.25	24.75	15.75	6.75	9
15	2	1	94.5	78.75	13.5	2.25	0
16	2	1	96.75	60.75	20.25	6.75	4.5
1	3	1	121.5	31.5	9	40.5	18
2	3	1	110.25	65.25	4.5	18	6.75
3	3	1	153	51.75	27	31.5	4.5
4	3	1	117	49.5	20.25	27	0
5	3	1	126	54	18	27	0
6	3	1	72	29.25	15.75	13.5	2.25
7	3	1	72	31.5	9	20.25	0
8	3	1	114.75	38.25	22.5	36	2.25
9	3	1	130.5	69.75	4.5	15.75	0

10	3	1	54	31.5	9	6.75	0
11	3	1	105.75	56.25	11.25	24.75	2.25
12	3	1	204.75	67.5	18	27	2.25
13	3	1	85.5	24.75	6.75	24.75	15.75
14	3	1	69.75	29.25	0	20.25	9
15	3	1	92.25	22.5	6.75	24.75	11.25
16	3	1	67.5	27	9	22.5	4.5

Appendix B. Total Fish and Fish Family Raw Data for 2007.

Reef 1	Rice Bay	Year	2007 = 2
Reef 2	Rocky Point		
Reef 3	Lindsay Reef		

Box Plot	Reef	Year	Total	Labridae	Acanthuri	Scaridae	Pomacentri
1	1	2	124	62	18	12	1
2	1	2	92	42	18	23	3
3	1	2	115	71	11	20	5
4	1	2	57	29	2	8	4
5	1	2	157	63	29	28	13
6	1	2	113	46	14	23	6
7	1	2	116	61	23	15	7
8	1	2	121	46	19	23	8
9	1	2	37	0	0	21	5
10	1	2	23	0	0	11	1
11	1	2	19	1	0	6	4
12	1	2	28	0	0	11	2
13	1	2	141	64	23	15	8
14	1	2	104	49	22	12	6
15	1	2	76	41	1	14	11
16	1	2	81	40	12	13	10
1	2	2	174	113	27	10	2
2	2	2	83	52	18	5	0
3	2	2	76	37	14	4	6
4	2	2	88	46	20	6	9
5	2	2	162	94	28	17	10
6	2	2	117	74	19	10	10
7	2	2	90	50	11	7	14
8	2	2	83	27	27	8	13
9	2	2	150	77	40	7	14
10	2	2	84	61	12	4	4
11	2	2	75	63	1	4	3
12	2	2	89	69	0	4	5
13	2	2	112	66	24	4	5
14	2	2	91	59	17	6	2
15	2	2	93	58	16	11	6
16	2	2	133	83	27	8	6
1	3	2	136	56	12	16	5
2	3	2	150	28	15	17	12
3	3	2	116	47	20	10	4
4	3	2	115	47	15	25	4
5	3	2	91	32	19	9	5
6	3	2	82	30	24	13	4
7	3	2	113	47	20	20	11
8	3	2	65	15	5	13	10
9	3	2	116	55	13	17	10

10	3	2	115	43	18	29	8
11	3	2	115	51	21	18	5
12	3	2	160	75	15	21	1
13	3	2	113	32	53	16	3
14	3	2	73	35	10	13	6
15	3	2	62	21	8	11	6
16	3	2	157	62	49	25	6

Appendix C. Fish by Feeding Guild Raw Data for 2001.

