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Monitoring Green Turtles (*Chelonia mydas)* Behavior and Abundance in Kāneʻohe Bay: Do Basking Coves Indicate Coral Substrate Selection?

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Abstract

Green turtles (*Chelonia mydas*) are key herbivores in Hawaii, where they control invasive algae. In Kaneohe Bay, they rest in basking coves near their feeding pastures. Yet, it is unknown if resting coves are associated with specific coral species. By determining if turtles have substrate preferences, we can infer the benefits of grazing in different reefs. Turtle abundance and behavior were recorded during snorkeling surveys of 9 patch reefs. Data were collected for 23 turtles identified through the 2 ½ months of surveys. These surveys revealed that turtles were most abundant in the northern/offshore sections, and least abundant in the central bay. The most common behaviors were resting (90%) and foraging (10%). Five substrate quadrats from each cove (turtle present) and adjacent area (turtle absent) were photographed to quantify coral cover using coralnet software. Basking coves were dominated by finger coral (*Porites compressa*), compared to neighboring areas, which included a variety of coral species. Due to statistical tests, no association between substrate was found. This research suggests that reefs dominated by *Porites compressa may be less* susceptible to algal overgrowth due to turtle grazing. Moreover, algal cover is expected to be lower in the northern section of the bay, where turtles are more numerous. Future studies should compare algae abundance and species composition in patch reefs with and without turtle coves. Limitations faced during this study include the number of reefs surveyed, the time of day, and the season.

<u>Keywords:</u> herbivore, *Chelonia mydas*, *Porites compressa* , substrate, invasive algal, foraging, Patch reef, Basking coves

Introduction

Kaneohe Bay is home to many marine organisms that coexist due to the unique features the islands have to offer, but due to the increasing population on the island, there have been significant changes to the bay. The coral sp. in Kaneohe Bay is a keystone species that provides a habitat for many marine organisms. The most abundant coral species in the bay is *Porites Compressa* which is recorded to inhibit 90% of the bay (Hunter, 1995). Starting in the 1940's due to the increasing population along the coast the coral health started to decline. Due to urbanization and runoff from the tower, there had been a huge increase in Green bubble algae *Dictyosphaeria cavernosa* (Banner, 1970). The growth of algae has caused a decline in coral health due to phosphate and nitrogen from runoff causing a decline in coral coverage. In a study done by Cynthia Hunter, they compare the algae growth along the 3 common coral species in the bay through 1971, 1983, and 1990. Through the 20 years, the incline of algae has caused a decline in coral percent coverage (Hunter, 1995). The percent coverage of algae increases as the coral coverage decreases. The species of coral that was least affected was *Pocillopora damicornis*, but it still had a decline of ⅓ of its population since the last 10 years it was monitored. We have seen a major decline in coral growth due to the urbanization of the growing towns along the coast. Due to poor treatment options in 1995 at least 800,00 tons of sewage water daily was dispersed into the bay's groundwater (Hunter, 1995). These chemicals being pushed into the ocean are causing algae spikes which is the cause for species of coral to decline in health. Coral reefs are keystone species, if they decline in health then it also damages the community it is built. The deteriorating coral reefs can't survive without help from other specimens.

Green Turtles (*Chelonia mydas*) are the most abundant marine herbivore in the bay (Mcdermind, 2007). According to the NOAA Technical Memorandum synopsis, the Geen turtle's diet consists of seagrass and algae species, most commonly Green algae *Chlorophyta* (Balazs, 1980). They have also been recorded eating red algae (*Rhodophyta)* and brown algae, (Turbinaria *ornata)* (Parker 2011). The *Chelonia mydas* also eat nonnative algae such as *Acanthophora spicifera* which has caused Green turtle growth to increase (Russell, 2015). The Green turtles often rest in areas that are located close to feeding pastures, which allows them to eat as frequently as needed. The Juvenile and adult Green turtles move throughout the bay for food but also to find designated areas to rest (Brill,1995). The younger Green turtles must eat more regularly than the fully grown adult Green turtles. Not much is known about *Chelonia mydas* basking areas underwater except that they rest near food pastures and tend to stay in Kaneohe Bay. There has been research done about the turtle's preferred preferences for basking areas on sand. There are specific conditions turtles look for when finding designated basking areas such as the sand temperature (Whittow,1982). Meaning there also could potentially be specific conditions turtles search for in their underwater basking areas.

