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Averyl Cheng
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Avery Cheng
Carleton College
School for International Training
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I. Abstract

In Bocas del Toro, Panamá, widespread tourism has been the main source of revenue and has become an increasing threat to seagrass meadows and the organisms they support. This study aimed to investigate and describe algae and diatom communities under three different regimes of anthropogenic disturbance: high, medium and low human impact. The biodiversity was analyzed by measuring the algae and diatom assemblages with Shannon-Weiner's Biodiversity Index, Evenness Index and Sorensen's coefficient. The data obtained from these three diversity indices were compared to the areas along an anthropogenic disturbance gradient of high, medium and low impact. A total of 12 species of algae and 25 genera of diatoms were found using the marine belt transect and quadrat method in triplicate for each site. Analysis showed that in the site with high human impact, the seagrass density was significantly lower, while algae biodiversity and abundance, and diatom biodiversity, were significantly higher. This study demonstrated that algae and diatom communities do, in fact, change in differing human impact sites. Thus, algae and diatoms can be accurate bioindicators of water quality and can be used to limit human impact on seagrass meadows.

II. Acknowledgements

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III. Introduction

Seagrass Ecosystems and its Threats

Seagrass meadows are vascular plants that make up one of the most productive and dynamic ecosystems in the world. Seagrass supports the global economy by stabilizing the ocean floor, preventing erosion or further damages to homes and ecosystems from storms, and providing thousands of fish, invertebrates and bird species with habitats, food, and nurseries (Orth et al. 2006). Commercial fisheries linked to seagrass are worth as much as US$3,500 per hectare globally every year. Despite the high-value ecosystem services it provides, seagrass meadows are highly undervalued for their importance in marine habitats and ecosystems and are currently subject to dangerous threats due to anthropogenic disruption (Waycott et al. 2009).

From 1879, 29% of the global studied areal extent containing seagrass have disappeared, and seagrass around the world are still declining at a rate of $110km^2$/year (Waycott et al. 2009). The rapid decline has mainly come from global climate change, nutrient pollution, physical manipulation and overexploitation of humans; all of which are serious threats to biodiversity (Wachnicka et al. 2012; Waycott et al. 2009). Eutrophication, another serious threat to seagrass abundance, is the process in which pollutants create imbalances within an established ecosystem. In seagrass habitats, additional nutrients cause an exponential growth of algae, thereby blocking the sunlight from seagrass, causing a reduction of photosynthesis and displacement of vascular plants (Valiela et al. 1997). Indirect and direct nutrient enrichment not only cause an accelerated seagrass loss, but may also lead to the replacement of seagrass by coarse-grained deposits and opportunistic algae (Cardoso et al. 2004; Han et al. 2016).

Site Description

The province of Bocas del Toro is located in the western region of Panamá, bordering the Caribbean Sea in the north, Costa Rica in the west and the province of Chiriquí in the south. Bocas del Toro has a land area of approximately 8917 km^5 and is estimated to have 68% of its land area covered in tropical rainforest (Guzman et al. 2005). Bocas del Toro receives approximately 2890mm of rainfall annually. Although there is no distinct rainy or dry season, there are two periods of high rainfall and two periods of low rainfall throughout the year. Bocas del Toro also encompasses an archipelago, many of which provide shallow water habitats for mangrove forests, seagrass meadows and coral reefs (Guzman et al. 2005). Vast seagrass meadows are mostly found in reef lagoon areas, where the dominating seagrass species is *Thalassia testudinum*, commonly known as sea turtle grass (Cruz-Palacios and Van Tussenbroek 2005). Other seagrass species such as *Halodule wrightii* and *Syringodium filiforme,* commonly known as shoal and manatee grass, may co-occur and dominate in some areas of Panamá (Biber et al. 2004). *T. testudinum* is an important habitat-forming seagrass species and remains relatively robust in areas of disturbance. A seagrass individual is typically comprised of a horizontal rhizome and several vertical vegetative shoots that inhabit the intertidal zone and provide for appropriate substrate for epiphytes (Hays 2004).

Since Bocas del Toro is highly popular for local and international tourists to visit, it is now considered to be a development priority zone. With more tourists, transportation as well as the recreational use of coastal resources would be employed more often, causing even greater damage to the seagrass ecosystems (Guzman et al. 2005). In addition to inadequate management of these coastal habitats, the rapid deforestation and pollution input would decrease the resilience of seagrass. Specifically in Bocas de Toro, seagrass are heavily impacted and influenced by their local surrounding ecosystems such as coral reefs, mangroves and coastal rivers (Guzman et al. 2005). *T. testudinum* living in coral reefs typically have short leaves and low amounts of epiphytes, while seagrasses inhabiting

mangrove habitats have long leaves but moderate amount of epiphytes. Those in fluvial habitats generally have long leaves and high amounts of epiphytes (Beltrones and Castrejón 1999). These local ecosystems also affect the sediment deposition and water clarity, both of which are vital factors in maintaining seagrass occurrence and abundance (Guzman et al. 2005).