Reef 1 **Rice Bay** **Year** **2001 = 1**
Reef 2 **Rocky Point**
Reef 3 **Lindsay Reef**

Box Plot	Reef	Year	Invertivore	Herbivore	Piscivore	Planktivore	Detrivore
1	1	1	15.75	36	4.5	0	0
2	1	1	38.25	24.75	4.5	0	4.5
3	1	1	49.5	15.75	13.5	0	0
4	1	1	63	36	9	2.25	0
5	1	1	29.25	9	13.5	0	0
6	1	1	9	15.75	4.5	0	0
7	1	1	6.75	15.75	4.5	0	0
8	1	1	94.5	31.5	22.5	0	0
9	1	1	31.5	4.5	6.75	0	0
10	1	1	24.75	6.75	0	0	0
11	1	1	33.75	22.5	2.25	0	0
12	1	1	31.5	29.25	2.25	2.25	0
13	1	1	22.5	22.5	0	0	0
14	1	1	22.5	11.25	11.25	2.25	0
15	1	1	65.25	38.25	6.75	2.25	2.25
16	1	1	18	6.75	6.75	0	0
1	2	1	72	29.25	4.5	4.5	4.5
2	2	1	63	47.25	0	0	9
3	2	1	65.25	58.5	2.25	2.25	0
4	2	1	56.25	36	11.25	0	0
5	2	1	49.5	54	0	0	0
6	2	1	60.75	27	0	0	0
7	2	1	67.5	45	4.5	0	4.5
8	2	1	63	42.75	6.75	2.25	6.75
9	2	1	51.75	36	0	0	2.25
10	2	1	38.25	47.25	0	0	2.25
11	2	1	58.5	31.5	0	0	2.25
12	2	1	40.5	49.5	0	2.25	4.5
13	2	1	92.25	56.25	2.25	0	0
14	2	1	31.5	31.5	4.5	0	4.5
15	2	1	78.75	15.75	9	0	0
16	2	1	65.25	31.5	6.75	2.25	4.5
1	3	1	56.25	63	2.25	6.75	9
2	3	1	83.25	29.25	2.25	2.25	4.5
3	3	1	90	65.25	13.5	0	4.5
4	3	1	69.75	49.5	6.75	2.25	0
5	3	1	81	45	4.5	0	0
6	3	1	42.75	31.5	2.25	0	0
7	3	1	42.75	29.25	0	0	0
8	3	1	51.75	63	9	0	2.25
9	3	1	110.25	22.5	0	0	0

10	3	1	38.25	15.75	0	0	0
11	3	1	67.5	38.25	4.5	0	2.25
12	3	1	159.75	83.25	22.5	0	0
13	3	1	42.75	47.25	4.5	2.25	9
14	3	1	49.5	31.5	6.75	0	0
15	3	1	49.5	45	9	2.25	11.25
16	3	1	33.75	36	2.25	0	2.25

Appendix D. Fish by Feeding Guild Raw Data for 2007.

Reef 1	**Rice Bay**			**Year**	**2007 = 2**		
Reef 2	**Rocky Point**						
Reef 3	**Lindsay Reef**						

Box Plot	**Reef**	**Year**	**Invertivore**	**Herbivore**	**Piscivore**	**Planktivore**	**Detrivore**
1	1	2	79	35	2	3	1
2	1	2	49	44	1	1	2
3	1	2	89	36	2	2	1
4	1	2	46	15	5	1	0
5	1	2	86	75	4	2	2
6	1	2	66	46	11	2	0
7	1	2	72	46	3	1	4
8	1	2	62	47	11	5	0
9	1	2	9	28	1	0	2
10	1	2	9	14	2	0	0
11	1	2	9	16	1	0	0
12	1	2	12	12	4	3	0
13	1	2	83	52	19	0	0
14	1	2	64	40	9	1	0
15	1	2	48	31	3	4	0
16	1	2	54	36	7	0	0
1	2	2	141	39	12	1	1
2	2	2	61	23	4	0	0
3	2	2	54	24	6	1	1
4	2	2	58	35	5	0	3
5	2	2	124	120	5	1	2
6	2	2	101	81	0	0	0
7	2	2	77	78	5	0	4
8	2	2	56	91	3	0	0
9	2	2	101	46	2	17	0
10	2	2	70	20	5	0	1
11	2	2	68	8	7	0	0
12	2	2	84	9	4	0	0
13	2	2	83	35	7	0	0
14	2	2	68	27	10	1	0
15	2	2	60	33	8	0	1
16	2	2	91	41	4	0	0
1	3	2	106	33	32	0	0
2	3	2	109	44	38	0	4
3	3	2	82	34	2	0	0
4	3	2	72	44	11	0	0
5	3	2	58	34	13	1	0
6	3	2	41	41	4	0	2
7	3	2	68	52	4	1	1
8	3	2	39	28	7	0	0
9	3	2	84	40	8	2	0

