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# Reef fish and coral assemblages on Hospital Point and near Bastimentos Island, Panama

Elaine Shen

*SIT Study Abroad*

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# Reef fish and coral assemblages on Hospital Point and near Bastimentos Island, Panama

Independent Study Project; SIT Panama Fall 2016

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Elaine Shen, Rice University 2018

## ABSTRACT

Because worldwide declines coral reef health are of major concern, studying coral reefs through the lens of conservation efforts at local scales is essential for determining and monitoring effective policy measures. In the Bocas del Toro Archipelago, there are conflicts of interest between exploitative rapid tourism development, overfishing practices, and national efforts to conserve the local marine biodiversity. Coral and reef fish species abundance richness, diversity, evenness, and similarity were measured to see how coral and reef fish assemblages changed between protected and unprotected areas. A total of 329 fish and 322.5 square meters of benthos were analyzed using underwater photo and video data along three 30 meter transects in Coral Cay, Hospital Point, and Piña Cay in November 2016. Unprotected sites (Coral Cay and Hospital Point) showed a significantly higher fish abundance and overall higher fish species diversity than the protected site (Piña Cay), however the protected area surveyed had a higher overall benthic macrofauna diversity. All sites were statistically different from each other in major benthic macrofauna categories, including gorgonian, macroalgae, and sand/rubble/pavement cover. There was no clear relationship between the coral cover and fish abundance in sites. Despite establishing statistical significance in some comparisons, all the conclusions were complicated by differences in weather conditions and depth between sites during data collection.

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## INTRODUCTION

### The relationship between Caribbean coral reefs, reef fish, and marine protected areas

Coral reefs are one of the most biodiverse ecosystems in the world and provide numerous ecosystem services, including shoreline protection and marine habitat (Perry et al. 2013). However, nearly 60% of the world's coral reefs have been classified as threatened due to overfishing, coastal development, and other human activities worldwide (Moberg and Rönnbäck 2003). In the Caribbean, coral cover has declined by an average of 80% in the last 40 years (Perry et al. 2013).

Corals are animals in the phylum Cnidaria and some, especially hard corals that build coral reefs, have an endosymbiotic relationship with the dinoflagellate algae zooxanthellae (genus *Symbiodinium*). This photosynthetic algae gives hard corals the energy necessary to build their calcium carbonate skeletons. These calcium carbonate skeletons are the main structural components of coral reefs (Sheppard et al. 2009). Reefs must maintain a delicate balance between reef calcium carbonate accretion and erosion. Under a threshold of around 10% live coral cover, the reef may be outcompeted by other encrusting organisms like macroalgae (Perry et al. 2013).

Reef fish depend on structurally and topographically complex coral structures for habitat (Grober-Dunsmore et al. 2007). Habitat complexity refers to diversities in vertical relief and benthic species composition (McCormick 1994). Worldwide, over 25% of the world's fish species live exclusively on coral reef habitats (Sheppard et al. 2009). In the Caribbean, fish density in both fished and non-fished species has only declined significantly in the last decade despite declines in coral reef health since the 1970s. Different historical and ecological causes may explain the longer lag time between coral reef health decline and changes in reef fish density. Unlike in the Indo-Pacific, there are no species of Caribbean reef fish that live and feed exclusively on corals, so non-coral habitats play a role in the speciation and persistence of Caribbean fish taxa (Paddock et al. 2009). This means that Caribbean reef fish find habitat in many different near-shore ecosystems, including those dominated by mangroves and seagrasses. The connectivity between mangroves, seagrasses, and coral habitats is important for mapping and planning conservation efforts.

One conservation management tool that has often been recommended by the scientific community is the designation of critical reef habitats as marine protected areas (MPAs) or marine reserves. One goal of MPAs is to help replenish fish and marine organism stocks in important fisheries through spillover effects; however, this requires strict restrictions on access, proper enforcement, and large enough protected areas. Spillover effects occur when local marine reserves enhance the production of fish eggs and larvae inside its borders and provide a net positive of adults and juveniles that emigrate outside its borders (Gell and Roberts 2003). Tropical MPAs are generally more successful than temperate MPAs because they protect highly targeted herbivorous reef fish populations, whose role in coral reefs is to consume macroalgae. Herbivorous fish generally help reduce the competition between corals and macroalgae, increasing the live coral cover and ensuring a net positive accretion of calcium carbonate (Lester et al. 2009). The efficacy of Panama's relatively new marine parks is poorly understood and requires monitoring over time at local scales to identify the area-specific nuances and challenges to their management.

## The Bocas del Toro Archipelago and Bastimentos Island National Park

On the northwestern coast of Panama near the Costa Rican border is a network of islands and reefs known as the Bocas del Toro Archipelago. This area receives about 3-5 meters of rainfall annually and does not exhibit pronounced seasonal patterns of temperature, but rather a wet and dry season (Collin 2005). Bocas del Toro has one of the highest diversities and abundances of corals in shallow Caribbean waters and varies in levels of exposure and complexity. Outside of the archipelago, waves and currents have a stronger effect than inside the archipelago, since the islands create barriers that allow for more sheltered, semi-lagoonal systems. This leads to markedly different fish distributions between areas that are sheltered and unsheltered from waves and currents. Exposed zones are physically more complex and contain a higher diversity of fish communities while sheltered zones are generally more isolated from one another. Gobies, damselfish, and wrasses are generally the most abundant functional groups in the region (Dominici-Arosemana and Wolff 2005). The narrow continental shelf provides no protective barrier to the shallow water (15m) reefs, resulting in massive and encrusting coral genuses of *Sidarastrea*, *Acropora*, *Orbicella*, and *Porites*. Coral cover in the Laguna de Chiriqui is approximately 20% with high macroalage growth (Clifton et al. 1997).

Locals, scientists, and outside observers have expressed concern that unsustainable tourism in Bocas del Toro is starting to degrade the natural environment (Kayes 2005; Claiborne 2010). Additionally, fishing in this region is widespread and more technically advanced than in other Panamanian reef areas, so the largest size-classes of fish are schools of mid-sized herbivores (Clifton et al. 1997). The absence of large predatory fish species in Bocas del Toro has been documented and a result of exploitative overfishing practices in the region (Windevoxhel and ter Heegde 2008). If large predatory fish species continue to be overfished, trophic level declines may result in the targeting of herbivorous reef fish and cause coral reef health decline (Pauly et al. 1998).