Macroalgae and their Significance

There are two primary producers that closely interact with seagrass: macroalgae, which are rooted in the soil and live beside the seagrass, and epiphytic microalgae, which are much smaller organisms that reside on seagrass leaf blades (Han et al. 2016). Some genera of macroalgae are rhizophytic including genera *Caulerpa*, *Penicillus*, and *Halimeda*, and help stabilize sediments in seagrass meadows, while other genera, including genera *Chondria*, *Gracilaria*, and *Dictoyta*, are detached and drift among the seagrass (Biber et al. 2004). Epiphytes, including the epiphytic microalgae, typically serve as food for herbivores. However, in otherwise healthy habitats, algae are important to the seagrass ecosystem and add to the complexity of the food web in both structure and function, as they serve as alternate food sources for herbivores (Río 2016).

Both top-down controls, such as herbivory, and bottom-up controls, such as light, salinity, nutrients and temperature conditions, are factors algal populations are stressed and impacted by. However, the importance of biotic and abiotic factors that control the composition and abundance of macroalgae components in seagrass remains largely undetermined. Seagrass typically dominate macroalgae when there are low nutrient concentrations in marine ecosystems because seagrass' roots and rhizomes are able to absorb nutrients in the sediment more efficiently (Biber et al. 2004; Han et al. 2016). With nutrient rich environments, this relationship is reversed. Though the seagrasses are able to absorb nutrients through their leaves, algae are able to more effectively absorb nutrients through the thallus, and thus dominate in more nutrient rich environments. Shifts in dominating populations dramatically changes ecosystem dynamics. Benefits that algae bring to the benthic fauna include habitat enhancement, food, and shelter. However, these benefits are only temporary, as they are highly seasonal and algal mats can shift position on the flats from exposure to wind and waves (Cardoso et al. 2004). In addition, the shading of seagrass by macroalgae lead to reduced shoot densities, slower growth rates and overall seagrass production decline (Han et al. 2016). Regarding top-down control, grazing rates by herbivores typically keep macroalgae and phytoplankton populations at a minimum, as macroalgae lack the chemical protection that many vascular plants have, making algae more desirable to eat compared to seagrasses (Valiela et al. 1997).

Epiphyte Communities

While macroalgae are constantly competing with seagrass for light, space and nutrients, epiphytic and microphytobenthic algae assemblages compete for nutrients in the water column and are thus more favorable towards the seagrass. These epiphytes are of great importance to seagrasses, as they represent more than half (62%) of seagrass bed primary production (Lebreton et al. 2011). The epiphytic biota community in *T. testudinum* is mostly comprised of coralline algae, foraminifera, diatoms, and a variety of taxa including sponges, worms, brittle stars and gastropods. An epiphytic community succession takes place on the blade of *T. testudinum*, where the basal diatom community first colonizes the blade and is then covered by the coralline algae community which is then covered by a community of larger taxa (Corlett and Jones 2006). In waters with high nutrient input, such as seagrass in close proximity to mangroves, brown algae would grow on the seagrass blades instead of the typical coralline algae. Since diatoms are the first epiphytic biota to colonize seagrass blades,

they are considered 'pioneer plants'. Pioneer plants create suitable environments for coralline algae and other epiphytic taxa to further colonize the seagrass blade (Corlett and Jones 2006). These diatoms are a type of epiphytic microalgae that reside on seagrass blades. They are also one of the most important algae groups because of their ability to be ecological indicators of water quality in marine ecosystems (Bellinger et al. 2006).

Diatoms and their Significance

With more than 100,000 species, diatoms are microscopic phytoplankton that carry out approximately 20% of the photosynthesis in the world (Armbrust 2009). Diatoms are distinct because their cell wall is made of silica called a frustule. Since their main limiting factor is silicon, they are not competing for nitrogen and phosphorous, which many other organisms need and are limited by. Their unique characteristics allow them to be main players of many biogeochemical cycles including carbon, nitrogen, phosphorus, silicon and iron. Although taxonomic studies of benthic diatoms are still lacking in some tropical and sub-tropical regions, diatoms have recently become the primary focus for monitoring purposes due to the frustules' ability to be preserved in sediments for historical reconstruction, their rapid response to stress, and the extensive knowledge of the narrow tolerance ranges for a large number of species (Beltrones and Castrejón 1999; Berllinger et al. 2006; Giorgio et al. 2016). Diatoms, along with macroalgae, tend to dominate in naturally-occurring high-nutrient environments, but are less abundant in low-nutrient environments due to their relatively low surface to volume body ratio. Smaller phytoplankton, in contrast, have higher surface to volume body ratios, making them more efficient in exploiting areas with low amounts of nutrients (Sarthou et al. 2005). As epiphytes, diatoms reside on seagrass blades as monospecific colonies, which are colonies attached to each other by their girdles, or in detached colonies that have several species of a single genus (Corlett and Jones 2007).

Diatoms are also main food sources for benthic grazers such as sea urchins, fish, gastropods, crustaceans, mammals and waterfowls. They are key players in energy flow from seagrass habitats to coral reefs, due to the lack of food and protection for juvenile fish in coral reefs (Valentine and Heck 1999). Without diatoms and epiphytes, there will be no food for herbivores in seagrass beds as epiphytes serve as their main food source. Seagrass itself has poor nutritional value and is made up of cellulose, which fish are unable to metabolize. Consequently, herbivorous fish desire to eat just the epiphytes, eating the seagrass solely as a means for consuming the epiphytes. These fish even select for seagrass leaves that only have an abundant amount of epiphytes and diatoms (Río 2016). Diatoms are not only able to adapt to local environmental changes and become tolerant to drought and low light conditions, but they are also able to respond strongly to large-scale climatic variables and fluctuations such as rising sea levels and changing mean annual temperatures by finding suitable habitats and having efficient nutrient uptake (Pajunen et al. 2016).

