

# Variation in population assemblage of Acanthuridae and Scaridae across human concentration levels during a bleaching event affecting the coral reefs of Guna Yala, Panama

Jackson Heather

## Abstract

Coral reefs are the ocean's most productive ecosystem, supporting a huge amount of biodiversity, and are relied upon by millions of people worldwide. As we progress into the Anthropocene, coral reef ecosystems are increasingly threatened by a swath of pressures. Of the most impactful are El-Niño Southern Oscillation-related heat pulses, which result in the bleaching and potential mortality of coral reefs. Bleaching events, in synergy with other threats, are increasing algal-dominated reefs, which impact the productiveness of coral reef ecosystems. Herbivorous fish are the prominent algal consumers and are essential in controlling algal blooms. Species from the family Acanthuridae and Scaridae are the most conspicuous of herbivorous fish on coral reefs, and through a diverse array of physiological differences compose several unique functional groups. The population distribution of Acanthuridae and Scaridae are directly correlated with coral reef characteristics and composition and can suffer from bleaching events as well. Despite their importance in maintaining reef health and improving resilience to disturbances, there is a very scarce collection of literature that describes the population assemblage of Acanthuridae and Scaridae spp. during bleaching events. This study aims to contribute to this underreported phenomenon. Visual surveys of Acanthuridae and Scaridae species were conducted to measure the average density, mean size, and biomass in terms of coral reef

characteristics across a human concentration gradient in Guna Yala, Panama. Results suggest a similar overall abundance of herbivorous fish between the two reef locations, with significantly larger sizes and biomass of *A. coeruleus*, *S. aurofrenatum*, *S. viride*, and *S. iseri* in reefs further away from human concentration. This correlates with significantly higher rugosity on these reefs. The mean size of each respective species appears to be lower than previously reported across the Caribbean. Additionally, the biomass distribution was strikingly skewed by *S. viride* which corresponds to almost  $\frac{3}{4}$  of the total biomass. This indicates that the current bleaching event is having drastic impacts on the distribution of herbivorous fish populations, which is exacerbated by proximity to human concentration. This can have very negative consequences for the recovery of these reefs following the bleaching event. Of specific concern are the coral reefs closer to humans. Data from benthic composition surveys show that macroalgae cover and overall coral bleaching are significantly higher compared to reefs far from humans. This study provides vital information that may be useful for future studies to identify coral reef resilience to bleaching events through the scope of Acanthuridae and Scaridae population distribution.

## Introduction

### Coral Reefs:

Coral reefs are biodiverse marine ecosystems that are limited to warm shallow areas where there

is adequate access to sunlight, water temperatures between 23 and 29°C, salinity between 32 and 42 parts per thousand (ppt), and a pH range of 7.8 to 8.4 (Jones, 2012). As a result, coral reefs are distributed predominantly among the coastal tropics and cover just 284,300 km<sup>2</sup> globally (Sheppard et al., 2017; Spalding et al., 2001). Corals are sessile marine animals that form a symbiotic relationship with zooxanthellae. In exchange for protection, zooxanthellae provide energy through photosynthesis. Aided by this symbiosis, the coral polyp produces calcified carbonate (CaCO<sub>3</sub>), building the necessary structure for these organisms to thrive (Osinga et al., 2011). This process is known as reef-building and ultimately supports 25% of all marine species, making coral reefs the most biodiverse marine ecosystem on the planet.

Coral reefs play important roles across a scale of ecosystems. To start, coral reefs are home to a huge scale of biodiversity, supporting an estimated 1- 9 million species of fish, clams, sponges, marine mammals, and invertebrates, for example (Reaka-Kudla et al., 1996). The 3-dimensional structural complexity of coral reefs enables intricate niche-partitioning and the coexistence of many species that have similar niches. Beyond their importance for marine ecosystems, coral reefs provide a multitude of necessary services for humans. For example, millions of people around the world rely on coral reefs as an economic resource, as coral fisheries alone support 6 million direct fishing jobs and produce more than \$6 billion a year in global revenue (Teh et al., 2013). In addition to the economic importance of coral reef fisheries, up to 400 million people in Africa and South Asia rely on these fisheries as their primary source of nutrients (Dulvy & Allison, 2009). Furthermore, coral reefs are crucial in their role of coastal protection. An estimated 200 million people benefit from wave and storm protection, as coral reefs limit the damage to property and infrastructure in coastal regions

around the world (Ferrario et al., 2014). Thus, it is clear how coral reefs are an essential ecosystem for marine organisms and humans alike, so the increase in threats to reef health and productivity is of grave concern.

### ***Threats to Coral Reefs:***

In the last several decades, anthropogenic stress has resulted in an increase in coral death and a subsequent decrease in coral coverage by approximately 50% around the world (Eddy et al., 2021; Hughes et al., 2018). Among the contributing factors is an increase of El-Niño Southern Oscillation-related heat pulses which result in coral bleaching and eventually coral death (Hughes et al., 2018). When the water temperature exceeds the tolerable limit of a coral symbiotic zooxanthellae are expelled, and the coral turns white. Following a sustained period of high water temperature, coral is unable to generate enough nutrients to survive, resulting in mortality (Lesser, 2011). Ocean acidification also contributes to the increase in coral mortality. Ocean acidification is the uptake of extra carbon dioxide (CO<sub>2</sub>) in the atmosphere due to anthropogenic production. The increasing levels of CO<sub>2</sub> in the ocean cause a decrease in pH levels, threatening the production and structural integrity of coral CaCO<sub>3</sub>. Coral reefs evolved to exist within a pH range of 8-8.4 and are unable to produce CaCO<sub>3</sub> as efficiently when the pH level drops below this range for an extended period (Mollica et al., 2018). It is estimated that the current levels of anthropogenic CO<sub>2</sub> production will cause coral reefs to be net-dissolving by 2050 (Eyre et al., 2018). This will decrease the reef-building ability of coral and further reduce coverage, contributing to the loss of habitat, biodiversity, and ecosystem services.

While global changes are a persistent threat to coral reef health, local anthropogenic stress can have drastic consequences for these ecosystems. There is a mosaic of pressure that human activity introduces

to these ecosystems such as coastal development, tourism, water pollution, and overfishing. The former two, however, have been identified as the top-ranked source of local pressure across a combined 63.1% of the world's coral reefs (Andrello et al., 2022). This is true for San Blas reefs, where water pollution and nutrient enrichment from deforestation runoff and local human concentration are the most direct threats to reef health (Shulman & Robertson, 1996). Nutrient enrichment or eutrophication occurs when human wastewater and agricultural runoff increase the availability of nutrients in the ocean, namely nitrogen and phosphorus. Eutrophication has severe consequences for coral reefs and has been linked as a primary cause for the increase of phase shifts (Morris et al., 2019).

