The relationship between substrate composition, community structure and feeding preferences of parrot fishes (Scaridae) in Anmardub, Guna Yala coastal reefs

Caitlin Amman
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The relationship between substrate composition, community structure and feeding preferences of parrot fishes (Scaridae) in Anmardub, Guna Yala coastal reefs

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SIT Panama
ABSTRACT

Coral reefs are important marine ecosystems, as they support biodiversity and generate buffer zones, yet their abundance is incredibly limited globally. One of the main threats that coral reefs face is excessive macroalgal coverage, which limits sunlight from reaching corals, and thus, limits the energy that can reach them. Parrot fish (Scaridae) are keystone herbivores, as they consume macroalgae growing on corals, which aids in reef survivability. While there is previous research on the abundances, sizes, and feeding habits of Scaridae species in the Caribbean, there is no published research on how community structure and feeding preferences of parrot fishes differ within coral reef ecosystems of varying substrate composition. This study assesses the community structure and feeding preferences of Scaridae in the fringing and barrier reefs, reefs of differing substrate composition, of Anurdub Island in Guna Yala, Panama. To determine the substrate composition of fringing and barrier reefs, percent coverages of sand, algae, sponge, dead coral, fire coral, coral rubble, hard coral, and soft coral, were quantified using a 1m² threaded quadrate along 6 30x1m belt transects at varying depth levels (0-2.0m, 2.1-4.0m, 4.1-6.0m) in each reef. These transects were placed 30m away from each other, and parallel to the shore. Using these same transects, visual censuses were conducted, in which Scaridae species within 1m of either side of the transects had their densities, size proportions (0-10.0cm, 10.1-20.0cm, 20.1cm+), and proportions of coral species consumption, recorded. Across all depth levels, the fringing reef has significantly higher percentages of sand coverage, t(62)=4.33, p<.001; t(60)=7.78, p<.001; t(59)=4.27, p<.001, and dead coral coverage, t(59)=6.47, p<.001; t(59)=8.72, p<.001; t(59)=4.30, p<.001, while the barrier reef has significantly higher percentages of hard coral coverage, t(116)=3.13, p=.0022; t(118)=8.03, p<.001, at the 0-2.0m and 2.1-4.0m depth levels. Thus, the barrier reef is generally healthier and more consistent than the fringing reef. Scaridae species densities differ significantly between fringing and barrier reefs at the 0-2.0m depth level, X² (4, N=184,164)=52.70, p<.001, as there are significantly higher densities of Scarus iseri and Sparisoma rubripinne in the fringing reef, and significantly higher densities of Nicholsina uesta, Sparisoma aurofrenatum, and Sparisoma viride in the barrier reef. Across all depths of fringing and barrier reefs, there is a weak positive correlation between substrate variability and Scaridae species diversity, R²=.0057, F(5)=.023, p=.89. There is also a significant difference in Scaridae coral species consumption proportions across all depth levels, X² (3, N=140,54)=66.55, p<.001; X² (4, N=20,47)=53.07 p<.001; X² (6, N=76,94)=108.74, p<.001, as significantly higher proportions of Scaridae consume macroalgae and algal turf on dead coral in the fringing reef, while significantly higher proportions of Scaridae consume macroalgae on coral rubble and Porites porites in the barrier reef. Based on these results, we can conclude that there is a relationship between coral reef substrate composition and Scaridae species densities at the 0-2.0m depth level, and across all depth levels, a relationship between coral reef substrate composition and Scaridae diversity and feeding preferences.
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# TABLE OF CONTENTS

Abstract .............................................................................................................................. 1
Acknowledgements ........................................................................................................ 2
Introduction .................................................................................................................... 4
Research Question ......................................................................................................... 9
Research Objectives ..................................................................................................... 9
Materials and Methods ................................................................................................. 9
Ethics ............................................................................................................................. 12
Results .......................................................................................................................... 13
Discussion ..................................................................................................................... 26
Conclusion .................................................................................................................... 28
References .................................................................................................................... 30
INTRODUCTION

Area of Study

Panama, a country that acts as a land bridge between North and South America, is composed of unique and diverse flora and fauna. The formation of this land bridge was caused due to the collision of the Cocos, Nazca, Caribbean, and South American tectonic plates, resulting in a connection of the Americas. Panama is defined, in part, by its tropical climate, and experiences both wet and dry seasons throughout the year (Clifton et al., 1997). Panama is surrounded by the Pacific Ocean on the south side, and the Caribbean Sea on the north side. While the Pacific Ocean is cooler and promotes primary plant growth, the Caribbean Sea is characterized by its richness in carbon, lack of nutrients, and warm temperatures, which are all conditions that permit the growth of coral reef ecosystems along the Caribbean coast (Leigh et al., 2014).

Guna Yala, an Indigenous Comarca that is legally controlled by the Guna community along the northeast to southern Caribbean coast, is an example of a region in Panama with some of the most diverse coral reefs. Guna Yala’s Comarca was established in 1938, which allowed the Guna community to have complete control of their territory (Guzmán et al., 2003). Guna Yala runs from Punta San Blas to Puerto Obaldia, and has a mean annual temperature and rainfall of 26-27°C and 1,600-3,000mm, respectively, and a relative humidity of 78 percent to 90 percent (Calzada et al., 2015; Stevens, 2018). Specifically, Guna Yala makes up 81 percent of all coral reefs in Panama (McEntee, 2012). Its abundance of coral reefs makes marine life, such as corals and fish, an important resource for the Guna community. Additionally, this is an essential region of study in order to understand the complexity of coral reef ecosystems.

Anmardub (9°28'11" N, 78°50'01" W), one of the 365 islands within the Guna Yala archipelago, was the location of study (Calzada et al., 2015). Anmardub is a tourist island that contains two types of coral reefs (fringing and barrier). While the fringing reef begins within 30m of the island on the eastern, northern, and western sides, the barrier reef begins 300m to the north of the island. Anmardub is composed of an area of about 200m², and it is a 45 minute boat ride east of Port Gardi.

Coral Reefs

Coral reef ecosystems are able to survive in warm shallow waters, and these ecosystems only make up an area of 260,000–600,000km² globally, which is less than .10 percent of the earth’s surface. Coral reefs are especially prevalent within the Indo-West Pacific, western and central Pacific, the Indo-Australian Archipelago, and Indian Ocean (Allan & Adrim, 2003). Corals are sessile marine organisms that rely on reproduction strategies, such as broadcasting and brooding, along with their symbiotic relationship with zooxanthellae, in order to survive and grow. Corals have a mutualistic relationship with zooxanthellae, in which coral provides a home and nutrients for the zooxanthellae, and the zooxanthellae releases coral excretion products and provides photosynthetic products to its coral host. It is this interaction between coral and zooxanthellae that enables calcification of coral’s carbon skeleton, and thus, reef building (Knowlton, 2001).