Changes in Diatom and Algae Communities

Due to their significance in seagrass ecosystems, diatoms as well as algae are deeply affected by human disturbances, especially tourism. In Panamá, tourism's total contribution to the GDP was $7,780 million dollars, which is around 17.5% of the GDP in 2014, and is expected to rise by a total of 5.0% in 2025 (World Travel and Tourism Council 2015). Diatoms are greatly affected by heavy metal stress resulting in deformities and alterations in morphology, structure and chemical compounds (Gautam 2016). It is well-known that benthic algae abundance and composition changes according to nitrogen and phosphorus availability. In diatom assemblages, eutrophication due to anthropogenic disturbances increases the proportion of tolerant species, the proportion of nitrogen-heterotroph species, and the proportion of motile forms. These assemblages are also relatively sensitive to nutrient

conditions. Diatoms are able to adapt to their environment, change community composition and alter their relative abundance to the new conditions (Licursi et al. 2016). Their ability to quickly adapt to their given environment helps researchers predict the effects of increased nutrients in various ecosystems (Valiela et al. 1997).

In algae, accelerated blooms and unusual succession between the phytoplankton species are results of human disturbance and nutrient input (Zhou 2016). The increase of tourism could lead to the loss of algae, diatom and seagrass populations and could substantially decrease the marine primary production around Panamá. Without these primary producers, there will be less food, and less energy for primary consumers and, consequently, the whole marine trophic web. This results in smaller fish, gastropod, and crustacean populations, and causes a decrease in food resources for those dependent on fisheries (Valentine and Heck 1999). The interconnected nature of seagrass ecosystems with the rest of marine life makes diatoms and algae equally as influential towards the environment and humans as seagrass (Giorgio et al. 2016).

Further Research

The seagrass meadow is a multifaceted, intertwined ecosystem and is the basis of a complex food web. Most research about algae and diatoms have been in lakes and freshwater ecosystems. Therefore, this study describes how the composition and abundance of periphytic plants including algae and diatoms in seagrass beds differ in distinctive sites of anthropogenic disturbances in the ocean. Further research regarding seagrass ecosystems need to be conducted so researchers are able to raise concerns about the conditions of marine ecosystems in Panamá, suggest future studies, and hopefully influence conservation policies (Lebreton et al. 2011).

IV. Research Question
What are the benthic algae and diatom community composition and abundance in seagrass meadows under three different human impact regimes in Playa Estrella, Bocas del Toro?

V. Methods and Materials
This research was conducted in three different sites along Playa Estrella on Isla Colon, the main island of Bocas del Toro. The three sites included: a site with low human impact, a site with medium human impact and a site with high human impact. Four main sets of data were collected for each site: seagrass shoot density, leaf blade height, and water turbidity were collected to characterize each site, while the abundance and composition of algae and diatoms were collected to understand the patterns of community distribution under these different regimes of human impact. To ensure environmental well-being, this study was approved by the Institutional Review Board (IRB). In order to randomize my methods and site selection, I swam in a random direction, for a random distance and dropped the beginning quadrat on a seagrass meadow without bias at each site (Kirkman 1995).

Seagrass Density

Two 30cm by 30cm subquadrats were taken on a 1m by 1m gridded quadrat placed along a 10m by 1m transect. For each site, this band transect was done three times; all of which ran parallel to the shore. In each of the two subquadrats, only *Thalassia testudinum* seagrass shoots were counted (Kirkman 1995). These counts were recorded on a fully equipped clipboard. Then, the average of the 30cm by 30cm subquadrat data was extrapolated to a square meter, resulting in the density of seagrass of the given area. To

compare the density of the three sites and to see if they were significantly different from each other, a t-test between each site was performed (Phillips and McRoy 1990).

Water Turbidity and Leaf Blade Height

In order to measure the water turbidity, a Secchi-disk was utilized to characterize each site. The Secchi-disk was lowered into the water at a depth of 0.30m and a measuring tape was drawn out from the disk until the disk is no longer visible. The length of the rope was then measured and recorded (Borkman and Smayda 1998).

The seagrass leaf blade height was recorded to characterize each site. For each of the three sites, three 20cm by 10cm quadrats were pegged down and five *Thalassia testudinum* shoots in the quadrat were cut and placed in a plastic bag (Kirkman 1995). The collected shoot was then separated into individual blades and the height of each blade was measured. To compare the leaf blade height of the three sites and to see if they were significantly different from each other, a t-test between each site was performed (Phillips and McRoy 1990).

Algae Composition and Abundance

Two 30cm by 30cm subquadrats on a 1m by 1m gridded quadrat was placed along a 10m by 1m transect in order to count and identify all the algae by species (Littler et al. 1989). These counts were recorded on a fully equipped clipboard. For each site, the belt transect method was repeated three times; all of which ran parallel to the shore (Kirkman 1995). The algae abundance was calculated through density, while the composition of algae was analyzed through the Shannon-Weiner biodiversity and evenness index, and the similarity index was analyzed through Sorensen's coefficient index. Then the average of the 30cm by 30cm subquadrat data was extrapolated to a square meter, resulting in the density of algae of the given area. Both the differences in algal biodiversity and density between each site were analyzed using a t-test (Phillips and McRoy 1990).