### ***Phase Shift in Coral Reefs:***

Phase shifts are the transformation of a coral-dominated reef to one of algal or other non-reef-building organisms (Norström et al., 2009). Corals are slow-growing organisms suited for nutrient-poor water, as their zooxanthellae symbiote provides the majority of their energy (Sheppard et al., 2017). Algae, on the other hand, are fast-growing filter feeders that thrive with increasing levels of nitrogen and phosphorus. Therefore, coral reefs impacted by excessive nutrients from anthropogenic sources are threatened by algal growth. There is extensive research showing excessive macroalgae growth on coral reefs specifically in locations with high levels of nitrogen, which is related directly to local human impacts (Adam et al., 2021). Furthermore, algal-dominated reefs exhibit up to 50% reduced calcification, which further exacerbate the declines in coral reef health. This shift has therefore resulted in an overall reduction in coral reef resilience to disturbance events (Fabricius, 2005; Morris et al., 2019; Wiedenmann et al., 2013). Reefs that have experienced phase shifts can lose their structural complexity, which limits protection and habitats

for fish, harming coral reef biodiversity (Cruz et al., 2015; Graham et al., 2014). Interestingly, current literature is divided on the relationship between local impacts and reef composition. On one hand, a collection of research has found a correlation between threatened reef health and proximity to human populations, indicating concern for decreased resilience on these reefs (Cruz et al., 2018; Smith et al., 2016). However, there exists literature that does not find such a correlation and instead points to global level pressure being the most accurate indicator of reef degradation (Bruno & Valdivia, 2016). While there is a consensus on the overall degrading state of coral reefs, using proximity to human concentration as a predictor of reef health is still a source of debate.

Despite some disagreement on the source of change, there is acknowledgment that a decrease in coral coverage and an increase in algae growth has occurred in the San Blas archipelago (Clifton et al., 1997; Shulman & Robertson, 1996) and the wider Caribbean (Jackson et al., 2014). Thus, the role of coral reef herbivores is essential in regulating algal growth. Following the mass mortality of *Diadema antillarum* in 1983-84, which reduced their population density by 98% (Lessios, 2015), herbivorous fish have become the prominent top-down pressure limiting algal growth.

### ***Acanthuridae and Scaridae:***

In the Caribbean, herbivorous fish are the most important regulators of micro and macroalgae growth. Consequently, research aimed at understanding herbivorous fish preference, distribution, and abundance during the Anthropocene is crucial. Of the herbivorous fish that populate the Caribbean, surgeonfish from the family Acanthuridae, and parrotfish from the family Scaridae, are the most abundant species and contribute the most biomass (Hernández-Landa & Aguilar-Perera, 2019). Acanthuridae and Scaridae

contain physiological differences that impact their respective foraging behavior and food preferences. Acanthuridae have a long evolutionary history dating back to Eocene reefs more than 50 million years ago which has led to substantial specialization among species (Bellwood & Wainwright, 2002). Worldwide, Acanthuridae is composed of six functional groups; browsers, water-column feeders, brushers, concealed croppers, sediment suckers, and croppers. Only the latter two functional roles are present in the Caribbean, limited to four species of sediment suckers and 2 species of croppers (Tebbett et al., 2022). There are three sediment suckers, *A. bahianus*, *A. tractus*, and *A. chirurgus*, and one cropper, *A. coeruleus*, in the scope of this study. Both possess multitentacled teeth, but sediment suckers commonly forage on soft or mixed substrata composed of microalgae and organic particulates, whereas croppers feed on hard substrata with algal turf (Tebbett et al., 2022).

Scaridae on the other hand are a part of the wrasse family Labridae, which originated around 76 million years ago in the Cretaceous period (Hughes et al., 2023). However, evidence points to a recent, rapid parrotfish speciation subject in the last 10 million years (Smith et al., 2008). The *Sparisoma* and *Scarus* genus that incapsulate Caribbean parrotfish have developed distinct beaks that enable several functional groups; browsers, scrapers, and excavators (Adam et al., 2018). Browsers, composed of *Sparisoma aurofrenatum* and *S. rubripinne*, feed on macroalgae. Scrapers such as *Scarus iseri* target algal turf on carbonate surfaces and excavators such as *S. viride* forage on crustose and endolithic algae (Adam et al., 2018).

Supporting the classification of certain Acanthuridae and Scaridae species into different functional groups, evidence exists that shows a diverse range of feeding behaviors across species. Evidence from a study in the Florida Keys by Duran et al. (2019) illustrates selective differences between

surgeonfish species, as *A. tractus* fed on macroalgae, specifically *Dicyota spp.*, more often than *A. coeruleus*. Alternatively, in a different study conducted in the Cayman Islands, *A. coeruleus* consumed macroalgae at a higher rate than *A. tractus*, specifically targeting *Lobophora* (Dell et al., 2020). This could be attributed to gut differences and varying nutrient digestion processes, as *A. coeruleus* secretes acid in its gut while *A. tractus* uses titration to digest nutrients (Dell et al., 2020; Tilghman et al., 2001).

Similar to the Acanthuridae family, there are prevalent inter-taxa foraging selection between Scaridae. General patterns are consistent throughout *Sparisoma* and *Scarus spp.*. For example, *S. aurofrenatum*, *S. chrysopterum*, and *S. rubripinne* most often feed on macroalgae, especially *Dicyota* (Adam et al., 2015, 2018). Additionally, *Sparisoma viride* is often grouped with small-bodied *Scarus spp.*, such as *Svetula*, *S. taeniopterus*, and *S. iseri*. This group predominantly forages on turf algal communities and crustose coralline algae (CCA) (Adam et al., 2018). These feeding preferences are not exclusively consistent, however, as some evidence shows that only *Sparisoma aurofrenatum* selectively forage on macroalgae (Dell et al., 2020). While there may be discrepancies among literature about the specific foraging selection of Scaridae, it is becoming increasingly understood that the feeding preference of Acanthuridae and Scaridae alike target algal communities (Smith et al., 2018).

Beyond the scope of individual species feeding preference, it is important to understand how herbivore richness impacts reef and algal community structure. A study by Burkepile and Hay (2008) analyzed the impact of herbivorous pressure between isolated and combined enclosures containing *S. aurofrenatum*, *S. viride*, and *A. chirurgus* on existing reefs. Results show that *A. chirurgus* is not efficient at limiting algal growth while *S. aurofrenatum* and *S. viride* are. However, they indicate that increased herbivore richness can have profound

effects on the decrease of algal coverage and the increase of coral coverage, even if it is a difference of one species (Burkepile & Hay, 2008). The study demonstrates intra-species differences, as *S. aurofrenatum* and *S. viride* consumed mostly crustose coralline algae (CCA) and turf algae, whereas *S. aurofrenatum* consumed significant amounts of macroalgae. Furthermore, Burkepile and Hay (2008) suggest parrotfish play a substantial role in limiting algal growth on reef ecosystems, whereas surgeonfish are not as important. However, when compared to a similar study by Burkepile and Hay (2010), *A. chirurgus* and *S. viride* played a vital role in limiting most kinds of macroalgae development on cinderblocks, whereas *S. aurofrenatum* and species richness did not. This demonstrates how a complex relationship of herbivorous pressure exerted by herbivorous fish limits algal development and growth. Although the latter study does not provide evidence of the importance of species richness, an extensive collection of research says otherwise (Bonaldo et al., 2017; Edwards et al., 2014; C. E. Sheppard et al., 2023).