One of the major conservation efforts in Bocas del Toro occurred when the Panamanian government created the country's first-ever marine park in 1988 on Bastimentos Island. The Bastimentos Island National Park encompasses over 13,226 hectares of land, contains more than 200 species of tropical fish, marine turtle nesting beaches, and mangrove, seagrass, and coral reef ecosystems (Rivera et al. 2012). The National System of Protected Areas (SINAP) of Panama and the Ministry of Environment manage the national park and the Marine Authority of Panama (AMP) manages the surrounding sea and lagoonal areas (Windevoxhel and ter Heegde 2008). Marine national parks are defined by SINAP as areas over 1,000 hectares that contain representative samples of major marine, coastal, and island ecosystems of national and international importance. They also serve to help the sustained take of organisms by residents neighboring the park (ANAM 2006). Other conservation and research efforts include the Smithsonian Institution's large research facility in Bocas del Toro, the presence of conservation NGO *Fundación Promar*, and Nature Conservancy's PROARCA program (Windevoxhel and ter Heegde 2008).

In 2001, the park's natural resources were in good condition, but threatened by unregulated tourism, an increase in demand for hotels and restaurants, overfishing, agricultural activities within the protected area, and hunting (ANAM 2001). Economic considerations led to most of the archipelago and coastal strip to be excluded from protected-area status in favor of development, so not all areas of high ecological value are protected (Windevoxhel and ter Heegde 2008). Because the Institute of Panamanian Tourism (IPAT) considers Bocas del Toro to

be a high-priority tourist development area and collaborates with powerful private-sector developers, economically profitable activities are generally favored over environmental or long-term sustainable development (Suman 2002; Windevoxhel and ter Heegde 2008). Effective conservation efforts have positively related with compliance, reserve visibility, and length of management time but negatively related with compliance, reserve visibility, and village population size. Thus, tourism and conservation in this area come in direct conflict. In practice, there is no enforcement of the park and local fishermen are able to continue practicing extractive practices and operations within park boundaries. Tourism has not provided a viable alternative to exploitative fishing and farming practices for some locals, but transitioning to tourism could offset ecological harms (Windevoxhel and ter Heegde 2008).

Currently, there has been no scientific effort to relate the presence of the Bastimentos Island National Park to changes in coral and reef fish diversity because no baseline study was conducted before the establishment of the park. Guzmán and Guevara (1998) stated that areas within national park boundaries did not include the greatest diversity of organisms in the region and had low reef development. This study will examine how coral and reef fish species abundance, richness, diversity, evenness, and similarity differ between a protected area bordering the national park (Cayo Piña) and unprotected areas (Hospital Point and Coral Cay).

## RESEARCH QUESTION

How do reef fish and coral reef assemblages change in species abundance, richness, diversity, evenness and similarity between protected area Piña Cay and unprotected areas Hospital Point and Coral Cay?

## RESEARCH OBJECTIVES

- To understand how reef fish and coral reef populations change in a local Caribbean ecosystem based on the management scheme (protected versus unprotected).
- To utilize photo, video, and editing software to document substrate and fish.

## METHODS

### Site selection

Three sites in the Bocas del Toro region of Panama were chosen primarily based on their level of protection (in terms of management scheme) and homogeneity in wave action and depth (Fig. 1). The slight exception was Hospital Point, whose site determination factored in the logistical constraints of budget and willingness of local boat drivers. The sites representing unprotected areas with high human usage were Hospital Point of Solarte Island (09° 20' 03"N and 82° 13' 06"W) and Coral Cay (9° 14'30"N, 82° 8'17"W) on the southeastern side of Bastimentos Island. Due to logistical and permitting restraints, only areas bordering the national park were considered to capture the spillover effects of the protected area (Gell and Roberts 2003). The site representing protected area with a low amount of human use was Piña Cay (9° 14'55"N, 82° 9'4"W). All of these sites were either near or on the unexposed lagoonal side of





**Fig. 1.** Study sites (denoted by triangles) off the shores of Hospital Point on Solarte Island and Bastimentos Island National Park: 1. Hospital Point 2. Piña Cay 3. Coral Cay. Photo retrieved from Wikipedia Commons.

Bastimentos Island to control for wave action from the rest of the Caribbean. Study sites were randomly selected by swimming to the closest area containing reef structure from the boat, which randomly anchored at all study sites.

#### Data collection

Three 30-meter transects spaced approximately three meters apart were run parallel to shore and repeated at each site for a total of nine 30-meter transects for photo and video data collection (Kaczmarek et al. 2005). Depths were relatively similar in all sites (0 m – 3m) and were measured using the transect tape prior to photo and video data collection. Informal observations of the topography, coral and reef fish populations, and human presence were also recorded.

A Nikon COOLPIX AW130 waterproof digital camera was used to collect photo and video data along each transect at each site. The transect tape served as a ruler and calibration tool for the area covered in the photo. A birds-eye view of the benthos at the surface of the water was taken along the entire transect in equally spaced increments. Three fin kicks were made in-between each photo captured to ensure that there was no substrate overlap in the photos. An equal amount of area to the left and right of the transect tape was captured in each photo by keeping transect tape in the middle of the camera frame. The area covered in each photo depended on the depth of the site. As many photos were taken as necessary to capture benthos along the entire length of the transects. At a depth of 0.5 meters, about 40 photos were needed to capture the entire 30-meter transect whereas lower depths of 1 to 2 meters only required 15-20 photos.

After a five to ten minute fish recovery period, a video of the benthos and fish was recorded in 1080p HD at birds-eye view while swimming slowly (3 fin kicks every 10 seconds) with the transects in the middle of the frame. (Assis et al. 2013; Watson et al. 2005). Videos were generally 1 minute and 40 seconds long using this recording method.

## Data analysis

### *Photo analysis*

Using public domain NIH ImageJ software, the area of each image was calculated using the flattest and deepest portion of the transect tape as a calibration tool (Rasband 2012). The width of the transect tape was measured to be 1.1 cm and used to convert the length and width of the image from pixels to centimeters.

Then, the raw images were uploaded onto photo-editing software Adobe Photoshop Lightroom 5 for color correction and basic lighting adjustments. Each photo was edited using Auto Tone the Auto Tone preset and the magenta tint of the photo was increased (slider moved to the right) by +70 to +80 percent. Afterwards, minor adjustments of exposure and contrast were made on each photo to increase the clarity of the substrate and minimize dark areas (Iqbal et al. 2010).