Within Guna Yala, previously known as San Blas, there exists networks of sea grasses and coral reefs along the continental shelf. In Guna Yala, there are 57 stony coral species, and 4 hydrocoral species, along with large abundances of brain corals, and gorgonian, or soft, corals. While shallow reefs typically consist of Acropora, Agaricia, Porites, and Millepora, or stony and
fire corals, deeper reefs contain *Orbicella faveolata*, *Orbicella franksi*, and *Orbicella cavernosa*, or colonial stony corals, also referred to as star corals. These reefs are known to have high macroalgal covers, which poses a threat to coral health, and thus, the biodiversity that they support (Clifton et al., 1997).

**Coral Reef Importance**

Although coral reef ecosystems cover less than 0.50 percent of the ocean floor globally, they are important due to their ability to support biodiversity, as well as their ability to generate buffer zones (Camargo et al., 2009; Knowlton, 2001; van Zanten et al., 2014). Coral reefs are the most diverse marine habitat per unit area. Interestingly, it is not the corals themselves that are particularly diverse, as while the minimum estimate of reef-building corals includes 835 species, reef biodiversity is estimated to range between 1 and 9 million species (Knowlton, 2001). This is due to the fact that many different organisms live within coral reefs, such as fish, sponges, tunicates, crabs, sea urchins, sea stars, marine worms, mollusks, copepods, shrimp, and barnacles (Glynn, 2012; Knowlton et al., 2010). Furthermore, coral reef ecosystems create buffer zones to enhance the growth and development of juvenile organisms, which enables their capacity to support biodiversity. Coral reefs are able to serve this function through dissipating wave energy (Ghiasian et al., 2021).

The development of buffer zones by coral reef ecosystems is not only important to juvenile marine populations, but also to the maintenance of shorelines. Coral reefs are able to reduce the risks of storm surges, erosion, and flooding within shoreline regions. These buffer zones are of the utmost importance, as they not only protect coastal land, which reduces the monetary and environmental costs of shoreline damage, but they also decrease fatalities within coastal populations. About 40 percent of the global population lives within 100km of any shoreline, which emphasizes the reliance of these coastal populations on buffer zones. Furthermore, these buffer zones enable tourism, and help to maintain fishery resources, which all have positive influences on the economy, as well as livelihoods (Ghiasian et al., 2021).

**Coral Reef Threats**

Despite the fact that Panama has prime conditions for coral reef growth, research shows that Caribbean coral reefs have been declining. Specifically, live coral cover of Caribbean reefs has decreased from over 50 percent in the 1970s to just 10 percent (Jackson et al., 2014). Furthermore, it has been indicated that globally, one-third of all corals are at risk of extinction, which would make corals the most endangered group of animals on the planet (Plaisance et al., 2011). Coral reefs rely on a variety of environmental factors in order to survive, such as temperature, sunlight, salinity, pH, nutrients, turbidity, and calcium carbonate saturation, thus making them vulnerable, as they are reliant on relatively stable conditions (Crabbe, 2008). There are a variety of reasons as to why these coral reefs are experiencing such a widespread collapse, such as climate change and global warming (Jackson et al., 2014). Specifically, global warming gives rise to prolonged above-normal temperatures, which can result in coral bleaching, in which the coral loses its zooxanthellae. Coral bleaching not only leads to a reduction in the growth rates of corals, but can also lead to coral death, as additional energy is then required of the coral for its survival (Crabbe, 2008).

One of the main threats that coral reefs face, particularly in Guna Yala, is excessive macroalgal cover (Clifton et al., 1997). For example, in the Caribbean, coral cover is only about 13 percent, while macroalgal cover is about 40 percent (Dell et al., 2020). Overnutrification,
especially through terrestrial runoff and pollution, can result in this excessive macroalgal cover. This is because when nutrient availability increases, dominance within coral reef communities shifts from nutrient-recycling symbiotic organisms, like corals, to benthic filter-feeding invertebrates, like macroalgae. As a result of this shift, calcification can be reduced up to 50 percent, and there is evidence that skeletal densities decrease in corals (Fabricius, 2005). Furthermore, a negative correlation between macroalgal coverage and live coral coverage, along with juvenile coral densities, has been identified, indicating that macroalgal cover reduces coral survivability and growth. Thus, for coral reefs to maintain their ability to support biodiversity and generate buffer zones, there must be a way for macroalgal populations to be restricted (Hoey et al., 2011). While sea urchins, *Diadema antillarum*, were prevalent herbivores that maintained this balance in the Caribbean, their mass die-off, which began in 1983, resulted in a 98 percent decrease in their population density (Lessios, 2015). As a result, coral reefs are dependent upon herbivorous fish communities to help maintain the macroalgal-coral balance due to their ability to regulate algal growth (Hoey et al., 2011).

**Scaridae**

Within the Caribbean, herbivorous fish are currently the single dominant herbivore group that coral reefs rely on to limit macroalgal growth. Thus, herbivorous fish are instrumental in the maintenance of coral reef ecosystems, as they provide resilience to reefs through ensuring corals have access to sunlight so that they can survive and reproduce (Burkepile and Hay, 2008). The two primary herbivorous fish in the Caribbean include parrot fish (Scaridae) and surgeonfish (Acanthuridae) (Adam et al., 2018). The Scaridae family is considered to be evolutionarily young, as this family is thought to have originated just 12 million years ago in the Tethys Sea, which eventually gave rise to the Indo-Pacific waters (Schwab & Marshall, 2003). Scaridae are a prevalent keystone herbivore for coral reef ecosystems, and they are known for their beak-like jaws that enable their consumption of macroalgae on corals (Adam et al., 2018; Cramer et al., 2017). There are a variety of methods that Scaridae use to consume macroalgae and algal turf, including browsing, scraping, and excavating. While ‘browsers’ feed on macroalgae directly, ‘scrapers’ consume diminutive algal turfs, along with its associated detritus, microbes, and infauna from its carbon skeleton, and ‘excavators’ consume crustose and endolithic algae from within the coral (Adam et al., 2018; Dell et al., 2020). Scaridae are primarily threatened by overfishing, which is harmful to coral health, as low Scaridae biomass correlates with low coral cover and high macroalgal cover (Jackson et al., 2014).

Despite the threats that Scaridae face, herbivorous fish, including Scaridae, comprise 27 percent of the total fish biomass in Panama, while in the wider Caribbean, herbivorous fish only comprise 10 percent of total fish biomass. In comparison, high-level carnivorous fish make up about 22 percent of the total fish biomass in Panama, while in the wider Caribbean, they make up 31 percent of total fish biomass (Seeman et al., 2018).