#### **Assemblage Factors:**

The distribution of Acanthuridae and Scaridae assemblages on reefs is essential to contextualize the impacts of their herbivorous presence. Several factors are associated with varying concentrations of Acanthuridae and Scaridae populations. In general, Acanthuridae and Scaridae inhabit fore-reef habitats between depths of 1 to 30 meters (Lewis & Wainwright, 1985). However, Acanthuridae and Scaridae assemblages differ in depth and reef structure. Multiple studies have demonstrated that Acanthuridae abundance and biomass are greater on the reef-flats (Hernández-Landa et al., 2015; Kopp et al., 2012), which can be attributed to large schools commonly found in shallow habitats (Lewis & Wainwright, 1985). The inverse is true for the larger Scaridae, which are more abundant and have

greater biomass in deeper reef-slope and reef-terrace environments (Hernández-Landa et al., 2015; Lewis & Wainwright, 1985). Therefore, this study will be conducted on reef fronts, which are straddled by reef flats closer to shore and deeper reef slopes facing the ocean.

There is a large consensus in the existing literature on the positive correlation between reef complexity and herbivorous fish biomass and abundance. High rugosity, which describes a structurally complex coral reef, is often related to of greater abundance of herbivorous fish. One explanation is that reef complexity provides more protection from predators both for recruits and developed fish (Almany, 2004). This can result in greater time spent avoiding predators and consequentially less time spent foraging. However, the higher biomass on structurally complex reefs, even with reduced foraging rates, can be responsible for up to 7.5 times more herbivorous pressure (Santano et al., 2021). The elevated algal consumption can result in “reef-halos”, where structurally complex reefs are composed of fewer resources - algae. This can lead to spikes of algae cover in adjacent areas if the distribution of herbivorous fish is indeed greater on structurally complex reefs (Madin et al., 2011). Thus, measuring the distribution of Acanthuridae and Scaridae has important implications when determining areas of resiliency.

The distribution of these crucial herbivorous fish species can be influenced by a plethora of factors. Turbidity, for example, plays a significant role in local coral reef ecosystems. Turbidity can impact the amount of sunlight that reaches coral and may impact many different organisms in coral reefs. This includes herbivorous fish, like Acanthuridae and Scaridae spp. Higher levels of suspended sediment in areas of high turbidity negatively impact the biomass and density of herbivorous fish, which has potential impacts

on ecosystem resilience (Moustaka et al., 2018). Additionally, reef proximity to seagrass beds or mangroves can impact Acanthuridae and Scaridae populations. There is an understanding that seagrass beds are crucial for the development of juvenile fish across many functional groups of fish, providing essential shelter as the potential to camouflage is abundant (Seemann et al., 2018). Interestingly, seagrass beds may also harbor greater densities of herbivores in comparison to reefs (Campbell et al., 2011). This could result from the daily migration of herbivorous fish into more nutrient-rich seagrass beds, which can potentially increase overall foraging levels due to a decrease in inter-specific competition (Dorenbosch et al., 2005). Because of the overall complexity and inter-connectedness of coral reef ecosystems, it is important to consider every factor that can impact the spatial distribution of herbivorous fish.

#### ***Bleaching Impacts on Acanthuridae and Scaridae:***

Bleaching events are one of the primary threats to coral reef health and are increasing with both frequency and severity (T. P. Hughes et al., 2018). As a result of bleaching-induced coral mortality, algae growth can skyrocket and further inhibit the recovery of reefs. So, understanding how herbivorous fish assemblage may change during bleaching events is important to predict areas of resilience (T. P. Hughes et al., 2007). There is a general disagreement among existing literature that describes how herbivorous fish population is impacted by bleaching events. On one hand, parrotfish abundance was found to be relatively resilient following a severe bleaching event in 2010 in Bonaire, recovering to even higher levels of abundance than the greater Caribbean (Steneck et al., 2019). It is important to note that this recovery, however, was attributed to uncommonly efficient regulations. To elaborate, spearfishing was banned in 1979 in Bonaire and there is a relatively

limited amount of fishing pressure, especially in comparison to the greater Caribbean (Steneck et al., 2019). In addition, herbivorous fish abundance has been found to increase directly following a bleaching event, when their food source, algae, is more common (Elma et al., 2023; Garpe et al., 2006). However, the long-term effects on herbivorous fish are not as optimistic. For example, one study found a drastic decrease in herbivorous fish assemblage 6 years after the major bleaching event of 1997/98 (Garpe et al., 2006). This decrease occurred after the coral reef degradation was fully realized and the structural complexity of the reefs had diminished. While these findings are vital to understanding the lasting impacts of bleaching events across the coral reef ecosystem, there is very little research that describes active changes during a bleaching event. One such study found a sharp decrease in biomass and abundance of herbivores during the bleaching event, which was attributed to a vertical migration to cooler waters (Magel et al., 2020). This study found that the abundance and biomass recovered one year after the bleaching event, yet proximity to human concentration was correlated with lower levels of abundance and biomass (Magel et al., 2020). These findings further advance the understanding of how localized human impacts may potentially affect herbivorous fish distribution and recovery from bleaching events, but more must be contributed to the conversation. Herbivores, namely species from the Acanthuridae and Scaridae families, are crucial for coral reef resilience especially during bleaching events (Graham et al., 2015). This current study is placed in a unique position to contribute valuable and scarce information to the discussion of herbivorous fish and coral resilience during an active bleaching event and has important implications for future studies and management plans.

#### ***Study Site:***

Panama is the only landmass connecting South

America to North America and has supported different ecosystems that boast incredibly biodiverse flora and fauna due to its crucial position in the Great American Interchange. Panama is bordered by Costa Rica in the west and Columbia in the east, separating the Caribbean Sea from the Pacific Ocean. Due to its position in the tropics, Panama has a dry season (December-May) and a wet season (June-November). The Pacific Ocean is categorized by its deep, cool, nutrient-rich water which is highly productive. In contrast, the Caribbean Sea has carbon-rich, nutrient-poor, warm waters which are essential for the growth of coral reefs (Leigh et al., 2014). Data collection was done in the San Blas Archipelago of Guna Yala during an El Nino year. There is decreased rainfall and an increase in water temperature during an El Nino year, which has led to an active bleaching event at the time of the study.

Guna Yala encompasses a 320,600-hectare stretch of land on the eastern Caribbean coast of Panama and borders Columbia on the southernmost end (Guzmán et al., 2003). This region has minimal seasonal temperature variation between 26° and 27°C, 1600-3000 mm of annual rainfall, and a relative humidity range between 78% and 90% (Amman 2022; Hurtado et al., 2018). Guna Yala is a self-autonomous indigenous comarca (reserve) founded in 1938. It is one of five indigenous comarcas in Panama and one of the most successful indigenous communities in the Americas. The Guna people rely on the rich fish and invertebrate populations for food and commerce and engage in coral mining to increase the size of islands to incorporate their population growth (Guzman et al 2003).