With the *Chelonia mydas* diet consisting of mostly algae and seagrass, their abundance can potentially help the declining coral coverage in the bay. If *Chelonia mydas* are known to rest near food pastures, the coral preferred by the turtles could be subjected to less algae damage. By investigating their behavior towards preferred coral species, we can potentially determine if the turtle's presence can help to restore the coral. Research done in Australia shows that sea turtle presence and activities actively help the decline of algae growth on the coral (Goatley, 2012). The turtles provide high productivity in these designated regions of the bay that they inhabit (Becker, 2019). Without any huge restrictions in the bay, the coral reefs are subjected to a lot of damage caused by overgrown amounts of Green algae (*Dictyosphaeria*). To solve the issue the increased volume of turtles could benefit the coral by eating away the algae causing destruction. If we can determine what the turtle's preferred species of coral is in their basking area, we can start to create more restrictions catered towards the reefs that have less abundance. Also restricting access to a specific coral that turtles prefer, can provide the turtles with a safe route to not only bask but to eat away the algae that causes destruction. By researching the preferred coral species, we can use the information to our advantage when finding ways to compete against the decreasing coral coverage.

In this independent research project, we will be investigating the behavior and abundance of Green Turtles (*Chelonia mydas*) in relation to their preferred coral species in basking areas. The goal of my research is to determine if the relationship between Green turtles and coral species can further help restore the deteriorating coral in the bay. By conducting surveys for behavior, abundance, and coral percent coverage in basking areas, we can conclude if they have a preferred coral species in their basking areas. We will be looking at contributing factors such as turtle abundance/ behavior as dependent variables and coral species/percent coverage being independent variables. Control variables are the time and location of surveys. We will be comparing the data from species/percent coverage of no turtle present to our sites used by the turtles (*Chelonia mydas*). We hypothesize that the Green turtles (*Chelonia mydas)* will prefer the more common species of coral (Porites *compressa*). We predict this due to the high percent coverage of this coral species throughout the bay. The null hypothesis would be that there is no relationship between the coral species and turtle abundance. Our statistical hypothesis is that there will be a higher abundance of turtles in coves that have a majority percent coverage of Porites compressa due to that species covering 90% of the bay. We also hypothesize that Chelonia's behavior will consist of resting. We predict this due to previous data showing that the turtles rest near feeding pastures. Our null hypothesis would be that *Chelonia mydas* will not consist of either of these behaviors. Our statistical hypothesis is that *Chelonia mydas* recorded will have a higher average of resting due to that being a common behavior in feeding pastures 3m-10m deep. 3m-10m is a similar depth range to what basking areas are being recorded at. Turtles going as deep as 20m are typically hiding from predators not basking. This study is important because turtles are the most abundant marine herbivores in Hawaiian Islands, and an increase in their abundance could help the dying coral reefs. Investigating if they have a preferred coral species for their basking area, can help us to determine which coral we should be protecting. Corals that are subjected to less turtle abundance need to be monitored due to the high potential for coral deterioration. Also, to help ensure the public remains at a safe distance from these animal's habitat.