The edited images were then uploaded onto Coral Point Count with extensions (CPCe 4.1), a program that identifies Caribbean reef organisms and benthic macrofauna to the lowest taxonomic group in a systematic way using random points and a coral code. These data can be exported from the program into an Excel file that compiles the information into proportions and calculates both Shannon's and Simpson's diversity indices (Kohler et al. 2006).

Slight depth variation between sites led to differences in the area covered in each photo and the number of random points needed to analyze each photo was thus considered. Photos were organized into three size classes ( $0 \text{ m}^2 - 1.5 \text{ m}^2$ ,  $1.5 \text{ m}^2 - 3.0 \text{ m}^2$ , and  $3.0 \text{ m}^2 - 5.0 \text{ m}^2$ ) to determine the minimum number of random points needed to analyze each photo in each size class. Three photos from each size class were selected from varying sites (if possible) and individually analyzed using 10, 20, and 40 random points. Percentages of live coral, sponge, and rubble cover were compared for similarity by the number of random points used on each photo by running one-way ANOVA tests with Bonferroni corrections. Because there were no statistically different results in substrate cover using 10, 20, or 40 points in any of the size classes, 10 random points were overlaid on every image and identified to the lowest taxonomic group. Online Caribbean taxonomic identification guide "Florent's Guide to the Tropical Reefs" was used for reference.

### *Video analysis*

Raw video footage was uploaded onto video editing software Final Cut Pro version 10.2.2 and edited using the “Balance Color” function to correct lighting and color. Fish individuals were identified to the species level when possible and approximated into four size classes: extra small (0 – 5 cm), small (5 – 10 cm), medium (10 – 15 cm), and large (15 cm – 25 cm). Video fractions of less than one second were used (Assis et al. 2013). Online Caribbean taxonomic identification guide “Florent’s Guide to the Tropical Reefs” was used for reference. Individuals that were unable to be identified to the species level were grouped to the family level. A general “Unknown” category captured any other individuals and was considered one species in diversity and richness calculations.

### *Statistical analyses*

Coral and reef fish species abundance, richness, Shannon’s diversity index (H), and species evenness ( $E_h$ ) were calculated for each of the sites (Wedding et al. 2008). Both coral and total benthic macrofauna diversity was recorded as  $H_c$  and  $H_b$ , respectively. The Sorenson’s coefficient was used to measure the species similarity between two out of three sites in every combination possible, totaling three comparisons of similarity. One-way ANOVA tests with Bonferroni corrections were used to measure various differences between sites, including fish abundance and major benthic category groups (coral, gorgonians, sponges, zooanthids, macroalgae, other live organisms, dead coral with algae, coralline algae, sand/pavement/rubble) (Hutcheson 1970). Tables and bar graphs were made to depict these data. The relationship between live coral cover and fish abundance was plotted on a scatterplot with exponential trendlines and  $R^2$  values were given for each site.

### Ethical considerations

This project was approved by the Local and International Review Boards (LRB/IRB).

## RESULTS

### Site observations (in chronological order)

#### *Hospital Point*

Data was collected at Hospital Point near Solarte Island on November 15, 2016 from 10:45 am – 1:30 pm. The weather conditions were overcast and the temperature was 28° C. The topography of the area consisted of a rocky cliff followed by 10 – 15 meters of reef flat before a steep drop off and fore reef. The depth of the sampled area was 1 – 2 meters. Little lagoonal protection was offered at this site and resulted in higher wave action in comparison to other sites. Area was characterized by zoanthid mats, large heads of *Siderastrea siderea* with a type of white syndrome, and *Agaricia tenuifolia* along the reef crest. Fish observed in the area included damselfish, a school of sturgeonfish, a school of grunts, adult parrotfish, blennies, gobies, butterflyfish, and trumpetfish. Hospital Point is a well-advertised dive site for tourists.

#### *Piña Cay*

Data was collected at Piña Cay on the southern side of Bastimentos Island on November 18, 2016 from 1:00 pm – 3:00 pm. The weather conditions were sunny and the temperature was

30° C. The topography of the area consisted of small mangrove islands surrounded by sheltered lagoonal waters. This site rested on top of a sandbar at a depth of 0.5 – 1 meters and was characterized by seagrass, green algae, and *Porites furcata* reef. There were a few damselfish, butterflyfish, and juvenile parrotfish observed in this area. This site was on the border of the Bastimentos Island National Park.

### *Coral Cay*

Data was collected at Coral Cay on the southeastern side of Bastimentos Island on November 25, 2016 from 10:00 am to 1:00 pm. The weather conditions were sunny and the temperature was 31° C. The depth of the water was 1.5 – 2 meters and the topography was relatively flat with a dominance of soft coral *Antillologorgia bipinnata*. Some larger mounding corals of *Orbicella annularis* were present. The most amounts of fish informally observed were at this site, including two species of butterflyfish, damselfish, large schools of juvenile parrotfish, sturgeonfish, wrasses, mackerels, blennies, and others. Three boats with tourists and students visited the site and snorkeled for about 40 minutes each during data collection. Coral Cay is one of the most heavily advertised sites for snorkeling and is included in most daylong trip packages by tour companies on Colon Island.

### Reef fish assemblages

A total of 329 fish were observed using video data, with 60 fish in the extra small (0 – 5 cm) size class, 224 fish in the small (5 – 10 cm) size class, 42 fish in the medium (10 – 15 cm) size class, and 3 fish in the large size class (15 cm – 25 cm). The most abundant fishes observed were damselfish, specifically Dusky Damselfish (*Stegastes adustus*), followed by juvenile parrotfish and wrasses (Table 1). Individuals that were unable to be identified to the species level were each considered one species for species richness and diversity. Large schools of extra-small fish were not factored into results due to their ubiquity across all habitats and difficulty to count. Wrasses, juvenile parrotfish and damselfish were present at all three sites (Table 1). Some species and size classes, including adult parrotfish and sturgeonfish, were informally observed but not captured in the video data.

Fish total abundance was compared using a one-way ANOVA test with Bonferroni corrections ( $\alpha = 0.05$ ) and showed a significant difference among sites ( $p = 0.00276$ ). Hospital Point had the highest abundance of fish at 220 individuals (Table 2). Post hoc two-tailed t-tests indicated that Hospital Point's fish abundance differed significantly from Coral Cay and Piña Cay ( $p = 0.01438$  and  $p = 0.00971$ , respectively). The unprotected sites (Coral Cay and Hospital Point) had a higher fish species richness and diversity than the site bordering the Bastimentos Island National Park (Piña Cay) (Table 2). Hospital Point had the highest species richness with 18 different species, but the lowest amount of species evenness (Table 2).