Guna Yala is home to 365 islands, which support 81% of Panama's reefs (McEntee 2012). These reefs are regarded as the most developed in Panama and support an abundant population of fish and coral (Guzman et al 2003, Rivera 2012). Only 49 of the 365 islands are inhabited. This study

was conducted among five reefs: the Smithsonian Reef, Korbinski Reef, Mosquito Island Reef, Cayos Limones 3, and Cayos Limones 4. The former three reefs are located close (<0.6 km) to high levels of human concentration, and the latter two are located far (>5.5 km) from levels of human concentration.

### **Research Question**

How does a current bleaching event impact the benthic composition and population distribution of Acanthuridae and Scaridae on coral reefs across a human concentration gradient in Guna Yala?

Does Acanthuridae and Scaridae feeding preference and coral reef community benthic composition change between proximity to dense human concentrations during a bleaching event?

### **Null Hypothesis:**

1. There is no statistical difference between benthic community composition between reefs close and far from human concentrations.
2. There is no statistical difference between bleaching on reefs close to or far from human concentrations.
3. There is no statistical difference between the structural rugosity of reefs close or far from human concentrations.
4. There is no significant difference between the abundance of Acanthuridae and Scaridae between reefs close or far from human concentration.
5. There is no significant size difference between Acanthuridae and Scaridae between reefs close or far from human concentration.
6. There is no significant difference in Acanthuridae and Scaridae biomass between reefs close to or far from human concentration.

### **Alternative Hypothesis:**

1. There is a statistical difference between benthic community composition between reefs close and far from human concentrations.
2. There is a statistical difference between bleaching on reefs close to or far from human concentrations.
3. There is a statistical difference between the structural rugosity of reefs close or far from human concentrations.
4. There is a significant difference between the abundance of Acanthuridae and Scaridae between reefs close or far from human concentration.
5. There are significantly larger Acanthuridae and Scaridae on reefs far from humans than on reefs close to humans.
6. There is significantly more biomass of Acanthuridae and Scaridae on reefs far from humans than on reefs close to humans.

### **Research Objective:**

1. Analyze if proximity to human concentration impacts the benthic community structure and extent of bleaching within coral reefs in Guna Yala.
2. Describe how Acanthuridae and Scaridae assemblage is distributed across coral reefs of varying levels of human concentration during a bleaching event.

### **Methodology**

This study was conducted at 5 different fringing reefs in the San Blas Archipelago of Guna Yala, Panama. Three of these reefs were located close to high concentrations of human populations; Guigalutopo reef (9°32'47"N 78°58'20"W), Korbiski Reef (9°32'52"N 78°57'38"W), and Smithsonianupoo reef (9°33'09"N 78°57'14"W). High concentration was determined by an island that was used for

residential use. Two reefs were located far from high concentrations of human population: Third Key reef (9°32'27"N 78°54'12"W) and Fourth Key reef (9°32'28"N 78°53'52"W) (Figure 1). Reefs deemed close to high levels of human concentration range from around 600 meters to 60 meters away from islands fully populated. Reefs deemed far from high levels of human concentration are approximately 5.5 km and 6.0 km away from islands fully populated.

Data was collected for 9 days between 11/24/2023 and 12/4/2023. All data was recorded between 1- and 3-meter depth to enable an adequate field of view and to allow for snorkeling. Data was not collected if there was precipitation. Acanthuridae and Scaridae assemblages were assessed for two days before data collection to get an understanding of which species were present. Extensive studying and practice in identifying fish species and accurately estimating each respective size group was conducted before the start of official data collection.



Figure 1: Map of (a) the 5 reefs, with Mosquito Island, Korbinski Reef, and Smithsonian Reef ranging from 0.6-0.06 km from the nearest densely populated island, respectively. Third Key and Fourth Key range 5.5-6.0 km from the nearest densely populated island, respectively.

from the nearest densely populated island, respectively, and (b) study site in relation to Panama as a whole (images from Google Earth).

### **Herbivory Visual Census:**

After arriving at a reef and locating the reef crest, the area of study was chosen haphazardly. A 30 x 3m transect was created traveling in the same direction as the reef crest, resulting in 90m<sup>2</sup> surveyed every transect. After waiting for 5 minutes to minimize human impact on fish behavior, I swam along the transect slowly (10s / m) and measured the abundance and approximate size (Hughes et al., 2007). I recorded data for the following 8 species: *A. Coeruleus*, *A. tractus*, *A. bahianus*, *A. chirurgus*, *S. aurofrenatum*, *S. viride*, *S. rubripinne*, and *Scarus iseri*. The size range estimates were 0.1-5 cm, 5.1-10 cm, 10.1-15 cm, 15.1-20 cm, 20.1-25cm, 25.1-30cm, 30.1-35 cm, 35.1-40 cm, 40.1-45 cm, and 45.1-50 cm, and were measured from tail to nose (Müller et al., 2021). From these size groupings, I calculated the biomass using the allometric formula allometric function  $W = aL^b$ , where  $W$  is the weight in grams,  $L$  is the total length, and  $a$  and  $b$  are specific constants for each fish species (Froese & Pauly 2010). The species were marked down to the species level and all juveniles were excluded (Smith et al., 2018). All data was recorded between 10:00 and 17:00 to avoid diurnal differences (Ferreira et al., 1998). 3 transects were performed a day, spaced at least 10 meters away from one another. A total of 1080m<sup>2</sup> at each reef classification was analyzed for fish assemblage.

### **Benthic Community Composition:**

To determine how Acanthuridae and Scaridae population distribution may vary between reefs, the benthic community structure was analyzed. This was performed after the visual census using a 1m<sup>2</sup> PVC quadrat along the 30m belt transect. The quadrat was placed every meter, covering a total of 30m<sup>2</sup> every transect. It was always conducted on the side closer to shore. A picture was taken using a

GoPro 10 and the benthic community composition was analyzed using Coral Point Count (Kohler & Gill, 2006) to compute the percent coverage of each benthic category. The substrate classifications are as follows; sea grass, bleached, partially bleached, healthy fire coral, gorgonians, sponges, zoanthid, debris, algae, bleached, partially bleached, and healthy hard coral. Algae was classified as turf algae, defined as mixed algae communities less than 2 cm in length (Adey and Steneck, 1985), crustose coralline algae (CCA), and macroalgae. Macroalgae was identified as a functional group. Following the use of quadrats, a 2.15m long metal chain with 1.75 cm long links ( $n = 123$ ) was used to calculate the rugosity index (RI), and analyze the structural complexity between reef sites. The equation is  $1 - (dm/Lt)$ , where  $dm$  is the total distance covered by the chain along the entire transect, and  $Lt$  is the total length of the chain (Risk 1972).