Scaridae also have a variety of survival strategies, especially involving camouflage, that allow them to evade predators, such as pointillism, burrowing, and creating mucous sacs at night. Pointillism is when bright complementary colors appear as an intermediate dull color with increasing distance. This form of camouflage is employed by the majority of male Scaridae. Specifically, when male Scaridae are viewed from a close distance, they have two complementary bright colors on their bodies, which are important for communication and mating practices. However, when they are viewed from a far distance by predators, male Scaridae appear grey-blue, as they blend into the reef background. Furthermore, some species of Scaridae, as a
form of self-protection from predation at night, will bury themselves in the sand, or will secrete a mucous sac around themselves. Through secreting a mucous sac, Scaridae can sense if the sac has been disturbed, and swim to a new location away from the potential predator. This mucous sac not only notifies Scaridae when there is movement outside of its envelope, but it also protects Scaridae from parasites, and limits olfactory stimuli that can be sensed by nocturnal predators, like the moray eel (Schwab & Marshall, 2003). Furthermore, Scaridae express protogynous hermaphroditism, a life strategy in which female Scaridae become male Scaridae in order to become more reproductively successful as size or age increases. There are also social advantages to this life strategy (Muñoz & Warner, 2003). This sex change is driven hormonally, as during the color transition from male to female, previous research indicates that there is a sharp increase in 11-ketotestosterone and a decrease in 17 beta-estradiol (Cardwell & Liley, 1991).

**Scaridae Abundances**

Within the Caribbean, there are 16 species of Scaridae, including: the Redband parrot fish (*Sparisoma aurofrenatum*), Princess parrot fish (*Scarus taeniopterus*), Striped parrot fish (*Scarus iseri*), Blue parrot fish (*Scarus coeruleus*), Midnight parrot fish (*Scarus coelestinus*), Rainbow parrot fish (*Scarus guacamaia*), Queen parrot fish (*Scarus vetula*), Saddled parrot fish (*Sparisoma frondosum*), Reef parrot fish (*Sparisoma amplum*), Stoplight parrot fish (*Sparisoma viride*), Redtail parrot fish (*Sparisoma chrysopterum*), Yellowtail parrot fish (*Sparisoma rubripinne*), Emerald parrot fish (*Nicolsina usta*), Greenblotch parrot fish (*Sparisoma atomarium*), Bucktooth parrot fish (*Sparisoma radians*), and the Bluelip parrot fish (*Cryptotomus roseus*) (Humann & Deloach, 2014). Globally, amongst both Scaridae and Acanthuridae, the two major herbivorous fish families, there are 179 known species. The vast majority of these species, 86 percent, are listed on the IUCN Red List of Threatened Species as being of Least Concern, and only 3 species within both these families are listed as being at elevated risk of global extinction (Comeros-Raynal et al., 2012). Although there are few threatened Scaridae species, there are some species that are more abundant than others. Specifically, some of the most common species of Scaridae within Caribbean reefs include the *S. aurofrenatum*, *S. taeniopterus*, and *S. iseri* (Burkepile & Hay, 2008; Seeman et al., 2018). *S. iseri* is a particularly abundant species in the Caribbean, as it makes up 72 percent of Scaridae biomass. This may be a result of its small body size, as this species matures at a length of about 65mm, which prevents *S. iseri* from being targeted by fisheries (Seeman et al., 2018).

**Scaridae Sizes**

Although Scaridae are generally not considered to be threatened, there is evidence that fishing practices influence Scaridae, as the majority of Scaridae are of small sizes. Generally, the overexploitation and targeting of larger fish may be the reason as to why 94 percent of all fish across all habitat types within the Caribbean are of small body size, which is considered to be of lengths ≤10cm. Specifically, according to previously conducted research, about 62 percent of Scaridae within the Caribbean are also of small body size, while only about 21 percent of Scaridae are of lengths 10.0-20.0cm, and only 17 percent of Scaridae are of lengths ≥20cm (Seemann et al., 2018). Furthermore, in heavily fished locations in the Caribbean, about 70 percent of Scaridae are of lengths <11cm, further indicating that fishing practices may contribute to the small sizes of Scaridae (Shantz et al., 2020).
**Scaridae Feeding Preferences**

While some Scaridae species prefer feeding on macroalgae growing on hard corals, other species prefer feeding on seagrasses. Specifically, *S. iseri*, *S. rubripinne*, and *N. usta* juveniles are considered to be associated with seagrass beds, as the consumption of seagrass is an important part of their diets (Dromard et al., 2017; León et al., 2022; Prado & Heck Jr., 2011). However, these species are not bound to solely feeding on seagrasses. For instance, *S. iseri* also is known to feed on microalgae living on dead coral pavements (Dromard et al., 2017). On the other hand, previous research indicates that *S. aurofrenatum*, *S. viride*, *S. vetula*, and *S. guacamaia*, associate with hard coral, as they are all considered to be coral predators (Miller & Hay, 1998; Rotjan & Lewis, 2006). Due to the fact that there are overlaps in the general feeding preferences and habits of Scaridae, the family may exhibit preferences for specific algal communities growing on substrates in order to reduce competition. This is suggested through research conducted by Burkepile & Hay, in which common Scaridae species, with similar feeding preferences, exhibited varying positive and negative relationships with the available macroalgae (2011).

Scaridae feeding preferences not only change in response to competition, but they also change in response to the environment that they live within. Specifically, videos taken through a previous study indicate that *S. viride*, and other large Scaridae species, prefer articulated coralline algae. However, when these species moved to a community with an overabundance of other algal types, Scaridae changed their community roles and instead removed the new algae. Thus, as benthic habitats change, there is evidence that Scaridae feeding habits also change. Furthermore, there are indications that Scaridae size may influence feeding preferences, as *S. viride*, which, in this study, was the largest species on average, had different feeding patterns compared to two smaller Scaridae species, *S. aurofrenatum* and *S. chrysopterum*. For instance, *S. viride* and other large Scaridae showed a preference for articulated coralline algae, while *S. aurofrenatum* and *S. chrysopterum* did not. Additionally, these two smaller species had similar feeding preferences throughout the study (Burkepile & Hay, 2011).

Furthermore, there is evidence that coralline feeding preferences of Scaridae are taxa-specific. In a previous study conducted in the Florida Keys reef tract, observations demonstrated that *Scarus* parrot fish prefer to feed on *P. astreoides* and *S. siderea*, while as *Sparisoma* parrot fish prefer to feed on *Colpophyllia natans* and *Omicrona faveolata*. These same observations were made in Brazilian coral reefs as well, indicating that this may be a wide-spread pattern (Burkepile & Hay, 2011). Across all Scaridae, there are some general feeding patterns that exist as well. Specifically, there is evidence that Scaridae prefer to feed on macroalgae and algal tufts on dead coral and coral rubble in comparison to living hard coral, and that spongovory is more common that corallivory (Bruggemann et al., 1994; Burkepile et al., 2019). Overall, it is important to understand the feeding patterns of Scaridae, as their roles in macroalgal consumption are crucial to the survival and growth of coral reefs, especially during this time of coral reef ecosystem decline. More effort should be made to study Scaridae community structure and feeding preferences in order to understand their roles in maintaining coral reefs.
RESEARCH QUESTION

Do Scaridae community structure and feeding preferences change with coral reef substrate composition?