Coral Cay had the highest species evenness with  $E_h = 0.85$ . Between-site fish species similarity was calculated using Sorenson's coefficient ( $S_s$ ) and converted into percentages of similarity. Hospital Point and Coral Cay were the most similar to each other with a percentage of similarity of 60.60%, followed by Piña Cay and Coral Cay at 52.17%. Hospital Point and Piña Cay had the lowest percentage of similarity at 38.46.

Species	Site		
	Coral Cay	Hospital Point	Piña Cay
Bicolor Damselfish ( <i>Stegastes partitus</i> )	5		
Black Hamlet ( <i>Hypoplectrus nigricans</i> )	1	4	
Bluehead Wrasse ( <i>Thalassoma bifasciatum</i> )		14	
Cocoa Damselfish ( <i>Stegastes variabilis</i> )	1		
Doctorfish ( <i>Acanthurus chirurgus</i> )	1		
Dusky Damselfish ( <i>Stegastes adustus</i> )	9	136	1
Flat Needlefish ( <i>Ablennes hians</i> )		1	
Four-eye Butterflyfish ( <i>Chaetodon capistratus</i> )	3	2	
French Grunt ( <i>Haemulon flavolineatum</i> )		2	
Harlequin Bass ( <i>Serranus tigrinus</i> )			1
Longfin Damselfish ( <i>Stegastes diencaeus</i> )	2	11	
Night Sergeant ( <i>Abudefduf taurus</i> )		1	
Princess Parrotfish ( <i>Scarus taeniopterus</i> )	17	5	23
Queen Parrotfish ( <i>Scarus vetula</i> )	1	1	
Redlip Blenny ( <i>Ophioblennius atlanticus</i> )		4	
Stoplight Parrotfish ( <i>Sparisoma viride</i> )	1	2	
Striped Parrotfish ( <i>Scarus iserti</i> )	4		8
Yellowtail Damselfish ( <i>Microspathodon chrysurus</i> )		10	
Unknown	3	15	1
Unknown (blenny)		1	
Unknown (goby)			5
Unknown (grunt)	2		
Unknown (juvenile parrotfish)		8	
Unknown (parrotfish)	3	1	2
Unknown (wrasse)	8	2	7

**Table 1.** Abundance of fish species by site. Common and scientific names of 18 fish species are given. Unknown categories were each considered one species.

	Site		
	Coral Cay	Hospital Point	Piña Cay
Total abundance	61	*220	48
Species richness	15	18	8
Shannon-Wiener index (H)	2.29	1.59	1.54
Species evenness ( $E_h$ )	0.85	0.52	0.74

**Table 2.** Summary data of fish abundance, species richness, diversity, and evenness by site. Asterisk (\*) denotes fish abundance value that was significantly different from the other two sites using a one-way ANOVA test and post hoc two-tailed t-tests with Bonferonni corrections ( $\alpha = 0.05$ ).

### Coral reef assemblages and substrate characteristics

A total of 9 hard coral species were found in photos taken along the 30 meter transects and only *Porites astreoides* was present in all three sites (Table 3). The highest percentage of live hard coral cover observed in a site was in Piña Cay with 19.34% *Porites furcata* cover (Table 3). Piña Cay also had the highest amount of high coral cover overall (Table 3).

Species	Site (% transect cover)		
	Coral Cay	Hospital Point	Piña Cay
<i>Agaricia tenuifolia</i>	0.18	4.13	
<i>Pseudodiploria strigosa</i>	0.35		
<i>Madracis mirabilis</i>	0.53		
<i>Millipora alcicornis</i>	5.09		
<i>Millipora complanata</i>		2.96	0.16
<i>Orbicella annularis</i>	1.40		
<i>Porites astreoides</i>	0.35	2.22	0.16
<i>Porites furcata</i>	0.53		19.34
<i>Siderastrea siderea</i>		6.54	
Total % cover	8.43	15.85	19.66

**Table 3.** Percent of transect covered by live hard coral species cover by site.

247 photos were overlaid with 10 points per photo in CPCe for a total of 2470 points analyzed (Table 4). Corals were identified to the species level and macroalgae, and soft corals were identified to the family level. Although some of the sites had more than one type of sponge present, CPCe only had one general sponge code that pooled all the species together. In Piña Cay, seagrasses were pooled into the “Other” category with echinoderms like starfish, sea urchins, and sea cucumbers.

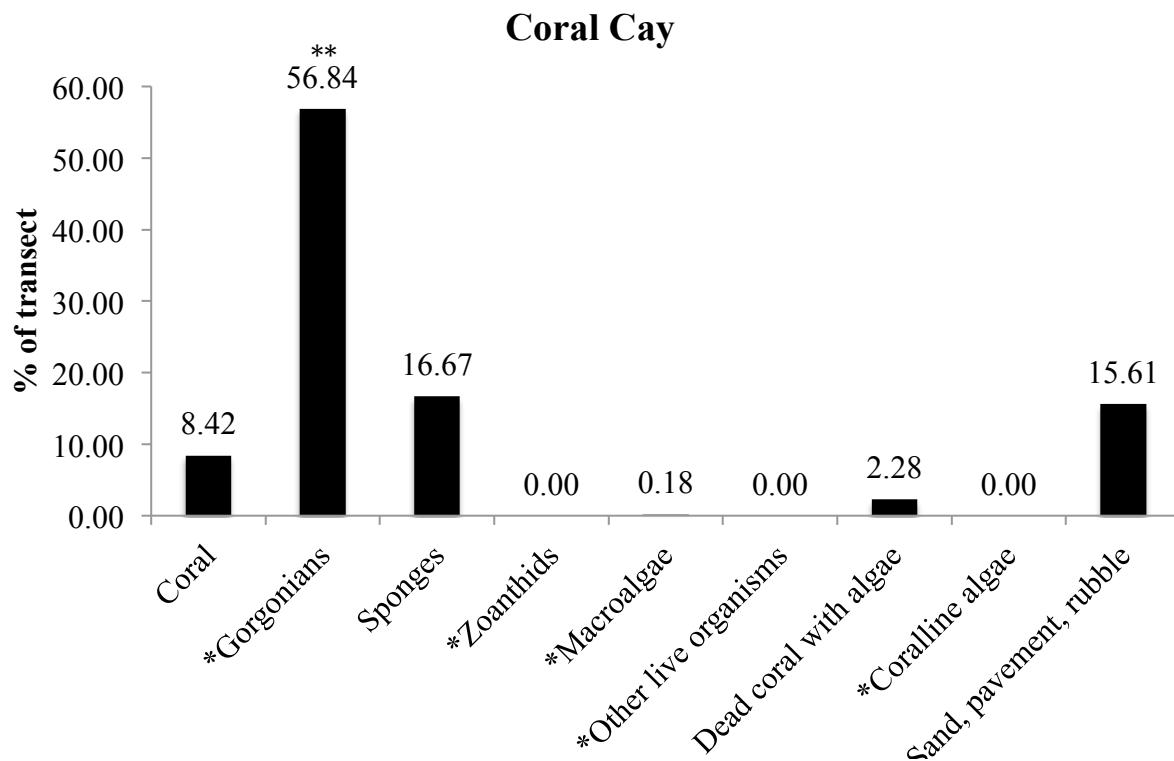
The benthic macrofauna diversity (including sponge, zoanthid, gorgonian, macroalgae,, and non-zero substrate values) was higher (1.62) for the site bordering the national park (Piña Cay) and lowest for the unprotected areas (Hospital Point and Coral Cay; 1.62 and 1.17, respectively) (Table 4). To isolate the coral community at each site, only live hard coral species were included in calculations of species richness and evenness. Coral Cay had the highest hard coral species richness with 7 species whereas Piña Cay had the lowest species richness with 3 species (Table 4). The coral species evenness was calculated to be very uneven in all three sites ( $E_h = 0.03, 0.0425, \text{ and } 0.11$ ).