Diatom Composition and Abundance

For each of the three sites, three 20cm by 10cm quadrats were pegged down and five *Thalassia testudinum* shoots in the quadrat was cut and placed in a plastic bag (Kirkman 1995). For diatom identification, the seagrass shoots collected were separated into individual blades and were observed under a compound microscope. Epiphytic diatoms on the seagrass were identified using an identification key of genera (Hasle et al. 1996; Beltrones and Castrejon 1999). To ensure efficiency and accuracy, it was assumed that there was an even distribution of genera between all the shoots in each site. Only the presence of a unique genus was recorded in each blade. The composition of diatoms was analyzed through the Shannon-Weiner biodiversity and evenness index, while the genera similarity was analyzed through Sorensen's coefficient. Once all the genera were identified, the sensitivity and tolerance to pollution was determined (Bellinger et al. 2006; Bathurst et al. 2010) Then the abundance of diatoms was obtained through the percent cover of diatoms on each blade (Phillips and McRoy 1990). For analysis, differences in diatom diversity and percent cover was tested using a t-test between all three sites (Phillips and McRoy 1990).

VI. Results

In the three different sites of Bocas del Toro, a total of 155 individuals of algae and 188 present genera in each diatom blade were recorded, including 12 species of macroalgae and 25 genera of diatoms. Using t-test, the high impact site had significantly greater seagrass density and significantly longer leaf blade height than the medium and low impact sites. The

high impact site had the lowest water turbidity of 0.84m and the greatest depth of 3.25m among the three sites. The low impact site had the highest water turbidity (2.40m) and a depth of 1.5m. For the medium impact site, the water turbidity was 1.06m and the depth was 0.97m, making it the shallowest site (Table 1).

Site Descriptions

Figure 1. Satellite image of all three sites. All three sites were more than 200 meters apart, to ensure that they were distinct and would not overlap.

Site 1:

This site was located on Starfish Beach, a very well-known attraction for numerous tourists who want to see starfish. Numerous restaurants, bars and bathrooms are stationed along the beach with many boats parked on the shore. The water is very calm, as most of the waves head south-east and a land mass was blocking the waves from hitting Starfish Beach. This site was classified as having "high" human impact.

Site 2:

This site was located 100m from a shore clearing that tourists would periodically go to. There is only one restaurant located inland of the clearing. This site was most exposed to waves and currents, and had boats parked next to the beach intermittently. This site was classified as having "medium" human impact.

Site 3:

This site was located in the middle of a narrow 20-minute walking trail to Starfish Beach. Along this site there are no direct boat or human activity, as it mostly had mangrove and palm cover with shallow waters. There was little exposure to waves, mainly coming from waves generated by boats farther out shuttling people to and from Starfish Beach. This site was classified as having "low" human impact.

Algae Composition and Abundance

The high, medium and low human impact sites had significantly different algae biodiversity and density. More specifically, the high impact site had significantly greater species biodiversity (1.039 ± 0.314) than the low and medium impact sites. Regarding the medium impact site, it had significantly higher species biodiversity (0.709 ± 0.274) than the species biodiversity in the low impact site (0 ± 0) (Table 2). As for abundance, the high impact site also had significantly higher algal density than the other two impact sites, with an average of 31.19 algal per m^2 (Table 2).

Both the high impact and medium impact site had 7 algal species found at each site with similar evenness while the low impact site had no species found (Table 2). Despite having similar numbers of species, the three sites were relatively unique from each other in terms of algal species. Out of the 12 species found, only 2 species were common in both sites (Table 3). *Halimeda tuna* was the most commonly found algal species in the medium impact site while *Asparagopsis taxiformis* was the most abundant species in the high impact site (Figure 3). Between these two sites, *Rosenvingea sanctae-crucis* was the most abundant common species found.

Figure 2. Algae species (from left to right): *Halimeda tuna, Spyridia hypnoides, Chondria littoralis, Sargassum polyceratium, Rosenvingea sanctae-crucis*
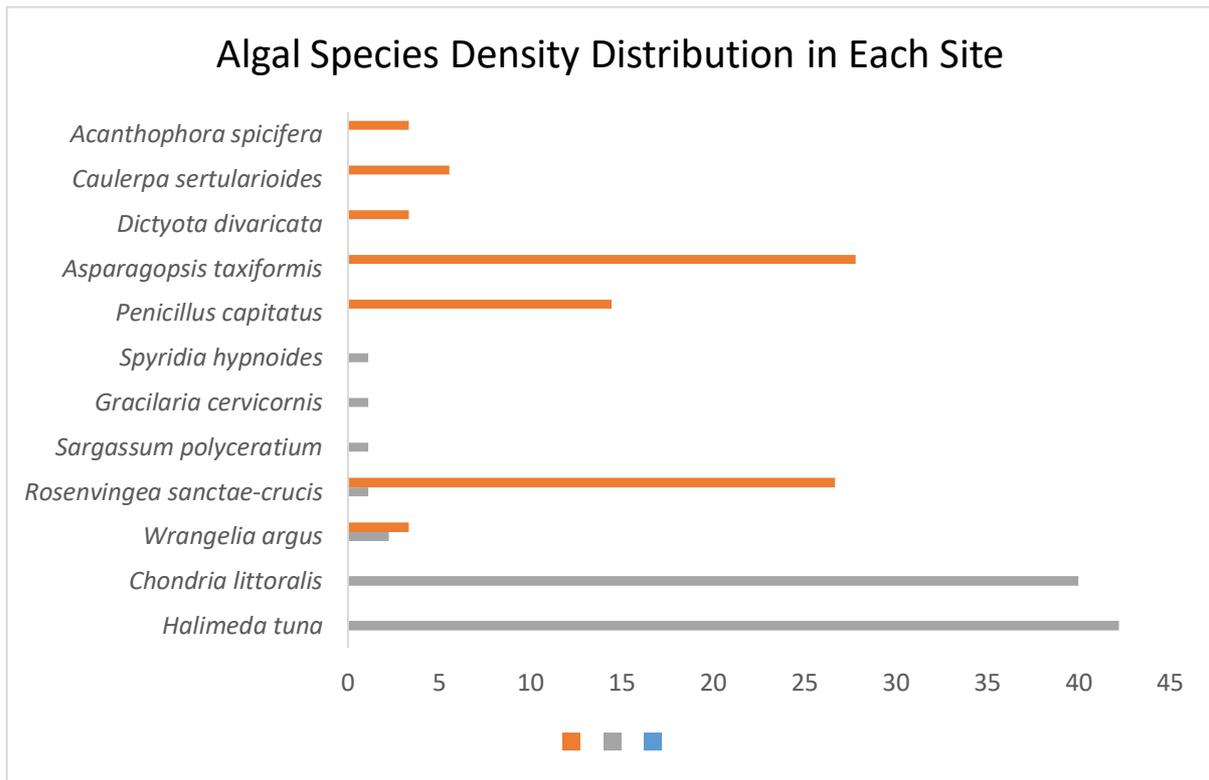
Figure 3. Relative abundance through a measure of density of algal species found.