### **Statistical Analysis:**

To determine if the percent coverage of debris, bleached fire coral, partially bleached fire coral, healthy fire coral, gorgonians, sponges, zoanthids, turf algae, crustose coralline algae, microalgae, sea grass, bleached, partially bleached, or healthy coral varied between the two reef classifications, two sample t-tests were conducted for each substrate. This data was visualized with bar graphs that show the percent cover and standard deviation. To test if the rugosity index was statistically significant, a two-sample t-test was conducted. Two sample t-tests were used to determine if any significant differences existed between the combined abundance of *Acanthurus coeruleus*, *A. tractus*, *A. bahianus*, *A. chirurgus*, *Sparisoma aurofrenatum*, *S. viride*, *S. rubripinne*, and *Scarus iseri* between the two reef classifications. Lastly, two-sample t-tests were used to identify if any species showed a statistically significant difference in average abundance, mean size, or biomass between the reefs far from or close to humans.

## Ethics

This study was approved by the International Review Board of the School of International Training. In my research, I closely watched my actions to ensure limited disruption and damage to the coral reef ecosystem. To limit my damage to the ecosystem, I only hammered rebar stakes into sandy areas, even if that meant extending my transect passed the allocated length. I will make sure my measuring tape is taut to limit the amount of damage it could have when it moves over coral with the swell. I placed my quadrats down lightly and purposefully. I wore swim pants and a long-sleeved swim shirt to eliminate sunscreen damage. I never stood on coral or used live coral to hang on to or to pull myself with during my studies. At every reef, I asked the boat driver to anchor in a sandy area away from any coral to limit anchorage damage. To limit my stress to Acanthuridae and Scaridae spp., I collected data in an efficient, timely manner.

## Results

### Herbivorous Fish Assemblage:

Four surgeonfish species and four parrotfish species were recorded across five reefs, two of which are located far from high levels of human concentration and the other 3 close to human concentration (Figure 1). A total of 413 fish were observed over nine days. *S. iseri* and *S. viride* contributed a majority of the total abundance, comprising 44% and 28%, respectively, of the total population recorded. In descending order, *S. aurofrenatum*, *A. coeruleus*, *S. rubripinne*, *A. tractus*, *A. chirurgus*, and *A. bahianus* contributed 8%, 6%, 4%, 4%, 3%, and 2%, respectively, of the total abundance.

To analyze the average density of herbivorous fish between the reefs far from human concentration and reefs close to human concentration, twelve 90m<sup>2</sup> visual transects were conducted. This data was used to compare the average density of all Acanthuridae and Scaridae species recorded.

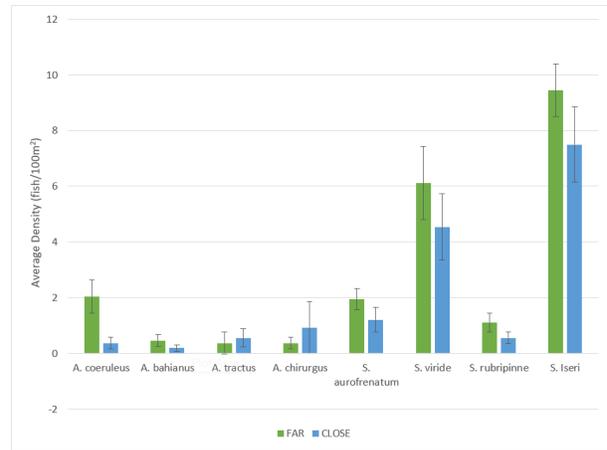


Figure 2: Comparing average density (fish/100m<sup>2</sup>) of Acanthuridae and Sparisoma species between reefs close to and far from human concentration. Error bars = ± 1 SE.

While there were relatively higher numbers of total fish found on reefs far from humans (n = 242) in comparison to reefs closer to human concentration (n = 171), there was no significant difference between the two ( $t(189) = 1.56$ ,  $p = 0.120$ ).

There is a significant difference in the density (fish/100m<sup>2</sup>) of *A. Coeruleus* between the reefs far away from human concentration and those close to human concentration ( $t(14) = 2.65$ ,  $p = 0.019$ ). There was no significant difference in the average density of *A. bahianus* ( $t(18) = 1.12$ ,  $p = 0.278$ ), *A. Tractus* ( $t(21) = 0.72$ ,  $p = 0.482$ ), *A. chirurgus* ( $t(12) = -0.59$ ,  $p = 0.569$ ), *Sparisoma aurofrenatum* ( $t(22) = 1.26$ ,  $p = 0.222$ ), *S. viride* ( $t(22) = 0.89$ ,  $p = 0.384$ ), *S. rubripinne* ( $t(19) = 1.39$ ,  $p = 0.180$ ), or *Scarus iseri* ( $t(20) = 1.17$ ,  $p = 0.254$ ) between fringing reefs far away and close to high levels of human concentration. Mean values and standard error are listed in Table 1.

Species were grouped and measured in 5 cm size increments during the visual census, and mean size was computed. This data enables the identification of differences between the mean size of all species between reefs close to and far from human concentrations.

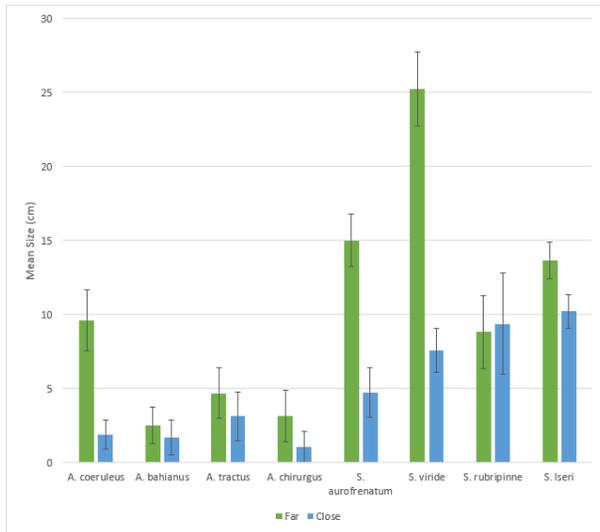


Figure 3: The mean size for each species compared between reef proximity levels to human concentration. Error bars = ± 1 SE.

There is no statistical difference between the mean size (cm) of *A. bahianus* ( $t(22) = 0.49$ ,  $p = 0.314$ ), *A. tractus* ( $t(22) = 0.66$ ,  $p = 0.258$ ), *A. chirurgus* ( $t(18) = 1.0$ ,  $p = 0.159$ ), and *S. rubripinne* ( $t(20) = -0.13$ ,  $p = 0.448$ ) on reefs far from and close to high levels of human concentration. However, there is a significantly larger mean size for *A. coeruleus*, ( $t(16) = 3.38$ ,  $p = 0.002$ ), *S. aurofrenatum* ( $t(22) = 4.2$ ,  $p < 0.001$ ), *S. viride* ( $t(18) = 6.04$ ,  $p < 0.001$ ), and *S. iseri* ( $t(22) = 2.21$ ,  $p = 0.019$ ) found on reefs far from human concentration. The mean values and standard error are listed in Table 1.

Biomass was computed and transformed to represent the amount of grams per 100m<sup>2</sup>. This data was collected with 90m<sup>2</sup> visual transects between depths of 1.5-3.0m depth across all reefs. This allowed the comparison of biomass distribution between all species across the two reef classifications.