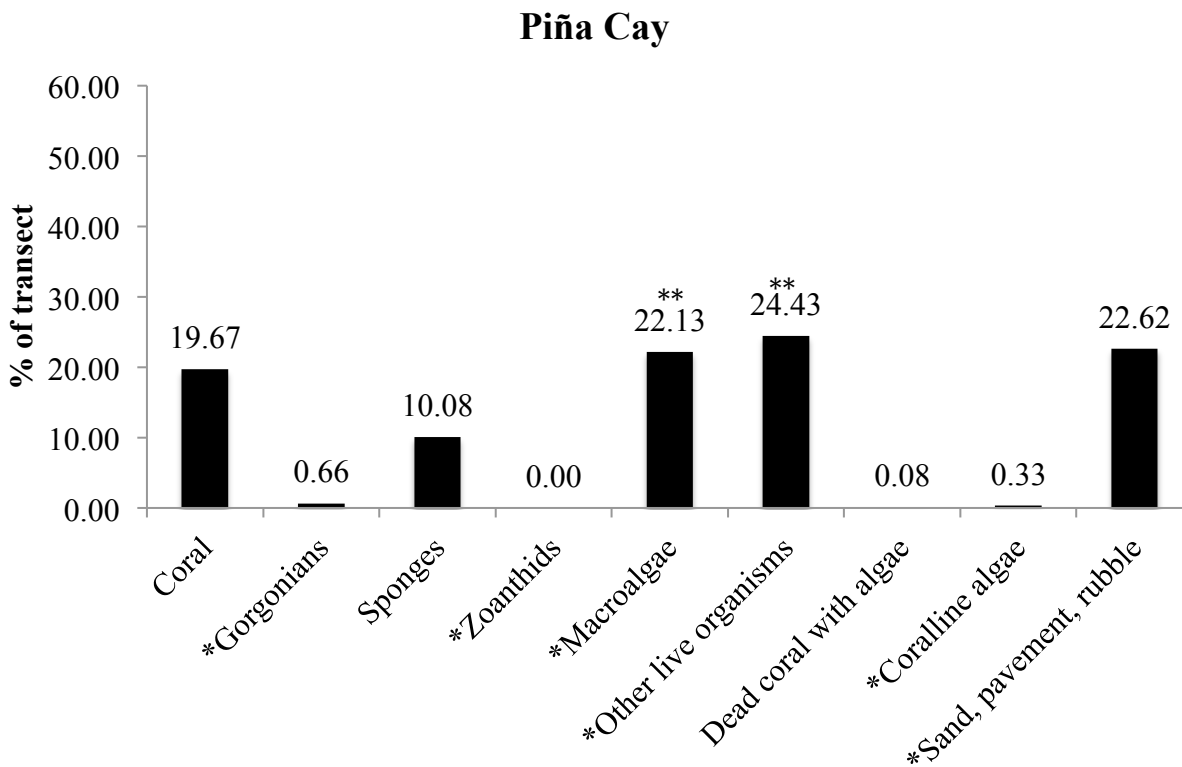
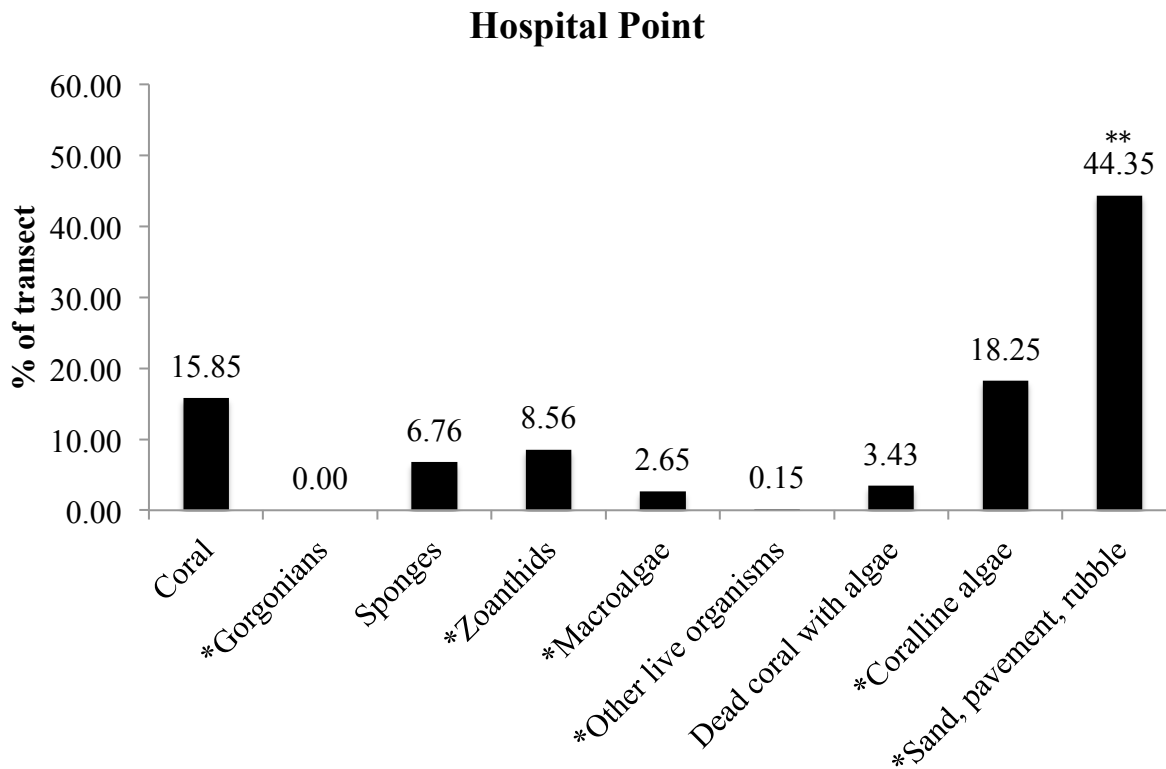
Between-site coral species similarity was calculated using Sorenson’s coefficient ( $S_s$ ) and converted into percentages of similarity. Hospital Point and Piña Cay were the most similar in coral species, with a percentage of similarity of 57.14%. Coral Cay had equal percentages of similarity of 36.36% between Hospital Point and Piña Cay.