Diatom Composition and Abundance

      Among the three sites, genera biodiversity was significantly different. With 25 genera found, the high impact site had the greatest genera biodiversity, evenness as well as richness and composition. However, biodiversity for the high impact site (2.558 ± 0.135) was only significantly higher than for the low impact site (1.612 ± 0.56). Yet, there was no significant difference in biodiversity between the high and medium impact site (2.158 ± 0.404). The medium and low impact site had slightly lower numbers of genera present—17 and 14 genera respectively. The percent cover of diatoms in each blade was also the highest in the high impact site, but there was no significant difference between the three sites, with an average of 69% of the blade covered by diatoms. The medium impact site obtained a slightly lower percent cover of 65% while the low impact site had a 48% diatom cover (Table 4).

      Regarding the similarity between the three sites, out of the 25 genera found, only 11 genera were commonly found in all three sites. The high human impact site had 4 unique genera, the medium impact site had no unique genera, and the low impact site had 1 unique genus (Table 5). In the high impact site, *Ctenaphora* and *Mastogloia* were the most commonly found diatom genera, while *Synedra* was the most commonly found genus in the medium impact site. For the low impact site as well as the overall proportion of genera detected, *Cocconeis* was the most common genus present (Figure 5).

      There were four out of 25 genera that were sensitive to high nutrient inputs. *Fragilaria* as well as *Kobayasiella* were found only in the low impact site, while *Mastogloia* and *Diploneis* were found in all three sites but were predominately found in the low impact site.
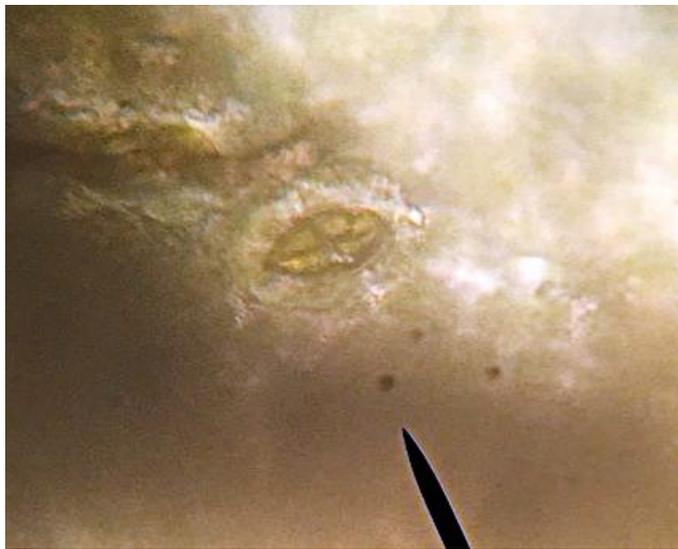
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Figure 4.1. Diatom genera *Cocconeis*