10	3	2	59	55	8	0	1
11	3	2	74	45	11	0	0
12	3	2	123	38	11	2	0
13	3	2	42	32	1	40	0
14	3	2	48	29	1	1	2
15	3	2	40	26	6	0	0
16	3	2	83	52	7	30	0

Appendix E. Coral Raw Data for 2001.

1	Rice Bay	Year	2001 = 1
2	Rocky Point		
3	Lindsay Reef		

Box Plot	Reef	Year	Total % coral cover	Coral Spp R	Scler Spp R	Gorg Spp R	Coral Shan (H)	Coral E	Scler % cover	Mille % cover	Gorgo % cover
1	1	1	3.425	15	9	6	1.9821	0.73	1.225	0	2.2
2	1	1	3.65	18	8	9	2.1264	0.74	1.15	0.1	2.4
3	1	1	5.05	16	10	6	1.9527	0.7	4.075	0	0.975
4	1	1	8.725	17	9	7	2.0766	0.73	1.9	0.25	6.575
5	1	1	1.4	11	7	4	0.5963	0.25	0.7	0	0.7
6	1	1	1.6	9	5	4	1.6801	0.76	0.5	0	1.1
7	1	1	6.15	17	8	7	2.2201	0.78	1.375	0.5	4.275
8	1	1	7.075	18	9	8	2.1572	0.75	3.225	0.25	3.6
9	1	1	0.5	8	5	3	0.3246	0.16	0.375	0	0.125
10	1	1	0.8	10	7	3	0.4849	0.21	0.65	0	0.15
11	1	1	1.05	9	5	3	1.9609	0.89	0.625	0.05	0.375
12	1	1	2.1	13	9	3	2.2573	0.88	1.4	0.05	0.65
13	1	1	0.925	7	4	2	1.4369	0.74	0.3	0.5	0.125
14	1	1	0.65	8	7	1	1.7256	0.83	0.575	0	0.075
15	1	1	1.825	13	8	5	2.1702	0.85	0.55	0	1.275
16	1	1	0.175	2	2	0	0.6829	0.99	0.175	0	0
1	2	1	5.75	12	6	4	2.04365	0.82	2.6	0.225	2.925
2	2	1	6.167	12	6	4	2.05648	0.83	3.175	0.206	2.827
3	2	1	20.85	20	11	8	2.40855	0.8	9.7	0.25	10.9
4	2	1	12.275	18	9	8	2.02807	0.7	2.425	1.6	8.25
5	2	1	7.8	15	8	7	1.44162	0.53	5.925	0	1.875
6	2	1	12.975	15	7	7	1.83954	0.68	2.825	0.1	10.05
7	2	1	6.9	16	10	6	2.09148	0.75	3.95	0	2.95
8	2	1	11.175	16	7	9	1.98856	0.72	3.65	0	7.525
9	2	1	9.725	16	8	7	1.93755	0.7	1.45	0.25	8.025