	Site		
	Coral Cay	Hospital Point	Piña Cay
# photos analyzed	57	68	122
# points analyzed	570	680	1220
Area covered in photo (m <sup>2</sup> )	119.86	163.59	39.07
Shannon's diversity index for all benthos (H <sub>b</sub> )	1.22	0.96	1.62
Shannon's diversity index for coral only (H <sub>c</sub> )	0.21	0.17	0.32
Coral species richness	7	4	3
Coral species evenness (E <sub>h</sub> )	0.03	0.0425	0.11

**Table 4.** Total number of photos and points analyzed are given by site, along with the total benthic macrofauna species diversity and coral species richness (other benthic organisms were not considered in determining species richness due to limitations in CPCe coral code).

Major benthic groups were summarized into percent cover of each transect. Three transects of photo data in each site allowed for three replicates and one-way ANOVA testing with post hoc t-tests and Bonferonni corrections. Overall, the three sites differed from each other in their benthic cover of gorgonians, zoanthids, macroalgae, other live organisms (mostly seagrasses with some echinoderms), coralline algae, and the category of sand, pavement, and rubble (Fig. 2). Percentage of hard coral cover did not statistically differ among sites ( $p = 0.176$ ). Hard coral cover ranged from 8.42% in Coral Cay to 19.67% in Piña Cay (Fig. 2). Coral Cay was dominated by gorgonians (specifically from the genus *Antillologorgia*) and had statistically more gorgonians than Piña Cay and Hospital Point ( $p = 0.00054$  and  $p = 0.00057$ , respectively) (Table 3). Piña Cay, the site bordering the Bastimentos Island National Park, had statistically more macroalgal and other live organisms than Hospital Point and Coral Cay ( $p = 0.00041$  and  $p = 0.00016$ , respectively). In all three sites, hard coral was not the most abundant group and its cover did not exceed 20% (Fig. 2).



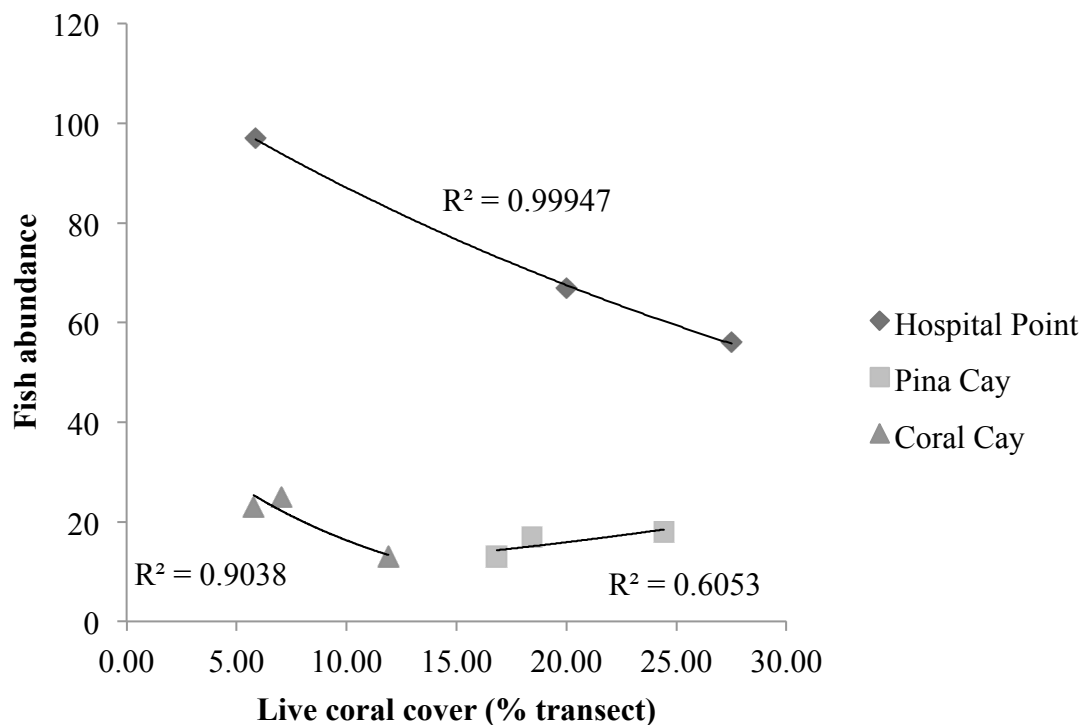


**Figure 2.** Bar graphs displaying transect percentages of major benthic categories in CPCe by site. Values above bars are of the entire site, whereas significance was determined by using three replicates in each site. One asterisk (\*) indicates significance ( $p < 0.05$ ) using one-way ANOVA testing. Two asterisks (\*\*) indicate percentages that were significantly different from the other two sites using post hoc two-tailed  $t$  tests with Bonferroni corrections ( $\alpha = 0.05$ ).



### Relationship between coral and fish assemblages

Graphing the fish abundance against the live coral cover of each transect showed almost no correlation when using one exponential trend line for all points ( $R^2 = 0.00012$ ). However, when exponential trend lines were given to each site, Hospital Point showed a strong negative correlation between live coral cover and fish abundance with  $R^2 = 0.99947$  (Fig. 3). Coral Cay also showed a fairly strong negative correlation between live coral cover and fish abundance with  $R^2 = 0.9038$  (Fig. 3). Piña Cay had a positive correlation between live coral cover and fish abundance with  $R^2 = 0.605$  (Fig. 3).