Figure 4.3. Diatom genera *Mastogloia*
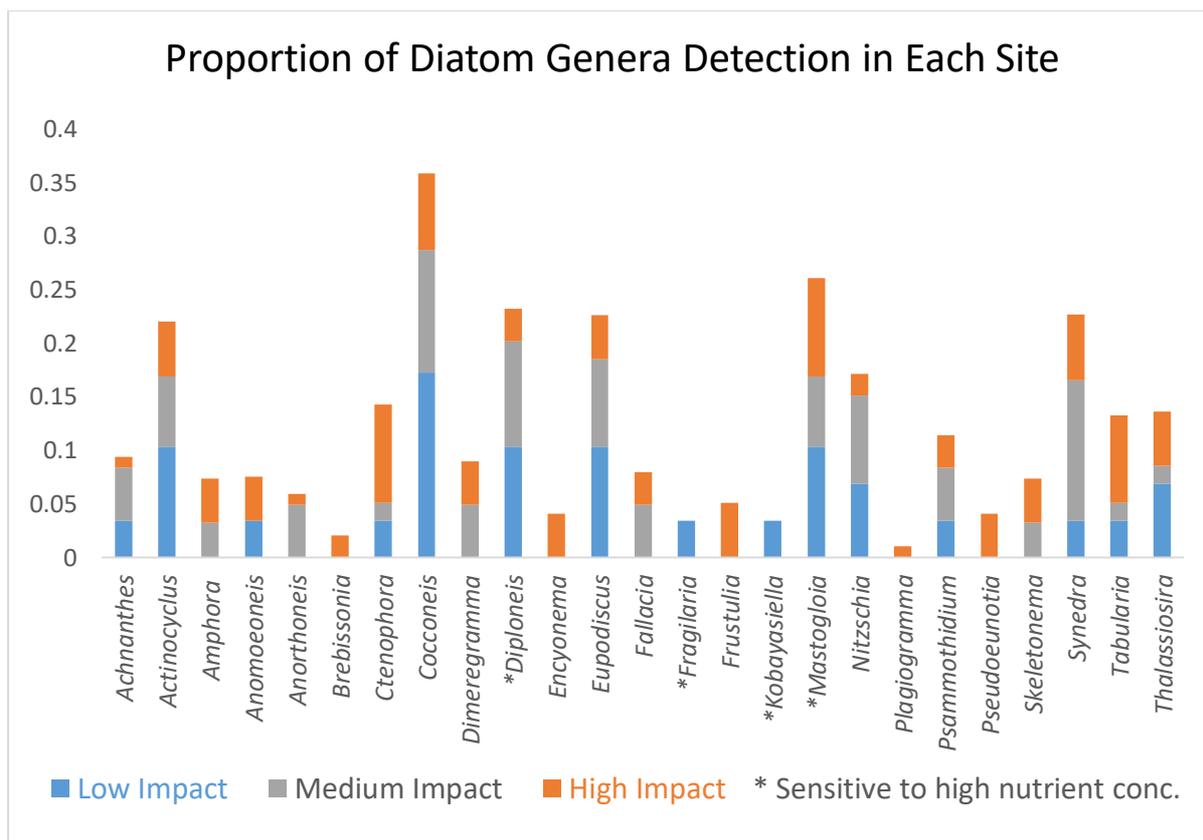

Figure 4.2. Diatom genera *Synedra*

Figure 5. Relative abundance in terms of proportion of the diatom genera found in each site.

VII. Discussion

Varying Site Disturbances

Under different human impact regimes, it was expected that more human disturbance would have higher turbidity. However, this was not the case, as the water turbidity of the high impact site was less (0.84m), compared to the turbidity of the low impact site which was 2.4m. This may be due to the exposure to waves and currents in the other two impact sites, whereas the high impact site was closed off from the waves, resulting in less sediment stir up. In the high impact site, the low turbidity allowed for the seagrass to acquire sunlight at a depth of 3.25m, which was much deeper than the medium and low impact sites which had a depth of 1m. It is important to note that physicochemical parameters like turbidity only give instantaneous measurements and could be widely affected by season, weather, tide, wind patterns and hurricane presence (Giorgio et al. 2016). For example, in this study, the turbidity was recorded a day after a hurricane hit. The hurricane may have greatly agitated the sediment and may be a possibility for the unexpected inverse relationship between water turbidity and human disturbance. Storms and hurricanes can also redistribute and homogenize sediments that was separately generated in periods between storms. Thus, researchers should not fully rely on physicochemical parameters for testing water quality, and should only be used as supporting evidence (Corlett et al. 2007).

Space and light competition with algae could account for the significant difference in seagrass blade height. Shading by algae lowers the amount of light reaching the ocean floor, causing the seagrass blades to invest more energy vertically in order to receive enough sunlight. Normally, seagrass density would be the main investment of energy, where they invest in growing horizontally by increasing the number of individual shoots across a rhizome (Cardoso et al. 2004; Biber et al. 2004). Increased amounts of algae shading, which

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ultimately came from increased nutrient input, could be the cause of the significantly different seagrass density between the three sites. This confirms the results found, where the least dense seagrass was found to be in the high impact site and the densest seagrass was in the low impact site. Human activities that may be a reason for the reduction of seagrass density around Bocas del Toro include tourists swimming, propeller scarring from boats, and high nutrient run-off from restaurants and bathrooms. With an increase in human activities, the seagrass that originally inhabited shallow waters could have been pushed deeper into the ocean which resulted in the drastic depth difference in the high impact site compared to the medium and low impact site (Valiela et al. 1997).