Methods

To test our hypotheses, we will start by conducting surveys from January to April. Surveys will be done weekly on Monday mornings from 9 am to 11 am on various reefs in Kaneohe Bay. Figure 2 includes the 9 reefs that will be surveyed during the designated time. Each Survey will consist of at least 15-minute rounds done 4 times per outing. Michael and David will be accompanying me on the survey, helping with my equipment and data retrieval. The equipment needed will be a timer, quadrat, underwater slate, and underwater camera. For each 15-minute round, I will survey the reef perimeter by going in a random direction and searching for a Green turtle (*Chelonia mydas*) inhibiting a basking cove. Sample size will vary from reef to depending on the Green turtles present. When the turtle is identified, I will record time/GPS, abundance of turtles, and its unique behavior using my behavior key. Table 1 below shows an example of images of the Green turtle's behaviors they may exhibit running from behavior 1-8. Figure 8 represents an example of a Green turtle inhibiting a basking cove. My Partners will then pick a random direction (Left or right) and we will move 1-2 meters over where there is no turtle present. I will additionally record turtle abundance and behavior in random neighboring coral, to indicate there is no presence. This field data will be recorded on a slate, this is where abundance and behavior will be monitored. For each of the original basking coves with a turtle present and the neighboring coves with no turtle present, there will be 4-5 quadrat images taken with the underwater camera (figure 1). The image of the quadrant will be similar to Figure 7, the original indicating turtles present and the neighboring indicating no turtle present. As you can see in Figure 1, the original and neighboring corals will be measured in the same way to compare any differences. These images will be used in the lab to assess the percent convergence of each coral species. These photographs will then be uploaded to coralnet, a software created by the University of California San Diego. The software will randomly pin 25 points, where we then can identify the substrate within the quadrat. For quadrat 2 located in the middle of the basking area, if a turtle is present then we do not record that quadrat. If the turtle (*Chelonia mydas*) additionally causes any rubbing onto the coral, it will not be monitored. We expect that there will also be reefs with zero *Chelonia mydas* abundance, this data is also valuable for determining restrictions. For our approach, we have used a similar methodology that was also used by Christopher H. R. Goatley in his paper ‘The Role of Turtles as Coral Reef Macro Herbivores”. In his research he tracked the abundance of turtles in Kaneohe Bay with photography. We also use a similar methodology used by Bailey Banner in her article “The Effects of Urban Pollution. Upon A Coral Reef System”, where they assess images of coral to determine coral percent coverage. Dr. Banner also uses a key to determine coral health level, we use this same approach when recording the level of turtles' behavior.

Table 1: Behavior key for *Chelonia mydas* identified during surveys.

Behavior key:
1= Eating
2=Resting
3= Moving away from basking area
4= Moving Around the basking area
5= Breathing and moving up/down
6= Circling basking area
7= Staying in basking area, with large breathes
8= Charging

Figure 1: Example of Quadrat images taken from original cove (*Chelonia mydas* present) and neighboring cove (No *Chelonia mydas* present).

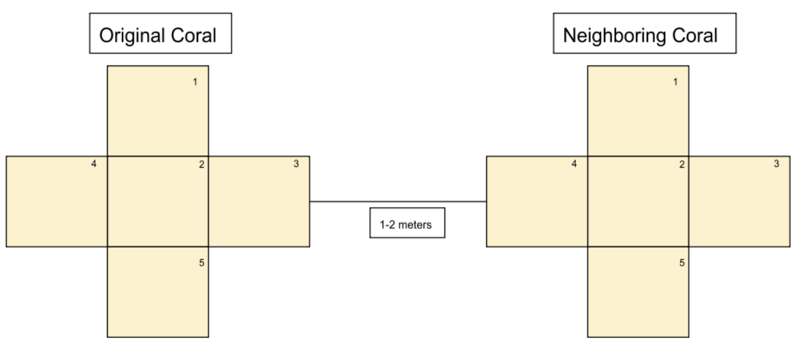


Figure 2: Map of Kaneohe Bay with designed 9 patch reefs being used for surveys.

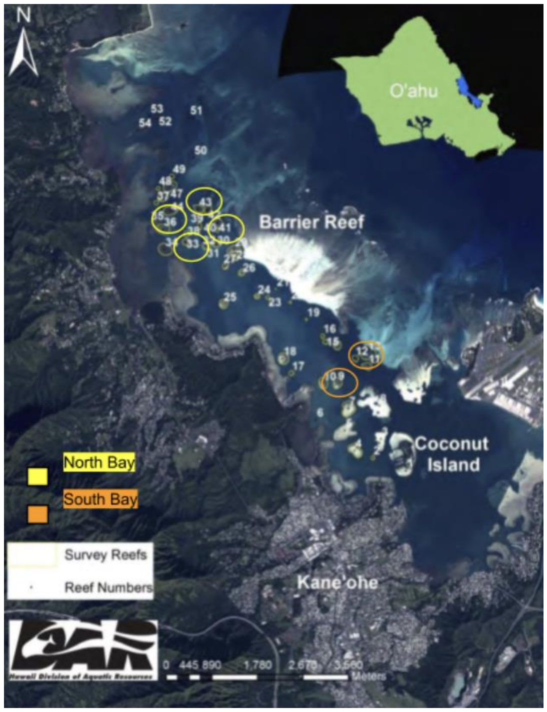


Figure 3: 23 Turtles counted within Kaneohe Bay, North Bay (65%) compared to South Bay(35%).