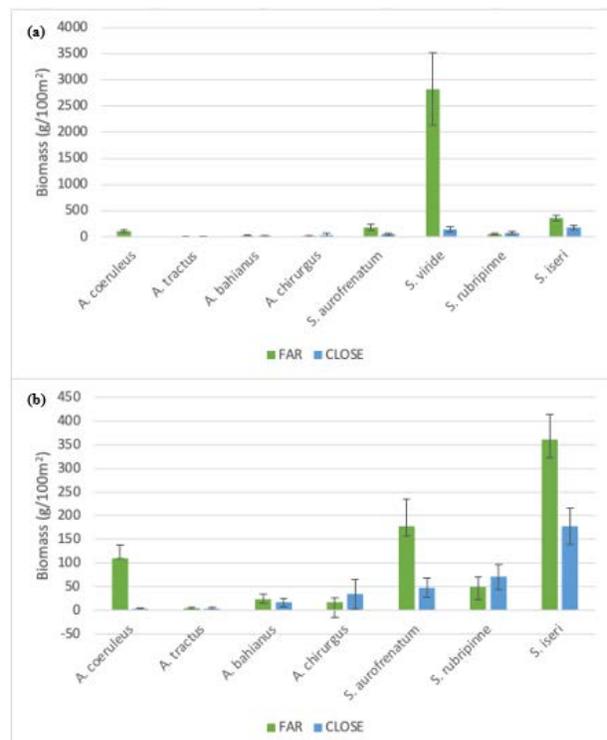


Figure 4: Distribution of the biomass (g/100m<sup>2</sup>) (a) for all 8 species and (b) excluding *S. viride* to visualize the scale of biomass distribution more accurately between the remaining 7 species. Error bars = ± 1 SE.

There was no significant difference in the biomass between the two reef classifications for *A. tractus* ( $t(21) = 0.80$ ,  $p = 0.216$ ), *A. bahianus* ( $t(21) = 0.07$ ,  $p = 0.474$ ), *A. chirurgus* ( $t(13) = -0.48$ ,  $p = 0.318$ ), or *S. rubripinne* ( $t(19) = -0.67$ ,  $p = 0.247$ ). However, the average biomass of *A. coeruleus* ( $t(11) = 3.44$ ,  $p < 0.01$ ), *S. viride* ( $t(11) = 3.47$ ,  $p < 0.01$ ), *S. aurofrenatum* ( $t(14) = 1.9$ ,  $p = 0.042$ ) and *S. iseri* ( $t(20) = 2.52$ ,  $p = 0.01$ ) were all significantly larger in the reefs far from human concentration. Mean biomass values and standard error are listed in Table 1.

Additionally, there was significantly greater total biomass of all species combined in reefs far from humans than in reefs close to human concentration ( $t(96) = 2.93$ ,  $p = 0.002$ ). *S. viride* had the most significant contribution, responsible for 72% of the biomass when compared with all species across both reef classifications. Interestingly, 69% of *S. viride*

biomass was from the reefs far from humans, and only 3% from reefs close to humans. The second most significant contribution was from *S. iseri*, which made up 13% of the biomass.

Reef Classification Site	Species	Fish Count	Abundance fish/100m <sup>2</sup> (SE)	Size (SE)	Biomass g/100m <sup>2</sup> (SE)
Far	<i>Acanthurus coeruleus</i>	22	2.0 (0.6)	9.6 (2.0)	98.9 (28.1)
	<i>Acanthurus bahianus</i>	5	0.5 (0.2)	2.5 (1.2)	4.3 (2.7)
	<i>Acanthurus tractus</i>	10	0.9 (0.4)	4.7 (1.7)	22.0 (10.0)
	<i>Acanthurus chirurgus</i>	4	0.4 (0.2)	3.1 (1.7)	15.4 (10.0)
	<i>Sparisoma aurofrenatum</i>	21	1.9 (3.4)	15.0 (1.77)	160.2 (56.7)
	<i>Sparisoma viride</i>	66	6.1 (1.3)	25.2 (2.5)	2544.6 (696.4)
	<i>Sparisoma rupripinne</i>	12	1.1 (0.3)	8.8 (4.1)	45.2 (20.6)
	<i>Scarus iseri</i>	102	9.4 (1.0)	13.7 (1.1)	324.9 (52.8)
	Close	<i>Acanthurus coeruleus</i>	4	0.4 (0.2)	1.9 (1.0)
<i>Acanthurus bahianus</i>		2	0.2 (0.1)	1.7 (1.2)	3.7 (2.7)
<i>Acanthurus tractus</i>		6	0.6 (0.3)	3.1 (1.6)	15.5 (9.0)
<i>Acanthurus chirurgus</i>		10	1.0 (1.0)	1.0 (1.0)	31.8 (31.8)
<i>Sparisoma aurofrenatum</i>		13	1.2 (0.4)	4.7 (1.7)	43.2 (20.3)
<i>Sparisoma viride</i>		49	4.5 (1.2)	7.6 (1.5)	124.7 (50.7)
<i>Sparisoma rupripinne</i>		6	0.6 (2.1)	9.4 (3.4)	63.8 (26.8)
<i>Scarus iseri</i>		81	7.5 (1.3)	10.2 (1.2)	159.9 (38.5)

Table 1: Total count, abundance (fish/100m<sup>2</sup>) (±SE), size (cm), and biomass (g/100m<sup>2</sup>) of all recorded species from reefs close to and far from high levels of human concentration.

### Benthic Community Analysis:

The benthic community structure and rugosity index (RI) of two reefs far from high concentrations of human population and 3 reefs close to high levels of human concentration were combined and analyzed to compare differences between the two classifications, as shown in Figure 1. The benthic community structure was assessed using twelve 30m<sup>2</sup> belt transects at each classification, resulting in a total of 360m<sup>2</sup> sampled. From this data, differences in the community composition were identified to compare how bleaching impact varies between the two reef classifications. It also allows for the identification of how reef structure may impact Acanthuridae and Scaridae assemblages.

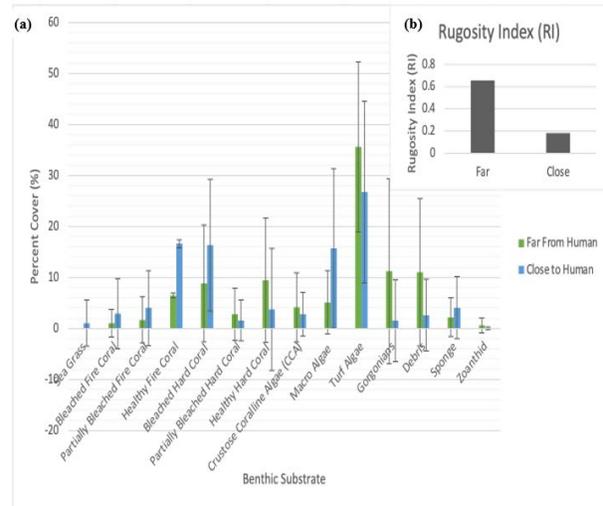


Figure 5: (a) Percent cover of 14 categories between the reef front of fringing reefs located far from human concentration and close to human concentration, (b) Rugosity index (RI). Error bars = ± 1 SD, n = 700.