Changes in Algae Biodiversity and Density

In the three sites, 12 species of macroalgae was found with significantly higher algal biodiversity in sites with greater human disturbance. Contrary to the results of this study, macroalgae richness is typically assumed to be greater in undisturbed areas than in disturbed areas due to the presence of rarer and nutrient-sensitive species. However, studies have shown that minor disturbances may increase diversity, which is consistent with our results (Bellinger et al. 2006). In a previous study in tropical streams, Bellinger et al. (2006) observed the greatest abundance in algae genera *Halimeda* and *Penicillus*. These results coincide with our study, where the most abundant algae genus was *Halimeda*. In a separate study, Smith et al. (2004) demonstrated that *Halimeda tuna* exhibits opportunistic strategies in deep environments that have frequent and high amounts of nutrients. This suggests that there are also repeated significant pulses of nutrient input in the medium site, allowing the *H. tuna* to become abundant. The algae density was significantly higher in the site characterized by high human impact. This is a result of numerous top-down and bottom-up controls of algae. High algae density could result from greater amounts of indirect and direct nitrogen input, specifically urine (Valiela et al. 2016). Another possible reason is the ability for algae to use lower levels of light more effectively than seagrass. Seagrass can only grow at depths receiving at least 11% of irridation, whereas macroalgae can grow at depths receiving 0.12% and, at times, less than 0.003% of light penetration. Algae growth also tends to be nutrient limited as opposed to seagrasses which are mainly limited by light (Valiela et al. 2016). Alternatively, the high algae density may be a consequence of decreased herbivory and grazers. Although herbivorous populations have characteristically controlled algae populations by grazing, increased nitrogen rates have caused lower densities of herbivorous amphipods and isopods due to more frequent hypoxic conditions. As a result of these lower rates of herbivory, algae growth has further enhanced (Valiela et al. 1997). Additionally, Han et al. (2016) showed that the leaf length of seagrass increased with macroalgae addition, which is consistent with the results of this study, as the leaf length of seagrass was significantly higher in sites that had greater algae density.

On account of the low seagrass density, high algal and diatom biodiversity, the opportunistic macroalgae in the site with high human impact may already be slowly replacing seagrass, implying that there is a high amount of nutrient input in this site (Cardoso et al. 2004; Han et al. 2016). If this were accurate, a possible reason for the unexpectedly low turbidity in this site is that there is now coarser sediment from the opportunistic macroalgae, making it harder to stir up. This is compared to the sites with medium and low impact that have much higher turbidities possibly because the algae has not yet started replacing the seagrass making the sediment fine and easy to stir up. Another possibility is that the manatee grass, which was more prevalent in the sites with medium and low impact keeps the substrate soft similar to loose muddy sand (Phillips 1960).

There are several potential explanations for not finding any algae in the site with low human impact. The lack of algae could have been the severe increase in water turbidity. The

turbidity could have impaired our vision whilst collecting data despite our efforts. It may also be because there is an intact herbivory population in the low impact site that helps maintain the algae populations at a minimum (Boyer et al. 2004).

Changes in Diatom Biodiversity and Percent Cover

This study found 25 diatom genera among the three sites, with *Cocconeis* and *Mastogloia* being the most abundant genera found. Our results are consistent with a previous study, where researchers found diatom genera *Cocconeis* and *Mastogloia* to be most abundant (Corlett and Jones 2006). Although all of pollution-sensitive genera were found in the site with low human impact, there were still some pollution-sensitive genera found in the medium and high impact site. This may be because it is not completely uninhabitable for the sensitive diatoms to be entirely absent in the medium and high impact sites. Another reason for finding pollution sensitive diatoms in medium and high impact site is the high variation of nutrient tolerance within each genera, some species may be more sensitive to pollution than other species in the same genera.

The data obtained from this study is consistent with an earlier study which also found significant different diatom diversity for high and low nutrient sites (Bellinger et al. 2006). Furthermore, there was no significant difference in percent cover of diatoms on seagrass blades between all the sites. This could be a result of the diatom's ability to quickly adapt and flourish in high nutrient environments and live under lower light intensities (Bellinger et al. 2006).

In a recent study, Pajunen et al. (2016) examined the relative importance of species using physical parameters by studying changes in abundances. They found that *Nitzschia palea* had the highest relative importance for total phosphorus, while *Surirella brebissonii* and *Nitzschia levidensis* species that had relatively high importance for conductivity predictions. *Achnanthes pusilla* showed the highest sensitivity to the length of a growing season and *Fragilaria exigua* showed the highest relative importance for predicting water balance. This is pertinent to this study because genera *Nitzschia*, *Achnanthes* and *Fragilaria* were all mostly found in the low and medium impact site and could predict local and global climatic changes such as total phosphorus, conductivity and water balance (Pajunen et al. 2016).

A possible source of error during diatom identification is the variable shape of frustule within a diatom genus. With a light microscope, researchers are less likely to accurately identify diatoms compared to those with a scanning electron microscope (Morales et al. 2001). Using a scanning electron microscope would have minimized the shape variation and also would have given a clearer picture of the frustule. Also, epiphytes on *Thalassia testudinum* have shown a distinct tripartite community structure with the epiphytic diatom community initially colonizing the seagrass blade (Corlett and Jones 2006). The coralline algae and other taxa could have covered up the basal layer of diatoms, so there may not have been as many visible diatoms as there are present.

Indicators of Environmental Change

Seagrass beds and all the associated biota are hard to recover due to the marked changes in the sediment. Since the sediment becomes coarser and more mobile with opportunistic algae mats, natural re-colonization of seagrass is difficult and artificial re-colonization will require additional coastal engineering (Cardoso et al. 2004). Prevention through monitoring and restrictions would involve less effort, time and money. This is especially relevant as the Panamanian government focuses on further developing tourism in Bocas del Toro. Monitoring and managing marine ecosystems need to be a priority for policymakers and conservationists alike. Despite its restricted scale, this study shows that

under different human impact regimes, there are differences in seagrass density and in algae biodiversity and abundances. Algae populations will keep rising with increased nutrient input while nutrient sensitive diatoms continue to decline. Due to their rapid responses to environmental stressors, their immense diversity in tolerance ranges and their ability to be well-preserved in sediment, diatoms need to be utilized more frequently as indicators of water quality. As demonstrated in this study, if not conducted in a controlled environment, physicochemical parameters can be highly variable. Thus, using diatoms and algae as bioindicators would be much more consistent for measuring water quality. Species and abundance measurements that monitor seagrass beds can act as indicators of environmental change and further prevent seagrass and associated biota ecosystem decline (Han et al. 2016; Bathurst et al. 2010; Giorgio et al. 2016; Pajunen et al. 2016).