Null Hypotheses:
1) There is no statistically significant difference between the substrate composition of Anmardub fringing and barrier reefs at the same depth levels
2) There is no statistically significant difference in Scaridae species densities between Anmardub fringing and barrier reefs at the same depth levels
3) There is no statistically significant difference in Scaridae size proportions between Anmardub fringing and barrier reefs at the same depth levels
4) There is no statistically significant difference in proportions of Scaridae coral species consumption between Anmardub fringing and barrier reefs at the same depth levels
5) There is no correlation between Scaridae Shannon diversities and substrate variability in Anmardub fringing and barrier reefs

Alternative Hypotheses:
1) There is a statistically significant difference between the substrate composition of Anmardub fringing and barrier reefs at the same depth levels
2) There is a statistically significant difference in Scaridae species densities between Anmardub fringing and barrier reefs at the same depth levels
3) There is a statistically significant difference in Scaridae size proportions between Anmardub fringing and barrier reefs at the same depth levels
4) There is a statistically significant difference in proportions of Scaridae coral species consumption between Anmardub fringing and barrier reefs at the same depth levels
5) There is a correlation between Scaridae Shannon diversities and substrate variability in Anmardub fringing and barrier reefs

RESEARCH OBJECTIVES

1. Identify two coral reefs of different substrate composition at 0-2.0m, 2.1-4.0m, and 4.1-6.0m depths based on percent coverages of sand, algae, sponge, dead coral, fire coral, coral rubble, hard coral, and soft coral.
2. Within these coral reefs of differing substrate composition, determine the Scaridae community structure and feeding preferences based on the abundances of Scaridae species, their relative sizes, their Shannon diversity, and the species of coral they are consuming.

MATERIALS AND METHODS

Study Site

This study was conducted in the fringing (9°28'13"N, 78°50'00"W) and barrier (9°28'22"N, 78°49'58"W) reefs off the coast of Anmardub in Panama’s Guna Yala Comarca (Figure 1). Anmardub was the chosen study area because it currently has no published research, and there is access to two distinct reefs, making it an ideal site to study ecological differences between these
reefs of varying substrate composition. Anmardub’s fringing reef is characterized by its inconsistency, dead coral, and presence of *Porites porites*, *Porites astreoides*, *Siderastrea siderea*, and *Millepora alcicornis*. On the other hand, the barrier reef is characterized by its consistency, macroalgal cover, and presence of *P. porites*, *Acropora palmata*, and *Orcicella annularis*. Shallower regions, of depths 0-2.0m, in both fringing and barrier reefs, have strong currents.

Throughout this study, conducted from April 6 to April 20, 2022, the weather was generally overcast, and air temperatures ranged from 24-33\(^\circ\)C. Humidity ranged from 49 percent to 100 percent, air pressure ranged from 1006-1015mbar, and wind velocity ranged from 0-28km/h (timeanddate, 2022). Data was collected from early-morning to mid-day, and only when there was a lack of presence of rain. To get an idea of the Scaridae species present, as well as the coral species present, the fringing and barrier reefs were observed two days prior to the start of data collection.

![Figure 1](image.png)

**Figure 1.** Images of study location provided through Google Maps. (A) Regional location of study in Panama within Guna Yala Comarca. (B) Reef study sites (indicated by dots) located off the coast of Anmardub (indicated by star).

**Coral Substrate Composition Sampling**

The composition of the barrier and fringing reefs at 0-2.0m, 2.1-4.0m, and 4.1-6.0m depths were determined using a 1m\(^2\) threaded quadrat along an entire 30m belt transect to measure percent coverages of sand, algae, sponge, dead coral, fire coral, coral rubble, hard coral, and soft coral (Figure 2). Percent coverage was quantified by dividing the number of points directly above each substrate by the total number of points, 81, within the 1m\(^2\) threaded quadrat. Depth was measured from the bottom of the coral to the top of the sea. Each 30m transect ran parallel to Anmardub’s shoreline, and the threaded quadrat was placed on the side of each transect farthest from the shore, creating a 30m\(^2\) belt transect (Ammar, 2009). Upon entering
each reef, the measuring tape was randomly dropped into the water at the 0-2.0m depth to indicate the start of the transect, and each of the progressive depth level transect was 30m from the original, traveling farther from the shoreline (Kaczmarsky et al., 2005). Within each reef, 6 belt transects, with 2 at each of the depth levels, were used to collect data. Overall, 180m² of each reef, and 60m² of each depth level within each reef, had its substrate composition evaluated.

**Figure 2.** Image of threaded quadrat used to quantify percent coverage of sand, algae, sponge, dead coral, fire coral, coral rubble, hard coral, and soft coral of 180m² in fringing and barrier reefs.

*Visual Scaridae Census*

After the substrate composition within the barrier and fringing reefs was evaluated along each of the 30m² belt transects, visual censuses were conducted to evaluate the Scaridae community structure and feeding preferences. The limits of the visual census were estimated at 1m on either side of the 30m transects used to evaluate the coral substrate composition. After doing each of the coral composition analyses, I swam to the beginning of the transect and waited for 10 minutes to limit the impact of human influence on the visual census data. During the visual census, I swam down the center of the 60m² belt transect slowly (4s/m), and recorded the abundances of different species of Scaridae, their size classes, and the species of coral they were consuming (Frehse et al., 2020; Irigoyen et al., 2013). The size classes were 0-10.0cm (small), 10.1-20.0cm (medium), and 20.1cm+ (large), and these fish lengths were estimated visually from nose to tail (Seeman et al., 2018). Scaridae coral consumption proportions, amongst the Scaridae eating, were calculated to indicate feeding preferences. To determine this, the abundances of Scaridae consuming macroalgae on recorded coral species were quantified in the transects. In each reef, 6 visual censuses were conducted, with 2 censuses at each depth level, just like with the coral composition data collection (Figure 3). No Scaridae behavioral data was collected. In order to identify the species of Scaridae, along with the coral species Scaridae were consuming, Caribbean fish and coral identification books were referenced (Humann, 1993; Humann & Deloach, 2014). A GoPro was used to practice identifying Scaridae and coral species present in each reef prior to the start of data collection. The GoPro was not used for formal data collection, as the boundaries of the 60m² visual census were unclear in the videos. During the visual census, if a Scaridae species was unknown, its physical description was noted, and after the visual census, the species was confirmed with a laminated copy of the Scaridae section of the
Caribbean fish identification book while in the water. If a coral species being consumed was unknown, it was described in vivid detail in the field notes, and was identified as soon as I returned to shore, with the Caribbean coral identification book. Overall, 360m² of each reef, and 120m² of each depth level within each reef, had Scaridae community structure and feeding preferences evaluated.

**Figure 3.** Image of visual census methodologies used to quantify Scaridae densities, size proportions, and proportions of coral species consumption in 360m² of both fringing and barrier reefs. (A) 60m² visual census over fringing coral reef at 2.1-4.0m depth. (B) *S. iseri* and *N. usta* within 1m either side of transect.