10	2	1	5.825	14	6	7	2.02026	0.77	1.925	1.6	2.3
11	2	1	2.625	11	7	3	1.97087	0.82	1.825	0.05	0.75
12	2	1	4.175	10	7	3	1.78316	0.77	1.95	0	2.225
13	2	1	8.275	12	8	3	1.69711	0.68	4.575	0.125	3.575
14	2	1	7.25	15	9	6	2.06878	0.76	4.075	0	3.175
15	2	1	10	12	5	7	1.46547	0.59	6.35	0	3.65
16	2	1	7.5	14	7	6	1.94883	0.74	2.6	0.2	4.7
1	3	1	5.7	17	12	4	1.33773	0.77	5.4	0.025	0.275
2	3	1	6.85	14	7	6	1.88126	0.98	4.75	0.025	2.075
3	3	1	9.025	16	9	6	1.88274	0.86	5.9	1.55	1.575
4	3	1	6.65	18	9	7	1.89459	1	5.65	0.05	0.95
5	3	1	9.025	16	7	7	1.69451	0.77	1.9	0.7	6.425
6	3	1	7	13	7	6	1.66688	0.86	2.4	0	4.6
7	3	1	12.425	15	9	6	2.09538	0.83	4.8	0	7.625
8	3	1	7.6	18	10	6	2.49155	1.23	3.713	0.3	3.675
9	3	1	7.975	12	6	6	1.87095	0.9	4.675	0	3.3
10	3	1	7.025	12	4	6	2.11619	1.09	4.15	0.475	2.45
11	3	1	12.475	17	10	6	1.89233	0.75	8.1	0.6	3.775
12	3	1	9.93	13	6	7	2.02234	0.88	4.55	0	5.38
13	3	1	2.875	14	10	3	2.32316	2.2	2.2	0.1	0.575
14	3	1	8.275	13	6	6	2.21544	1.05	4.2	0.35	3.725
15	3	1	8.175	13	7	6	1.77395	0.84	6.15	0	2.025
16	3	1	9.075	14	10	4	1.7808	0.81	6.05	0	3.025

Appendix F. Coral Raw Data for 2007.

1	Rice	Year	2007 = 2
2	Rocky		
3	Lindsay		

Box Plot	Reef	Year	Total % coral	Coral Spp R	Scler Spp R	Gorg Spp R	Coral Shan (H)	Coral E	Scler % cover	Mille % cover	Gorgo % cover
1	1	2	7.06	11	4	7	1.94122	0.81	0.36	0.48	6.22
2	1	2	13	14	3	10	2.34105	0.89	0.96	1.4	10.64
3	1	2	4.46	13	7	6	2.06031	0.8	1.62	0.2	2.64
4	1	2	1.552	9	4	6	1.95092	0.89	0.8	0	0.752
5	1	2	6.7	13	6	8	2.08998	0.81	2.52	0	4.18
6	1	2	3.86	14	7	8	2.44759	0.93	1.06	0	2.8
7	1	2	9.18	14	4	8	2.30804	0.87	2.7	0.4	6.08
8	1	2	9.18	17	8	10	1.99455	0.7	1.82	0	7.36
9	1	2	10.58	14	9	5	2.14433	0.81	3.84	0.22	6.52
10	1	2	4.8	12	6	7	2.09279	0.84	1.84	0	2.96
11	1	2	5.36	13	6	7	2.3754	0.93	2.28	0.28	2.8
12	1	2	5.54	12	4	9	2.07146	0.83	0.58	0	4.96
13	1	2	0	0	0	0	0	0	0	0	0
14	1	2	0	0	0	0	0	0	0	0	0
15	1	2	9.1	21	10	7	2.08251	0.68	2.3	0.6	6.2
16	1	2	7.4	11	6	6	1.7853	0.74	3	0	4.4
1	2	2	15.54	12	7	6	1.66456	0.67	7.7	0	7.84
2	2	2	13.78	15	6	10	1.87602	0.69	8.12	0	5.66
3	2	2	15.06	12	7	5	1.34373	0.54	11.88	0.4	2.78
4	2	2	16.52	15	9	7	2.2869	0.84	6.94	1.36	8.22
5	2	2	9.86	13	7	7	2.17269	0.85	3.26	0.1	6.5
6	2	2	11.22	10	7	4	1.62396	0.71	5.74	0	5.48
7	2	2	8.06	10	4	7	1.56654	0.68	6.82	0	1.78
8	2	2	21.66	11	3	9	1.95662	0.82	8.2	0	13.46
9	2	2	8.42	11	2	8	2.05402	0.86	3.66	0.7	4.06
10	2	2	17.48	12	4	7	1.86287	0.75	10.92	2.04	4.52
11	2	2	19.24	15	6	9	1.61187	0.6	13.12	0.1	6.02
12	2	2	14.22	15	7	8	1.86398	0.69	8.3	0.08	5.84
13	2	2	9.84	12	6	5	1.93115	0.78	3.42	0.44	5.98
14	2	2	16	14	6	8	1.76988	0.67	10.32	0.04	5.64
15	2	2	14.28	10	5	6	0.98817	0.43	12.2	0	2.08
16	2	2	12.84	17	9	8	2.09415	0.74	6.8	0.4	5.64
1	3	2	18.9	9	6	3	1.49677	0.68	6.9	0.4	11.6
2	3	2	14.348	12	7	5	2.04289	0.82	9.388	0.6	4.36
3	3	2	11.56	9	6	4	1.78236	0.81	8.08	0	3.48
4	3	2	7.44	10	6	4	1.7485	0.76	4.76	0.4	2.28
5	3	2	8.98	14	9	4	2.01398	0.76	5.44	0.5	3.04
6	3	2	7.324	9	7	3	1.91313	0.87	4.404	0	2.92