There is a statistical difference between the percent cover of seagrass ( $t(349) = -4.41, p < 0.001$ ), gorgonians ( $t(479) = 9.04, p < 0.001$ ), debris ( $t(507) = 9.8, p < 0.001$ ), sponge ( $t(585) = -4.89, p < 0.001$ ), and zoanthids ( $t(371) = 6.45, p < 0.001$ ), between the reefs close to and far from human concentration. Additionally, there is a significant difference in the bleached hard coral ( $t(688) = -8.08, p < 0.001$ ), partially bleached hard coral ( $t(661) = 3.44, p < 0.001$ ), and healthy hard coral ( $t(698) = 6.32, p < 0.001$ ) between the two classifications. There is a significant difference between the percent cover of bleached fire coral ( $t(454) = -4.82, p < 0.001$ ), partially bleached fire coral ( $t(583) = -4.97, p < 0.001$ ), and healthy fire coral ( $t(555) = -11.38, p < 0.001$ ). Lastly, there is a significant difference between the percent cover of crustose coralline algae ( $t(585) = 3.24, p = 0.013$ ), macroalgae ( $t(457) = -11.76, p < 0.001$ ), and turf algae ( $t(695) = 6.83, p < 0.001$ ) between reefs located near human concentration and reefs located far from human concentration. The Rugosity index (b) was significantly greater at the reefs further away, with an RI value of 0.66 and 0.18

at reefs located far from and close to high levels of human concentration, respectively  $t(22)=4.88$ ,  $p < 0.001$ ). Percent cover and standard deviation values are listed in Table 2.

Reef Classification Site	Benthic Substrate	Mean Percent Cover (SD)
Far	Sea Grass	0 (0)
	Bleached Fire Coral	1.0 (2.7)
	Partially Bleached Fire Coral	1.7 (4.5)
	Healthy Fire Coral	6.5 (0.4)
	Bleached Hard Coral	8.8 (11.5)
	Partially Bleached Hard Coral	2.8 (5.1)
	Healthy Hard Coral	9.4 (12.2)
	Crustose Coralline Algae (CCA)	4.1 (6.8)
	Macroalgae	5.1 (6.2)
	Turf Algae	35.6 (16.6)
	Gorgonians	11.2 (18.2)
	Debris	11.0 (14.5)
	Sponge	2.2 (3.8)
	Zoanthid	0.6 (1.5)
Close	Sea Grass	1.1 (4.5)
	Bleached Fire Coral	2.9 (6.8)
	Partially Bleached Fire Coral	4.0 (7.3)
	Healthy Fire Coral	16.6 (0.8)
	Bleached Hard Coral	16.3 (13.0)
	Partially Bleached Hard Coral	1.6 (4.0)
	Healthy Hard Coral	3.7 (12.0)
	Crustose Coralline Algae (CCA)	2.8 (4.2)
	Macroalgae	15.7 (15.6)
	Turf Algae	26.8 (17.8)
	Gorgonians	1.5 (8.0)
	Debris	2.6 (7.1)
	Sponge	4.1 (6.1)
	Zoanthid	4 (0.27)

Table 2: Mean percent cover ( $\pm$ SD) of each benthic substrate from reefs close to and far from high levels of human concentration.

## Discussion

### *Herbivorous Fish Assemblage:*

This study was able to analyze and describe the distribution of some of the most conspicuous herbivorous fish species found across the Caribbean during an active bleaching event. The scope of this investigation was through a spatial variation of reefs that are located close to human populations (<0.6 kilometers), and those further away from high concentrations of human populations (>5.5 kilometers). Thus, it is interesting that while there was a greater total abundance of the eight species measured, there was no significant difference in the overall distribution. This can be explained by the limited impacts of fishing on these species of surgeonfish and parrotfish throughout the Guna Yala comarca, as red snapper and lobster are the most important parts of the local diet (personal observations). Other studies that describe the

distribution of surgeonfish and parrotfish note a clear difference between abundance in comparison to areas of varying fishing levels. Sherman et al. (2022) describes a higher population of parrotfish in areas of decreased fishing, even though the associated reefs have lower rugosity. These areas, however, are often classified with more commercial fishing, which is rare in Guna Yala. Therefore, the potential anthropogenic impacts may be attributed to coral mining and nutrient enrichment (Guzman et al., 2003), which are associated with threats to coral health rather than fish assemblage. There could be evidence of an indirect effect of these specific anthropogenic stresses on the abundance of surgeonfish and parrotfish populations through the difference in reef structure (see discussion).

In terms of the average density, this study found comparatively less density than other research conducted in the Caribbean. When looking at surgeonfish specifically, the average density (fish/100m<sup>2</sup>) was very low across all 4 species. For example, there is between two and four times greater abundance of *A. coeruleus* in a study conducted in the Bahamas and the Gulf of Mexico, respectively (Duran et al., 2019; Hernández-Landa & Aguilar-Perera, 2019). This study also reports a mean density of *A. tractus* that is more than 5 times smaller than the mean density found by Duran et al. (2019). Furthermore, the average density of *S. aurofrenatum* and *S. iseri* was less in the study by Sherman et al. (2022), while *S. viride* was similar. However, this study reports a high density of *S. rubripinne*, which is consistent with the findings from (Hernández-Landa & Aguilar-Perera, 2019).

The results from this study suggest that proximity to human concentration may negatively impact the mean size of Acanthuridae and Scaridae spp. In fact, there is a threefold increase in the size of *S. viride*, *S. aurofrenatum*, and *A. coeruleus* in reefs farther from human concentration. Despite this, only the mean size of *S. iseri* across both reef

classifications and *S. viride* from far reefs is consistent with previous studies. The remaining mean size from all other species is lower in this study than in other studies (Hernández-Landa et al., 2015; Hernández-Landa & Aguilar-Perera, 2019). This variation could be explained through the impact of the current bleaching event. Previous research has shown fish are poor at adapting to increasing temperature, and will often move greater distances to properly thermoregulate (Nay et al., 2015). This often includes local migration to greater depths, where cooler water temperature acts as a refuge from the heated surface temperature. Thus, larger individuals of all species from this study may have migrated to lower depths, past the observational limit of snorkeling.

The difference in mean size between species far from and close to human concentration indicates a potential distribution of larger fish where there is less local human impact. When considering that there was no significant difference in abundance distribution between the two location classifications, the potential for this relationship is heightened. As previously mentioned, fishing in Guna Yala excludes commercial fishing and is limited to local consumption (Clifton et al., 1997). Even the impact of local subsistence fishing seems to have an impact on the distribution of larger fish, which are more commonly found on reefs far from human concentration (Figure 2). Furthermore, there are consequences for algal growth between larger and smaller herbivores. Specifically, larger Scaridae are found to exhibit slower bite rates while removing substantial parts of algae assemblages. This is beneficial for coral reefs, as this results in new substrate available for coral recruitment (Bonaldo & Bellwood, 2008). Smaller herbivorous fish, on the other hand, take substantially smaller bites that do not result in new space for coral recruitment and therefore have limited impact on altering the benthic community structure (Bonaldo et al., 2014,

however, see (Cernohorsky et al., 2015). Thus, the reefs with smaller assemblages of herbivorous fish are more likely to have decreased resilience, especially following bleaching events with increased coral mortality.