**Statistical Analysis**

To analyze the coral composition data, t-tests were conducted to determine if the percent coverages of sand, algae, sponge, dead coral, fire coral, coral rubble, hard coral, and soft coral, at the same depth levels (0-2.0m, 2.1-4.0m, 4.1-6.0m) within the fringing and barrier reefs, were statistically significantly different. Bar graphs showing the average percent coverages, along with standard deviations, were used to represent this data. To determine whether Scaridae densities, size class proportions, as well as proportions of Scaridae coral species consumption, were statistically significantly different among fringing and barrier reefs at the same depths, chi-square tests for independence were conducted. This data was represented through bar graphs of average densities and proportions, along with standard deviations. The correlation between Scaridae Shannon diversity (H') and substrate variability (CV), across both fringing and barrier reefs, was represented through a scatter plot, and quantified through the R-value of the line of best fit:

\[ H' = \sum_{i=1}^{n} p_i \ln p_i \]

\[ CV = \frac{\sigma}{\mu} \]

**ETHICS**

This study was approved by the Institutional Review Board, and no interviews were conducted during this study. However, prior to conducting my study, I considered the potential negative impacts I could have on the coral reef ecosystems in Guna Yala, and how I could minimize these negative impacts. It was noted that I could negatively impact the coral reefs in Guna Yala by accidentally kicking the coral, using sunscreen that harms coral reefs, and causing stress on marine life within the coral reef ecosystems. In order to prevent these negative impacts,
I remained vigilant, and kept my legs suspended at the top of the water while wearing flippers. Furthermore, I used reef-safe sunscreen to avoid putting extra stress on the coral reefs. Finally, I tried to limit the stress that I could have potentially caused Scaridae, and other living organisms in my areas of study, through my choice of methodology, along with the amount of time I spent in the coral reefs. For instance, I set up my transects for the substrate composition assessment and visual censuses in a timely manner, and was efficient in recording my data. Additionally, the visual census method is considered to be a rapid and nondestructive methodology (Frehse et al., 2020).

RESULTS

Reef Coverage and Scaridae Community Structure and Feeding Preferences 0-2.0m Depth

Fringing and barrier reef substrate coverage was quantified at the 0-2.0m depth level in two 30m² belt transects per reef using a threaded quadrat, as shown in Figure 4. Through this data, differences in the substrate composition at the 0-2.0m depth level are able to be identified, allowing for a comparison of Scaridae community structure and feeding preferences within reefs of varying substrate composition.

![Fringing and Barrier Reef Average Percent Substrate Coverage at 0-2.0m Depth](image)

**Figure 4.** Average percent substrate measured in 60m² of both fringing and barrier reef sites in Anmardub, Guna Yala. Quantified with 1m² threaded quadrat across 2 30m transects at 0-2.0m depth per reef. Error Bars=±1SD, n=60.

There is statistically significantly more sand, t(62)=4.33, p<.001, and dead coral, t(59)=6.47, p<.001, coverage in the fringing reef compared to in the barrier reef. Additionally, there is statistically significantly more sponge, t(85)=4.72, p<.001, coral rubble, t(107)=3.06, p=.0028, fire coral, t(101)=3.77, p<.001, hard coral, t(116)=3.13, p=.0022, and soft coral, t(59)=2.66, p=.010, coverage in the barrier reef compared to in the fringing reef (Figure 4).
Fringing and barrier reef Scaridae species densities were quantified at the 0-2.0m depth level using visual census methodologies in 2 60m² transects per reef, as shown in Figure 5. Through this data, differences in Scaridae abundances are able to be compared in reefs of significantly different substrate composition.

**Figure 5.** Average Scaridae species densities measured in 120m² of both fringing and barrier reef sites in Anmardub, Guna Yala. Quantified through visual census methodology across 2 30m transects at 0-2.0m depth per reef. Error Bars=±1SD, n=184, 164.

There is a statistically significant difference between the Scaridae species densities in the fringing reef and the barrier reef, $X^2$ (4, N=184,164)=52.70, p<.001. The fringing reef has larger densities of *S. iseri* (M=1.22, SD=.45) and *S. rubripinne* (M=.025, SD=.035) compared to in the barrier reef. The barrier reef has higher densities of *N. usta* (M=.66, SD=.18), *S. aurofrenatum* (M=.033, SD=.024), *S. viride* (M=.067, SD=.047) compared to in the barrier reef (Figure 5).

Fringing and barrier reef Scaridae size proportions, based on their lengths, were quantified at the 0-2.0m depth level using visual census methodologies in 2 60m² transects per reef, as shown in Figure 6. Through this data, differences in Scaridae lengths (0-10.0cm, 10.1-20.0cm, 20.1cm+) are able to be compared in reefs of significantly different substrate composition.
Figure 6. Average Scaridae size proportions measured in 120m$^2$ of both fringing and barrier reef sites in Anmardub, Guna Yala. Lengths quantified through visual census methodology across 230m transects at 0-2.0m depth per reef. Error Bars=$\pm$1SD, n=184,164.

The fringing reef has a slightly larger proportion of Scaridae of lengths 0-10.0cm (M=.90, SD=.060), and a slightly larger proportion of Scaridae of lengths 20.1cm+ (M=.037, SD=.039) compared to Scaridae in the barrier reef. The barrier reef has a slightly larger proportion of Scaridae of lengths 10.1-20.0cm (M=.12, SD=.051) compared to in the fringing reef (Figure 6). However, there is not a statistically significant difference between Scaridae size proportions in the fringing and barrier reefs, $X^2(2, N=184,164)=4.64, p=.098$.

The fringing and barrier reef Scaridae proportions of coral species consumption, amongst the Scaridae observed eating, were quantified at the 0-2.0m depth level using visual census methodologies in 260m$^2$ transects per reef, as shown in Figure 7. Through this data, differences in Scaridae feeding preferences are able to be compared between reefs of statistically significantly different substrate composition.
There is a statistically significant difference between the Scaridae coral consumption proportions of the fringing reef and barrier reef, $X^2 (3, N=140,54)=66.55, p<.001$. Larger proportions of Scaridae within the fringing reef consume macroalgae and algal turf on dead coral ($M=.71, SD=.14$) and *S. siderea* ($M=.027, SD=.038$) compared to in the barrier reef. On the other hand, larger proportions of Scaridae within the barrier reef consume macroalgae on coral rubble ($M=.50, SD=.71$) and *P. porites* ($M=.50, SD=.71$) compared to in the fringing reef (Figure 7).

**Reef Coverage and Scaridae Community Structure and Feeding Preferences 2.1-4.0m Depth**

Fringing and barrier reef substrate coverage was quantified at the 2.1-4.0m depth level in two 30m$^2$ belt transects per reef using a threaded quadrat, as shown in Figure 8. Through this data, differences in the substrate composition at the 2.1-4.0m depth level are able to be identified, allowing for a comparison of Scaridae community structure and feeding preferences in reefs of varying substrate composition.
Figure 8. Average percent substrate measured in 60m² of both fringing and barrier reef sites in Anmandub, Guna Yala. Quantified with 1m² threaded quadrat across 2 30m transects at 2.1-4.0m depth per reef. Error Bars=±1SD, n=60.

There is statistically significantly more sand, t(60)=7.78, p<.001, and dead coral, t(59)=8.72, p<.001, coverage in the fringing reef compared to in the barrier reef. On the other hand, there is statistically significantly more algae, t(107)=3.96, p<.001, coral rubble, t(63)=3.21, p=.0021, fire coral, t(84)=3.88, p<.001, and hard coral, t(118)=8.03, p<.001, coverage in the barrier reef compared to in the fringing reef (Figure 8).