**Fig. 3.** Scatter plot showing the relationship between live coral cover (% transect) by the fish abundance. Exponential trend lines are given to each site to depict the site-specific differences.

## DISCUSSION

The unprotected sites of Hospital Point and Coral Cay generally had a higher species abundance, richness, and diversity of fish species, but not as much benthic diversity as the protected area Piña Cay. Hospital Point had a statistically higher fish abundance than Coral Cay and Piña Cay (220 individuals,  $p < 0.05$ ), but a lower amount of fish species evenness than the other two sites (Table 2). This area consisted largely of fish in the smaller size classes (0 cm – 10 cm), similar to what Seamann et al. reported in 2014. Hospital Point also had the lowest coral diversity and benthic macrofauna diversity compared to the other two sites (Table 4).

The live coral cover in this site was drastically lower than what was previously reported in Seamann et al. (2014). This study found only 15.85% coral cover and 44.35% pavement/rubble/sand cover compared to 56% coral cover and about 7% sand and rubble cover at similar depths (Seamann et al. 2014). Additionally, Seamann et al. (2014) reported no *Siderastrea siderea* cover and focused on a dominance of *Agaricia* species at Hospital Point, whereas this study found the majority of live hard coral cover to be *Siderastrea siderea* (6.54%) at shallow depths.

Although the higher sand and rubble cover reported in this study may signal a decline in coral reef health and contradict the significant increase in hard coral cover described by Seamann et al. (2014), the absence of slow-developing *Siderastrea siderea* cover in their paper suggests that their surveying effort may not have included the reef flat and instead started at the reef crest where there *Agaricia* cover began. The observation of *Siderastrea siderea* at such shallow depths also seems unusual, given that previous reports only confine its distribution to depths greater than 1 meter (Collin 2005; Seamann et al. 2014). Combining the sampling effort in this paper with results from Seamann et al. (2014) provides a better picture of the coral diversity and abundance at this site. Seamann et al. (2014) observed that Hospital Point in general experienced a high recovery rate of coral cover that was similar to reported rates from reefs put under protected status. Since Hospital Point is not a protected area, Seamann et al. (2014) inferred that local dive stations have increased the conservation effort in this area so that it can continue being a dive site for tourists. The large amount of rubble and dead coral reported for Hospital Point in this paper suggests that the same level of protection from tourism companies may not be afforded to shallower depths (under 2 meters) in this location.

Coral Cay had the highest species diversity and evenness of fish and the middlemost value of abundance (Table 2). Over half of the fish species overlapped between Hospital Point and Coral Cay with 57.14% fish species similarity. However, Hospital Point and Coral Cay only overlapped in 36.36% of the coral species observed. The differences in species similarity of coral and fish between unprotected areas Hospital Point and Coral Cay support the idea that Caribbean reef fish species are not exclusive to particular coral species (Paddack et al. 2009). Coral Cay had the highest coral species richness but lowest amount of coral species evenness (Table 4). Coral Cay has a statistically higher amount of gorgonian cover than the other two sites that makes up the majority of the benthos ( $p < 0.05$ ) (Fig. 2). Soft coral dominated areas can represent an early successional stage of a reef or an alternate stage of non-calcifying benthos. These areas may signal either a new reef or a reef undergoing a phase shift from a reef-building (coral and coralline algae) dominated state to a non reef-building state. The greater the area and the longer these non-calcifying zones persist, the harder it is for reefs to accrete calcium carbonate in significant amounts (Done 1999). The combination of gorgonian-dominated benthos and low percentage of hard coral cover in 120 m<sup>2</sup> of surveyed area in Coral Cay suggests that net reef accretion will be very difficult to achieve. However, informal observations of large adult fish (groupers, parrotfish, and mackerels) in this area of high tourism suggests that shifting from overfishing to ecotourism may be the key to bringing back larger size classes and trophic levels of fish species.

The protected area represented by Piña Cay had the least amount of fish abundance, species richness, and diversity (Table 2). However, it had the highest benthic and coral diversity (Table 4). The fairly homogenous and healthy *Porites furcata* cover of 19.34% was not surprising at this shallow depth and matches previously described reefs in Almirante Bay (Collin 2005). *P. furcata* reefs are able to meet the ecosystem roles (natural filtering, coastal protection,

marine habitat) of complex reefs despite their small colony size. They also help maintain reef structure in areas that experience high disturbance (Lirman et al. 2013). The opportunistic *P. furcata* life history consisting of high larval recruitment, small colony size, and strong trophic plasticity allows them to be more resilient against eutrophication and high turbidity (Seamann et al. 2014). Although Piña Cay experiences less anthropogenic influence due to its protected status, preserving robust species like *P. furcata* can help mitigate hard coral cover loss in the entire bay through larval dispersal to nearby areas (Seamann et al. 2014). In terms of coral cover, a study done by Guzmán and Guevara (1998) showed that an area near Piña Cay, west Adriana Cay (9°14'21 "N , 82°10'23" W), had a reef area dominated by hard coral and macroalgae as well (43.9% and 30.6%, respectively).

A look at how coral affects reef fish assemblages showed a strong negative relationship between live hard coral cover and fish abundance in unprotected sites Hospital Point and Coral Cay and a weaker positive relationship in protected site Piña Cay ( $R^2 = 0.99947, 0.9038, \text{ and } 0.605$ , respectively). These results are unusual since live coral and fish abundances are generally positively correlated. The most plausible reasons for why Piña Cay exhibited the least amount of fish abundances with the most amount of live coral cover was due to high researcher interference with fish behavior and bias towards shallower depths for live coral cover due to limitations of image data (explained further below). Other explanations include the fact that the use of summary statistics like total abundance may mask trends at the individual species level and their habitat use. For example, site-attached fish or species with obligate associations are more correlated with certain benthic characteristics than species with a wider range of habitat or life stages. Another is that different ways of measuring substrate complexity yield different results – although percentage cover of coral is used in a majority of coral reef studies, habitat complexity consists of both a diversity of substratum types and vertical relief (McCormick 1994). Thus, live coral cover is not necessarily a good determinant of habitat complexity and fish abundances and data analyses methods should better incorporate depth-based variables. No clear relationship was demonstrated between live coral cover and reef fish assemblages in this study.