VIII. Conclusion

This study set out to juxtapose the biodiversity and abundance of algae and diatom communities in respect to three human impact regimes in *Thalassia testudinum* seagrass. Analysis revealed that there were significantly lower values of seagrass density in areas with significantly higher algae density, algae biodiversity, and diatom biodiversity. These results coincide with the site that was characterized with the most anthropogenic disturbance. This study can hypothesize that anthropogenic impact and an increase in nutrient input is a possible reason for the changes in community composition and abundances described above. Although the genera of diatoms slightly differed between the three sites, the abundance of diatoms did not show any significant differences. This confirms that diatoms are able to inhabit and adapt to nutrient rich habitats when necessary. Futhermore, in low impact sites, the absence of opportunistic macroalgae such as *Halimeda tuna* and the presence of nutrient sensitive diatoms such as *Mastogloia*, implicate tourism and other anthropogenic activities as being destructive to marine ecosystem. This further reinforces the effectiveness of diatoms as ecological indicators in marine environments. Future studies may include the abundance of coralline algae and other drift algae on seagrass beds with high nutrient environments. Another study could examine the threshold at which nutrient-sensitive diatoms become completely absent in nutrient rich environments.

IX. Works Cited

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X. Appendix

Table 1. Physical parameters used to characterize each of the three sites.

Site Characteristics	Low Impact	Medium Impact	High Impact
Water Depth (m)	1.5	0.97	3.25
Water Turbidity (m)	2.4	1.06	0.84
Seagrass Density (shoot/m^2)	461.30 ± 39.47	332.59 ± 13.64	145.0 ± 18.35
Leaf Height (cm)	20.58 ± 1.57	20.35 ± 5.20	29.57 ± 4.82

Table 2. Comparison of algae composition and abundances across each site.

	Algae Community Characteristics	Low Impact	Medium Impact	High Impact
Composition	Species Biodiversity*	0	0.709 ± 0.274	1.039 ± 0.314
	Species Evenness	0	0.794 ± 0.169	0.876 ± 0.086
	Species Richness	0	7	7
Abundance	Density (individual/m^2)	0	29.63 ± 13.07	31.19 ± 10.74

*Using Shannon-Weiner Biodiversity Index to compare the sites

Table 3. Algae species similarity between each site.

Site Comparison	Species in common	Sorensen's coefficient
High Impact & Medium Impact	2	0.286
High Impact & Low Impact	0	0
Medium Impact & Low Impact	0	0

Table 4. Comparison of diatom composition and abundances across each site.

	Diatom Community Characteristics	Low Impact	Medium Impact	High Impact
Composition	Genus Biodiversity*	1.612 ± 0.56	2.158 ± 0.404	2.558 ± 0.135
	Genus Evenness	0.982 ± 0.019	0.986 ± 0.022	0.99 ± 0.030
	Genus Richness	14	17	22

Abundance	Percent cover per shoot	0.484 ± 0.14	0.652 ± 0.2	0.686 ± 0.285

*Using Shannon-Weiner Biodiversity Index to compare the sites

Table 5. Similarity of genera between each site.

Site Comparison	Genera in common	Sorensen's coefficient
High Impact & Medium Impact	16	0.821
High Impact & Low Impact	12	0.667
Medium Impact & Low Impact	12	0.585

Table 6. Presence of diatom genera in each site and their corresponding tolerance to high amounts of nutrient concentrations.

Genus Scientific Name	Low Impact	Medium Impact	High Impact	Tolerance to High Nutrient Environments
Achnanthes	Y	Y	N	Tolerant
Actinocyclus	Y	Y	Y	Tolerant
Amphora	N	Y	Y	Tolerant
Anomoeoneis	Y	N	Y	N/A
Anorthoneis	N	Y	Y	N/A
Brebissonia	N	N	Y	N/A
Ctenophora	Y	Y	Y	Tolerant
Cocconeis	Y	Y	Y	Tolerant
Dimeregramma	N	Y	Y	N/A
Diploneis	Y	Y	Y	Sensitive
Encyonema	N	N	Y	Tolerant
Eupodiscus	Y	Y	Y	N/A
Fallacia	N	Y	Y	N/A
Fragilaria	N	N	Y	Sensitive
Frustulia	N	N	Y	Tolerant
Kobayasiella	Y	N	N	Sensitive
Mastogloia	Y	Y	Y	Sensitive
Nitzschia	Y	Y	Y	Tolerant
Plagiogramma	N	N	Y	N/A
Psammothidium	Y	Y	Y	N/A
Pseudoeunotia	N	N	Y	N/A
Skeletonema	N	Y	Y	Tolerant
Synedra	Y	Y	Y	Tolerant
Tabularia	Y	Y	Y	Tolerant

Thalassiosira	Y	Y	Y	Tolerant