Fringing and barrier reef Scaridae species densities were quantified at the 2.1-4.0m depth level using visual census methodologies in 2 60m² transects per reef, as shown in Figure 9. Through this data, differences in Scaridae abundances are able to be compared in reefs of significantly different substrate composition.
**Figure 9.** Average Scaridae species densities measured in 120m² of both fringing and barrier reef sites in Anmardub, Guna Yala. Quantified through visual census methodology across 2 30m transects at 2.1-4.0m depth per reef. Error Bars=±1SD, n=45, 48.

The fringing reef has slightly greater densities of *N. usta* (M=.083, SD=.12) and *S. viride* (M=.017, SD=.024) compared to in the barrier reef. The barrier reef has slightly greater densities of *S. iseri* (M=.33, SD=.41) and *S. aurofrenatum* (M=.017, SD=.023) compared to in the fringing reef (Figure 9). However, there is not a statistically significant difference between Scaridae species densities of the fringing and barrier reefs, $X^2 (3, N=45,48)=4.94, p=.18$.

Fringing and barrier reef Scaridae size proportions, based on their lengths, were quantified at the 2.1-4.0m depth level using visual census methodologies in 2 60m² transects per reef, as shown in Figure 10. Through this data, differences in Scaridae lengths (0-10.0cm, 10.1-20.0cm, 20.1cm+) are able to be compared in reefs of significantly different substrate composition.
The fringing reef has a slightly larger proportion of Scaridae of lengths 10.1-20.0cm (M=.21, SD=.11) and 20.1cm+ (M=.039, SD=.056) compared to Scaridae in the barrier reef. The barrier reef has a slightly larger proportion of Scaridae of lengths 0-10.0cm (M=.93, SD=.026) compared to Scaridae in the fringing reef (Figure 10). However, there is not a statistically significant difference between Scaridae size proportions in the fringing and barrier reefs, $X^2 (2, N=45,48)=5.76, p=.056$.

The fringing and barrier reef Scaridae proportions of coral consumption, amongst the Scaridae observed eating, were quantified at the 2.1-4.0m depth level using visual census methodologies in 2 60m$^2$ transects per reef, as shown in Figure 11. Through this data, differences in Scaridae feeding preferences are able to be compared between reefs of statistically significantly different substrate composition.
There is a statistically significant difference between the Scaridae coral consumption proportions of the fringing and barrier reefs, $X^2 (4, N=20,47)=53.07$ $p<.001$. Larger proportions of Scaridae within the fringing reef consume macroalgae and algal turf on dead coral ($M=.23$, $SD=.33$), *M. alcicornis* ($M=.36$, $SD=.51$), and *S. siderea* ($M=.41$, $SD=.18$), compared to Scaridae in the barrier reef. Additionally, there are larger proportions of Scaridae in the barrier reef at the 2.1-4.0m depth level that consume macroalgae on coral rubble ($M=.50$, $SD=.71$) and *P. porites* ($M=.41$, $SD=.57$) compared to in the fringing reef (Figure 11).

**Reef Coverage and Scaridae Community Structure and Feeding Preferences 4.1-6.0m Depth**

Fringing and barrier reef substrate coverage was quantified at the 4.1-6.0m depth level in two 30m² belt transects per reef using a threaded quadrat, as shown in Figure 12. Through this data, differences in the substrate composition at the 4.1-6.0m depth level are able to be identified, allowing for a comparison of Scaridae community structure and feeding preferences within these reefs of varying substrate composition.
Figure 12. Average percent substrate coverage measured in 60m² fringing and barrier reef sites in Anmardub, Guna Yala. Quantified with 1m² threaded quadrat across 2 30m transects at 4.1-6.0m depth per reef. Error Bars=±1SD, n=60.

There is statistically significantly more sand, t(59)=4.27, p<.001, dead coral, t(59)=4.30, p<.001, and fire coral, t(72)=2.70, p=.0087, coverage in the fringing reef compared to in the barrier reef. Additionally, there is statistically significantly more algae, t(118)=4.58, p<.001, and sponge, t(117)=2.09, p=.039, coverage in the barrier reef compared to the fringing reef (Figure 12).

Fringing and barrier reef Scaridae species densities were quantified at the 4.1-6.0m depth level using visual census methodologies in 2 60m² transects per reef, as shown in Figure 13. Through this data, differences in Scaridae abundances are able to be compared in reefs of significantly different substrate composition.
Figure 13. Average Scaridae species densities measured in 120m² of both fringing and barrier reef sites in Anmardub, Guna Yala. Quantified through visual census methodology across 2 30m transects at 4.1-6.0m depth per reef. Error Bars=±1SD, n=96, 107.

The fringing reef has slightly greater densities of *S. iseri* (M=.44, SD=.48) compared to the barrier reef. On the other hand, the barrier reef has slightly greater densities of *N. usta* (M=.46, SD=.65), *S. rubripinne* (M=.0083, SD=.012), *S. aurofrenatum* (M=.025, SD=.012), and *S. viride* (M=.05, SD=0), compared to in the fringing reef (Figure 13). However, there is not a statistically significant difference between Scaridae species densities of the fringing and barrier reefs, $X^2(4, N=96,107)=6.42, p=.17$.

Fringing and barrier reef Scaridae size proportions, based on their lengths, were quantified at the 4.1-6.0m depth level using visual census methodologies in 2 60m² transects per reef, as shown in Figure 14. Through this data, differences in Scaridae lengths (0-10.0cm, 10.1-20.0cm, 20.1cm+) are able to be compared in reefs of significantly different substrate composition.
Figure 14. Average Scaridae size proportions measured in 120m² of both fringing and barrier reef sites in Anmardub, Guna Yala. Lengths quantified through visual census methodology across 2 30m transects at 4.1-6.0m depth per reef. Error Bars=±1SD, n=96, 107.

The fringing reef has slightly larger proportions of Scaridae of lengths 20.1cm+ (M=.14, SD=.15) compared to Scaridae in the barrier reef. The barrier reef has slightly larger proportions of Scaridae of lengths 0-10.0cm (M=.74, SD=.21) and 10.1-20.0cm (M=.14, SD=.12) compared to Scaridae in the fringing reef (Figure 14). However, there is not a statistically significant difference between Scaridae size proportions in the fringing and barrier reefs,  $X^2$ (2, N=96,107)=1.55, p=.46.

The fringing and barrier reef Scaridae proportions of coral species consumption, amongst the Scaridae observed eating, were quantified at the 4.1-6.0m depth level using visual census methodologies in 2 60m² transects per reef, as shown in Figure 15. Through this data, differences in Scaridae feeding preferences are able to be compared between reefs of statistically significantly different substrate composition.
Figure 15. Average Scaridae coral species consumption proportions measured in 120m$^2$ of both fringing and barrier reef sites in Anmardub, Guna Yala. Proportions quantified through visual census methodology across 2 30m transects at 4.1-6.0m depth per reef. Error Bars=±1SD, n=76, 94.