Overall, these data suggest that the protection status of the areas surrounding Bastimentos Island is not a good determinant of coral reef and fish abundance, richness, diversity, evenness, and similarity. However, there were many confounding variables that provide alternative explanations to the results presented in this paper. The main challenge to comparing fish data between sites was factoring in the different weather conditions experienced during data collection. Because fish are generally more active in the early morning and evening (and field data collection was conducted in the late morning and early afternoon), the data reported underestimate the fish populations of each of the sites (Hobson 1972). Hospital Point may have reported a higher abundance because the day was more overcast and the small decrease in water temperature and sunlight could have been enough to influence reef fish behavior (Biro and Stamps 2010). On the sunnier days when data at Coral Cay and Piña Cay were collected, reef fish were informally observed to be largely absent or hiding within three-dimensional structure that obstructed them from the camera's view.

Water depth also played an important role in fish presence, visibility, and identification. There was deeper water and a greater distance between the researcher and the fish at Hospital Point and Coral Cay, allowing for fewer disturbances (positive/negative attractions) as a result of human presence (Tessier et al. 2005). On the other hand, deeper depths resulted in a lower resolution of individuals in the video frame, making them harder to identify. Although it is well established that reef fish populations and diversity are greater in topographically complex areas,

fish were harder to find in sites containing high coral and soft coral cover since they all hid from the camera's view (Grober-Dunsmore et al. 2007). Species that were more territorial and exhibited more aggressive behavior (like damselfish) were more likely to be active during the day regardless of human presence. Larger fish were more elusive and wary of humans due to the widespread fishing activity in the Bocas region (Clifton et al. 1997). Thus, measurements of fish abundance, richness, diversity, evenness, and similarity were all underestimates of the actual fish assemblages in all three sites.

For coral species and distribution, depth and wave action seemed to have a greater influence on the species richness and similarity rather than the level of protection. Since there was no comparable baseline study done on coral reef health and distribution prior to the designation of the national park, it was difficult to isolate the level of protection as a variable. The results in this study generally confirmed the results given by Seamann et al. (2014), which indicated that turbidity and wave action were the largest determinants of coral distribution in this region. For example, Hospital Point had higher exposure to wave action and therefore had wave-resistant species like *Agaricia tenuifolia* and *Siderastrea siderea* whereas Coral Cay and Piña Cay had smaller finger corals like *Porites furcata* and *Madracis mirabilis*, which are more characteristic of lagoonal reefs (Clifton et al. 1997). The statistically different covers of other benthos like zoanths, soft corals, and macroalgae were also indicators that depth (and other related abiotic factors like temperature) may have been more important in explaining coral populations than protection status.

Moreover, because 10 random points were analyzed in CPCe regardless of the depth and area covered in each photo, coral colonies at shallower depths were most likely overrepresented while coral colonies at deeper depths were most likely underrepresented in the data analysis. This problem was exacerbated by the fact that more photos were taken (and thus analyzed) at shallower depths in order to document the entire transect's benthos. Also, limitations to the coral code provided by CPCe affected values of overall macrofaunal benthic diversity. The code allowed identification of macroalgae and soft corals to the species level but grouped all sponges into one general category, which was considered one species in diversity calculations. Although there was a high sponge diversity informally observed in Coral Cay and Piña Cay, it was not factored into final diversity calculations.

Using an underwater camera for photo and video data is a non-destructive and time saving method for understanding coral and reef fish populations in shallow water environments. Photographing benthos with even a small, compact, lower-end, digital camera is sufficient to capture enough resolution to identify most benthic macrofauna to the species level. However in both photo and video analysis, editing software was essential to increasing the clarity of the frame (Iqbal et al. 2010). Areas with high turbidity and green tint could be captured and analyzed fairly accurately after color and lighting correction.

Using video data to quantify fish communities was more challenging. Although the video method allowed for more time to identify individuals by non-fish specialists, generally slate (in the water) methods yield more accurate depictions of fish assemblages because observers spend more time in the water. Additionally, video cameras have smaller fields of view than observers (Tessier et al. 2005). Video censuses are more valuable in conditions when there is high fish recruitment and abundance of more permanent species (Tessier et al. 2005). Both slate and video methods would have underestimated reef fish abundance and diversity in very shallow water conditions (0 m – 1m) in this study since it was informally observed that the researcher's

presence scared away a sizable amount of the fish populations in the study sites (particularly in Piña Cay, the shallowest area surveyed).

Despite the limitations of this study, scientists and policymakers should encourage more permanent and standardized monitoring efforts of Bocas del Toro region in the face of increasing tourism. As informally observed and noted in previous literature, ecotourism may bolster conservation efforts in the area since it serves as an alternative source of income to exploitative fishing practices. Careful monitoring of tourism development and ecosystems in this region and coupled with diligent in law enforcement can save the reefs near Bastimentos Island and replenish overfished fish populations in the area.

## CONCLUSION

The unprotected areas of Coral Cay and Hospital Point exhibited a more abundant, diverse, and species rich fish assemblage than the protected area of Piña Cay. Hospital Point had a statistically higher amount of fish observed than in the other two sites. However, Piña Cay had the highest benthic and coral diversity. The relationships between live coral cover and reef fish abundance in these areas remain unclear since live coral cover and habitat complexity are different measurements of topography and do not necessarily explain each other. Overall, each site exhibited statistically different characteristics from the two others, resulting in unique community compositions of coral and reef fish in all three sites. Confounding variables of depth and weather conditions affected validity of results. The difference in coral and fish assemblages could not be differentiated based on whether it was a protected area or not. Thus, the hypothesis that there would be a higher species richness, diversity, and abundance of fish and coral in protected areas compared to unprotected areas remains unanswered. However, documenting coral and reef fish species using underwater camera equipment still allowed for the understanding coral and reef fish populations. An initial first glance at the community composition of these sites highlighted only a fraction of the large coral and reef fish diversity in the Bocas del Toro Archipelago.

Using underwater cameras may be a useful tool to increase efficiency in the field for photographing benthos, but taking videos to describe fish populations may not be as accurate depending on site-specific differences. Future studies measuring the efficacy of the Bastimentos National Park on replenishing fish populations should use extreme caution in determining sites and appropriate weather conditions for field data collection since the variability in depth, turbidity, wave action, and weather can greatly influence fish activity. Because reef benthos can be surveyed fairly easily along a transect by taking photos and analyzing them later in CPCe, future monitoring projects should attempt to use underwater photography to cover as much area as possible. Modifying the coral code so that all living macrofaunal substrata can be identified to the species level would also more accurately describe substrate characteristics.

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