Across all reefs surveyed, the distribution of biomass was largely contributed by *S. viride*. The vast majority of this contribution, however, was from reefs far from human populations (Figure 3a). While the results of this study share some consistencies with others, the extent varies greatly with previous studies from across the Caribbean. In one study by Hernández-Landa & Aguilar-Perera (2019), *S. viride* also composed the highest biomass for two shallow reefs, at 23.7 -31.6% contribution, respectively. The 73% contribution to biomass by *S. viride* found in this study is drastically different, however. This can also be compared to a study by Hernández-Landa et al. (2014), where *S. viride* only makes up 18.9% of the biomass on the reef front. Additionally, the current study had much higher biomass of *S. iseri*, and comparatively lesser biomass from the remaining species, namely *A. bahianus* and *S. rubripinne*. In terms of total family biomass, this study found less biomass for both Acanthuridae and Scaridae, with more drastic differences for the former (Hernández-Landa & Aguilar-Perera, 2019). These differences may also be explained by the impacts of the current bleaching event. Bleaching events can have a direct impact on the biomass of herbivorous fish, seen with a sharp decrease in biomass during a bleaching event compared to prior (Magel et al., 2020). This study reports meaningful data on the biomass of herbivorous fish in a time of bleaching, placing it in unique standing among related literature.

#### ***Benthic Community Structure:***

Proximity to human populations seems to have an impact on the composition of reef structures in Guna Yala, Panama (Figure 5, Table 2). In terms of algal cover, the reefs further from

human concentration appear to be healthier, with less macroalgae and greater amounts of crustose coralline algae in comparison to the reefs in proximity to human concentration (Figure 5a). This correlates with the higher total biomass and larger mean size of herbivorous fish on far reefs. The combination of the two is often attributed to a positive impact on reducing algal coverage and improving overall reef health, and this study suggests the same conclusion (Steneck et al., 2014). In addition to the algal matrix, the reefs studied exhibit greater bleaching on coral reefs close to people and reefs farther away contain more healthy coral. Due to the proximity between the two reef classifications, this is not likely due to regional differences. Instead, this suggests a positive relationship between the bleaching of coral and proximity to human concentration. This is of substantial concern, as the reefs closer to humans may face greater loss facing the current bleaching event. This may be further exacerbated by the generally small sizes of herbivorous fish found on close reefs, which are less effective at reducing macroalgae (Bonaldo et al., 2014). This study suggests negative implications for the resilience of closer reefs to human population, and future research can potentially demonstrate the post-disturbance outcomes for these reefs.

Greater abundance and biodiversity of herbivorous fish are associated with higher levels of rugosity, which this study supports (Graham & Nash, 2013). Interestingly, the results from this study indicate a general population skew towards far reefs which have both higher levels of turf algae and structural complexity. This finding is in contrast to a notion of resource and refuge tradeoff in coral reefs, where herbivores selectively forage between areas with more algae or more refuge in the form of structural integrity (Randall, 1965). This study, however, found that higher herbivorous biomass was found in high structural, turf algae-

covered reefs. This matches the results of (Santano et al., 2021) which was recorded following a recent disturbance by a typhoon, and suggests an increasing relationship of structurally complex, algal-dominated reefs following disturbances. If this trend materializes in coral reefs, then the distribution of Acanthuridae and Scaridae may continue to centralize in complex reefs as there will be a source of both refuge and resources. How this will impact the greater coral reef system is still in question.

## Conclusion

This study found a mix of trends that support the notion of a difference in assemblage by Acanthuridae and Scaridae species. While there was not a significant difference, there was a larger total number of fish recorded on reefs farther from human concentration. When compared between the two reef locations, the mean sizes of *A. coeruleus*, *S. aurofrenatum*, *S. viride*, and *S. iseri* were all greater in reefs far away from human concentration than in reefs closer to human concentration. Consequentially, the biomass density was significantly higher for the same respective species on reefs farther from humans, which makes sense as the biomass equation is directly related to length. However, the vast contribution of *S. viride* to the total biomass is worth stressing as highly unusual, especially when compared to other herbivorous fish assemblage studies conducted in the Caribbean. This could be a result of the relatively small scope of the study, as a collection of large *S. viride* recorded on far reefs may not have had such drastic impacts on studies with larger sample sizes. Additionally, this study only recorded 8 total species, split evenly between the Acanthuridae and Scaridae family. Other similar studies report a significantly greater number of Scaridae species. Nonetheless, this result is especially intriguing when considering the position of this study during a current bleaching event.

This study is rare in its place among current literature as effectively describes Acanthuridae and Scaridae assemblage during a bleaching event. The data demonstrates differences in the population as compared to other studies. This implies that the bleaching event is impacting the spatial composition of Acanthuridae and Scaridae species. Given previous research on the spatial and temporal distribution of these herbivorous fish, these species may be seeking refuge in deeper, cooler waters. However, there is very limited data present in the Guna Yala comarca on the assemblage of Acanthuridae and Scaridae species, so a direct comparison is difficult. Therefore, the need for future work is imperative. This can reveal the characteristics of Acanthuridae and Scaridae distribution specifically in Guna Yala, Panamá, which can highlight species of higher or lower resiliency to bleaching events, respectively.

This study also described the implications of the active bleaching event for coral reef community structure in terms of proximity to human concentration. There was a significant difference in the amount of bleached, partially bleached, and non-bleached fire coral, bleached hard coral, and macroalgae in reefs located closer to populated islands. In contrast, far reefs were characterized by higher percent coverage of partially bleached and healthy hard coral, gorgonians, crustose coralline algae, and turf algae. These metrics indicate that the generally healthier coral reefs are found further away from human concentration. This is even further supported by a large difference in rugosity between the two reef classifications, with higher complexity of reefs farther from humans. This data additionally suggests a potential compounding impact of the local human population on the bleaching extent and severity. When coupled with the difference in Acanthuridae and Scaridae distribution, the results of this study imply that the reefs located closer to humans will show reduced resiliency to the current

bleaching events. This will have to be tested in future research, however.

My research ultimately analyzed a comparison of Acanthuridae and Scaridae population distribution across reef locations of varying proximity to the local population. It is important to mention that the original scope of the project was to measure feeding preference; however, this shifted due to technical difficulties post-data collection. Therefore, my research may not have encompassed enough species to describe the population distribution of Acanthuridae and Scaridae species to the extent that is warranted and needed in this understudied region of the world. While the data attained and results synthesized may indicate impacts on human population, this study did not measure any of the impacts from the populated islands in question. Therefore, the results discussed merely suggest a correlation. Future research should aim to analyze the recovery and resiliency of coral reefs in Guna Yala, Panama to the active bleaching event. It would be interesting to see if population dynamics vary from the current study and potentially identify species of particular resiliency to bleaching disturbances. This research could provide very meaningful data that could influence management over herbivorous fish fishing and other anthropogenic impacts.

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