7	3	2	2.28	7	5	3	1.44364	0.74	0.96	0	1.32
8	3	2	7.384	11	6	2	2.13728	0.89	5.264	0.08	2.04
9	3	2	9.26	11	6	4	1.79189	0.75	2.08	0.5	6.68
10	3	2	9.04	10	6	5	2.02467	0.88	5.76	0	3.28
11	3	2	9.28	9	4	5	1.97997	0.9	4.16	0.8	4.32
12	3	2	6.84	7	5	3	1.88153	0.97	4.84	0	2
13	3	2	9.92	10	6	4	1.65395	0.72	6.46	0.4	3.06
14	3	2	9.42	12	9	3	1.97449	0.79	5.82	0.1	3.5
15	3	2	9.36	8	5	4	1.86816	0.9	3	0	6.36
16	3	2	9.96	12	6	6	1.83818	0.74	3.44	0.08	6.44

Appendix G. Fish Data from the Second Observer in 2007.

1	Rice	Year	2007 = 2
2	Rocky	Observer 3	
3	Lindsay		

Box Plot	Reef	Year	Observer	Species	Total Fish
1	1	2	3	20	113
2	1	2	3	16	118
3	1	2	3	22	101
4	1	2	3	13	43
5	1	2	3	21	132
6	1	2	3	23	117
7	1	2	3	19	117
8	1	2	3	23	165
9	1	2	3	12	37
10	1	2	3	10	38
11	1	2	3	15	40
12	1	2	3	14	34
13	1	2	3	26	188
14	1	2	3	21	122
15	1	2	3	19	93
16	1	2	3	20	107
1	2	2	3	23	168
2	2	2	3	14	92
3	2	2	3	16	105
4	2	2	3	18	125
5	2	2	3	18	159
6	2	2	3	21	140
7	2	2	3	16	129
8	2	2	3	15	88
9	2	2	3	21	110
10	2	2	3	17	127
11	2	2	3	19	93
12	2	2	3	15	93
13	2	2	3	19	82
14	2	2	3	13	60
15	2	2	3	12	88
16	2	2	3	24	108
1	3	2	3	22	131
2	3	2	3	18	153
3	3	2	3	21	95
4	3	2	3	18	91
5	3	2	3	17	104
6	3	2	3	15	83
7	3	2	3	21	93
8	3	2	3	17	81

9	3	2	3	26	135
10	3	2	3	20	127
11	3	2	3	21	122
12	3	2	3	22	158
13	3	2	3	17	59
14	3	2	3	14	64
15	3	2	3	17	98
16	3	2	3	21	146