There is a statistically significant difference between the Scaridae coral consumption proportions in the fringing and barrier reefs, $X^2 (6, N=76,94)=108.74, p<.001$. Larger proportions of Scaridae in the fringing reef consume macroalgae and algal turf on dead coral (M=.40, SD=.39), *M. alcicornis* (M=.015, SD=.021), and *Agaricia tenuifolia* (M=.13, SD=.18), than Scaridae in the barrier reef. Additionally, there are larger proportions of Scaridae in the barrier reef that consume macroalgae on coral rubble (M=.15, SD=.21), *P. porites* (M=.80, SD=.14), *Diplora strigosa* (M=.025, SD=.035), and *Montastraea annularis* (M=.025, SD=.035) compared to in the fringing reef (Figure 15).

**Correlation of Reef Substrate Variance and Scaridae Shannon Diversity**

The fringing and barrier reef Scaridae Shannon diversities, accounting for richness and evenness, at each depth level of each reef were calculated based on Scaridae species abundances. These Shannon diversity values were compared to the coefficients of variance calculated for each reef at each depth level. With this data, the correlation between reef substrate variance and Scaridae Shannon diversity is able to be quantified through an R-value, as shown in Figure 16.
Figure 16. Shannon diversity Scaridae values plotted as a function of reef substrate coefficients of variance at each depth level of fringing and barrier reefs in Anmardub, Guna Yala, n=6.

There is a weak positive correlation between Scaridae Shannon diversity and reef substrate coefficients of variance, $R^2=.0057$, $F(5)=.023$, $p=.89$ (Figure 16). Thus, Scaridae community structure becomes increasingly diverse as reef substrate variability increases.

Sources of Error

Throughout this study, there were potential sources of error. For instance, the transects for both the coral composition and Scaridae visual census data collection in both reefs may not have been set up exactly parallel to shore, and may not have remained straight due to presence of currents and substrate. There was bad visibility when collecting coral coverage and Scaridae visual census data in the barrier reef for one of the transects at the 2.1-4.0m depth level. When collecting coral coverage data, the 1m$^2$ threaded quadrat was weighed down with rebar, but at times shifted due to waves, which could have affected the coral coverage data collection. When collecting Scaridae visual census data, Scaridae may have not been counted, or they may have been counted multiple times.
DISCUSSION

*Reef Substrate Composition*

Across all three depth levels (0-2.0m, 2.1-4.0m, 4.1-6.0m), the fringing reef has significantly higher percentages of sand and dead coral coverage compared to in the barrier reef, indicating a rejection of the null hypothesis. On the other hand, the barrier reef has significantly higher percentages of hard coral coverage at the 0-2.0m and 2.1-4.0m depth levels compared to in the fringing reef, also resulting in a rejection of the null hypothesis. Generally, it can be argued that the barrier reef is both healthier and more consistent compared to the fringing reef at these depth levels. This may be because the fringing reef is more affected by tourism, as it is only 30m from the coast of Anmardub, a tourist island, while the barrier reef is 300m from shore. Intensive tourism can have detrimental impacts on coral coverage, as through a study conducted in Akmal, Mexico, it was estimated that from summer 2011 to summer 2014, when monthly snorkelers increased by 400 percent, coral cover decreased by 79 percent (Gil et al., 2015).

However, it is also important to note that the barrier reef has significantly higher percentages of algal coverage at the 2.1-4.0m and 4.1-6.0m depth levels compared to in the fringing reef. This may be because the barrier reef is more affected by fishing practices, as observed throughout my data collection. For example, as indicated through an overfishing simulation experiment, herbivore exclusion can increase algal cover up to sixfold (Zaneveld et al., 2016). Thus, Scaridae populations in the fringing reef are potentially able to better retain macroalgal populations, as there is lower hard coral coverage and less fishing, while Scaridae populations in the barrier reef are less capable of retaining macroalgal populations, as there is higher hard coral coverage, and a presence of fishing practices. Overall, the reef substrate composition data indicates a more consistent and healthier barrier reef with high algal cover, potentially due to fishing practices and lack of tourism, and an inconsistent and less healthy fringing reef, potentially due to the impact of tourism and lack of fishing practices.

*Reef Substrate Composition Relationship with Scaridae Community Structure*

Scaridae species densities differ significantly between fringing and barrier reefs at the 0-2.0m depth level, thus indicating there is a relationship between substrate composition and Scaridae species densities at shallow depths, and a rejection of the null hypothesis. At this depth level, there are higher densities of *S. iseri* and *S. rubripinne* in the fringing reef, or in the inconsistent and less healthy reef, and higher densities of *N. uesta*, *S. aurofrenatum*, and *S. viride* in the barrier reef, or in the consistent and healthier reef.

These results are comparable to previous research, as *S. iseri* and *S. rubripinne* juveniles, which are more frequently observed than adults throughout the study, are commonly associated with seagrass beds (Dromard et al., 2017; León et al., 2022). Thus, it makes sense that *S. iseri* and *S. rubripinne* juveniles would exist in higher densities at the 0-2.0m depth level of the fringing reef, as there are seagrass beds interspersed within the fringing reef at this depth level. Furthermore, previous research indicates that *S. aurofrenatum* and *S. viride* are associated with hard coral, as they are both coral predators (Miller & Hay, 1998). This makes sense, as *S. aurofrenatum* and *S. viride* are found in higher densities in the shallow barrier reef, where there is significantly higher hard coral coverage than in the fringing reef. On the other hand, based on previous research, *N. uesta* also associate with seagrass beds, yet there are higher densities of *N. uesta* in the barrier reef compared to in the fringing reef (Prado & Heck Jr., 2011).
Scaridae species size proportions do not differ significantly between fringing and barrier reefs at any depth levels, thus indicating there is no relationship between substrate composition and Scaridae sizes, and a non-rejection of the null hypothesis. Across all depth levels and reefs, there are higher averages of Scaridae of lengths 0-10.0cm, indicating that there are generally larger abundances of small Scaridae in both fringing and barrier reefs. According to previous research, the majority of Scaridae populations are of lengths <11cm Caribbean-wide, primarily as a result of fishing practices. This Scaridae size restriction can have negative influences on coral reef ecosystems, as smaller Scaridae are not able to retain microalgal growth as successfully as larger Scaridae (Shantz et al., 2020).

Across all depths of fringing and barrier reefs, there is a weak positive correlation between substrate variability and Scaridae species diversity, indicating a rejection of the null hypothesis. This data demonstrates that when more substrate types are available, different species of Scaridae are able to coexist. Unfortunately, there are no previous studies regarding the influence of substrate variability of Scaridae diversity specifically.

While not many studies within the Caribbean discuss the relationship between substrate variability and species diversity, research conducted in Hawaii suggests that habitats of higher levels of complexity have larger fish abundances. In fact, fish abundances, in these high complexity habitats, can exceed up to 2 times the levels supported by primary production. Furthermore, this study suggests that half of fish biomass variance can be explained by habitat complexity alone, which emphasizes the influence of the environment on fish (Grigg, 1994). Additionally, according to a previous study conducted in the Northeast Atlantic, 40 percent to 56 percent of changes in overall marine species richness can be explained by variance in the environment. During this study, species richness was assessed in flank and summit ecosystems, in which the flank ecosystem experienced high substrate and oceanographic variance, while the summit ecosystem did not. Interestingly, the flank ecosystem had more sponges, antipatharins, solitary corals, and reef building corals, in comparison to the summit ecosystem, indicating that species composition is influenced by environmental variability (Henry et al., 2014). Overall, as indicated by previous research and the study conducted, habitats of greater variability can support a greater diversity of species of marine life, such as Scaridae, compared to habitats of lower variability.

Reef Substrate Composition Relationship with Scaridae Feeding Preferences

Scaridae coral species consumption proportions differ significantly between fringing and barrier reefs at all depth levels (0-2.0m, 2.1-4.0m, 4.1-6.0m), indicating that there is a relationship between substrate composition and Scaridae feeding preferences, and a rejection of the null hypothesis. In the fringing reef, or the inconsistent and less healthy reef, there are larger proportions of Scaridae consuming macroalgae and algal turf on dead coral compared to in the barrier reef. In the barrier reef, the more consistent and healthier reef, there are larger proportions of Scaridae consuming macroalgae on coral rubble and *Porites*, the most prevalent hard coral species across all reefs, in comparison to in the fringing reef.

This data indicates that in the fringing reef, where there is lower coverage of macroalgae and hard coral, compared to in the barrier reef, Scaridae prefer to eat macroalgae and algal turf on dead coral. This may be due to the fact that dead coral has a significantly higher coverage in the fringing reef compared to in the barrier reef, and thus it is an abundant substrate available to Scaridae in the fringing reef that fosters macroalgal and algal turf growth. This finding is similar to previously published research conducted in Curacao, in which the majority, 68.10 percent, of
the reef of study consisted of turf algal cover on dead coral substrate. Within this reef, 80 percent of herbivorous fish bites were taken from the dead coral substrate covered with turf algae (Vermeij et al., 2013). Like in these previous studies, the results indicate that Scaridae prefer to feed on turf algae on dead coral when it is highly abundant in the reef ecosystem.

This data also indicates that in the barrier reef, where there is higher coverage of macroalgae and hard coral, compared to in the fringing reef, Scaridae prefer to feed on macroalgae on coral rubble and *P. porites*. This is likely because these substrates, which also foster macroalgal growth, are more available to Scaridae in the barrier reef. According to previous research, there is evidence that Scaridae prefer to feed on macroalgae and algal turf on dead coral and coral rubble in comparison to living hard coral (Bruggemann et al., 1994). Due to the fact that there is significantly lower coverages of dead coral in the barrier reef compared to in the fringing reef, dead coral is likely not as available for Scaridae to feed on. However, there is significantly greater coral rubble coverage in the barrier reef at the 0-2.0m and 2.1-4.0m depth levels compared to in the fringing reef, and no statistically significant difference in coral rubble coverage at the 4.1-6.0m depth level in the barrier reef compared to in the fringing reef, making coral rubble a more available substrate for Scaridae to feed on. As a result of this, Scaridae consumption of macroalgae on coral rubble is prevalent in the barrier reef. On the other hand, previous research indicates that Scaridae consumption of macroalgae on *P. porites* is uncommon within the depth levels tested (Frydl, 1979).

**CONCLUSION**

Upon analyzing the results, the sand, dead coral, sponge, coral rubble, fire coral, hard coral, and soft coral substrate percent coverages of Amnardub fringing and barrier reefs at the 0-2.0m depth level significantly differed, resulting in a rejection of the null hypothesis. At this depth level, Scaridae species densities and Scaridae coral species consumption proportions differed significantly between reefs, indicating a rejection of the null hypothesis, while Scaridae size proportions did not significantly differ, resulting in a non-rejection of the null hypothesis. At the 2.1-4.0m depth level, sand, dead coral, algae, coral rubble, fire coral, and hard coral substrate percent coverage significantly differed between fringing and barrier reefs, resulting in a rejection of the null hypothesis. At this depth level, Scaridae densities and size proportions did not significantly differ between reefs, resulting in a non-rejection of the null hypothesis, while Scaridae coral species consumption proportions significantly differed, resulting in a rejection of the null hypothesis. At the 4.1-6.0m depth level, sand, dead coral, fire coral, algae, and sponge percent substrate coverage significantly differed between fringing and barrier reefs, resulting in a rejection of the null hypothesis. At this depth level, Scaridae densities and size proportions did not significantly differ between reefs, resulting in a non-rejection of the null hypothesis, while Scaridae coral species consumption proportions significantly differed, resulting in a rejection of the null hypothesis. There is a weak positive correlation between substrate variability and Scaridae Shannon diversity across both reefs, resulting in a rejection of the null hypothesis.

Based upon the coral coverage data, the fringing reef is inconsistent and less healthy compared to the barrier reef, as the fringing reef has significantly higher percentages of sand and dead coral coverages at all depth levels, and the barrier reef has significantly higher percentages of hard coral coverage at the 0-2.0m and 2.1-4.0m depth levels. There is a relationship between reef substrate composition and Scaridae species densities at the 0-2.0m depth level, as there are significantly greater densities of *S. iseri* and *S. rubripinne* in the fringing reef, and significantly
greater densities of *N. usta, S. aurofrenatum,* and *S. viride* in the barrier reef. There is no relationship between the substrate composition of reefs and Scaridae size proportions, which may be a result of overfishing of large Scaridae. There is a weak positive correlation between substrate variability and Scaridae Shannon diversity, indicating that more Scaridae species live in habitats consisting of more substrate varieties. At all depth levels, there is a relationship between reef substrate composition and Scaridae coral consumption proportions, as significantly greater proportions of Scaridae consume macroalgae and algal turf on dead coral in the fringing reef, while significantly greater proportions of Scaridae consume macroalgae on coral rubble and *P. porites* in the barrier reef.

Throughout this research project, I focused on the community structure and feeding preferences of Scaridae in reefs of varying substrate composition in Anmardub, Guna Yala. However, I did not collect behavioral data on Scaridae. Interestingly, throughout my study, I observed Scaridae scraping their heads on sand without consuming anything. Thus, for future research, I would recommend collecting data on which Scaridae species tend to exhibit this behavior, and within which contexts these species exhibit this behavior. Furthermore, as recorded through my visual census data, Scaridae consume bleached *M. alcicornis* at 2.1-4.0m and 4.1-6.0m depth levels within both fringing and barrier reefs. Fire corals contain nematocyst cells in their epidermis as a form of protection from predation, yet in my study, along with in other studies, Scaridae have been observed scraping fire coral (Garcia et al., 2009; Littler et al., 1987). Thus, future research should focus on whether bleaching takes away fire corals’ ability to sting Scaridae, along with the thickness of algal tufts growing on fire coral, as this data could indicate Scaridae’s motivation to consume algae on fire coral.
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