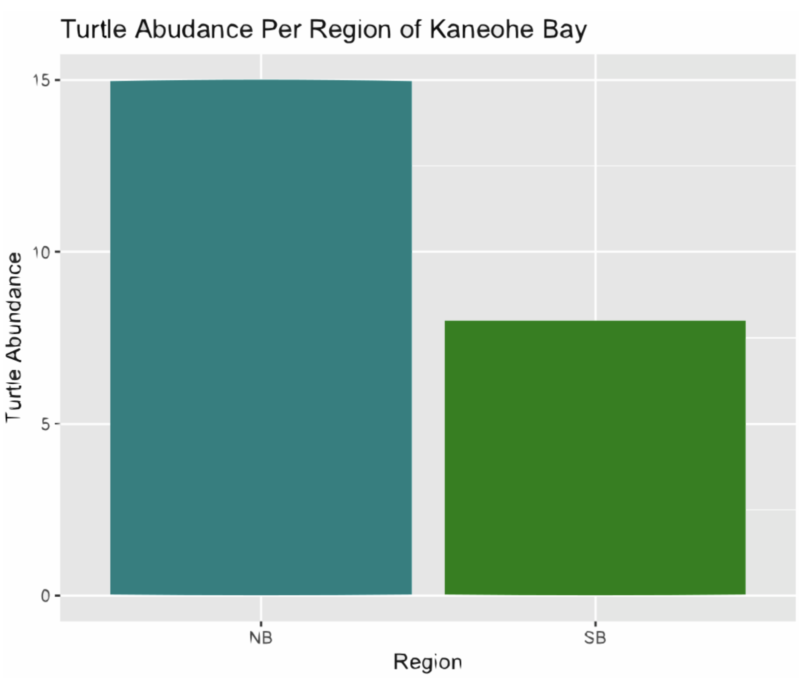


Figure 4: Abundance for each of the 4 region of Kaneohe Bay (South offshore, South onshore, North offshore, and North onshore) .

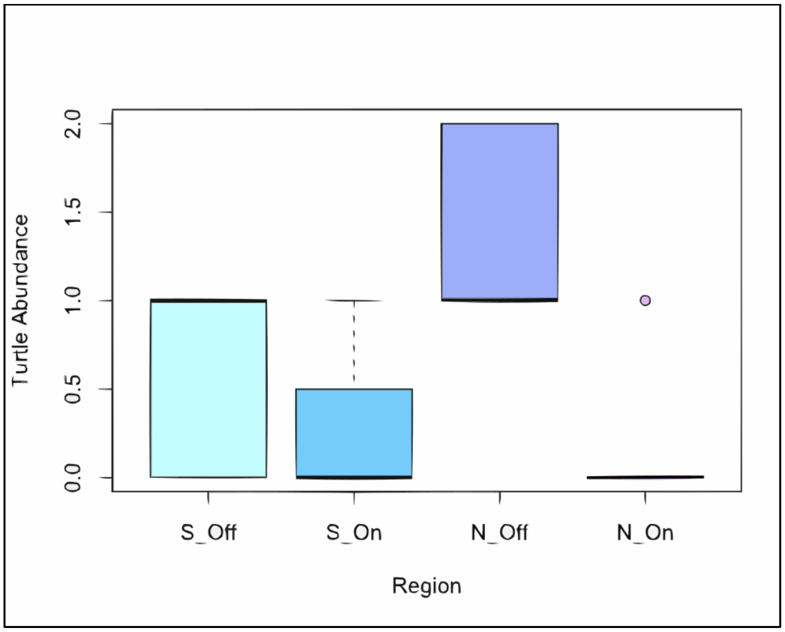


Figure 5: Turtle behavior of all 9 reefs, resting (90%) and foraging (10%).

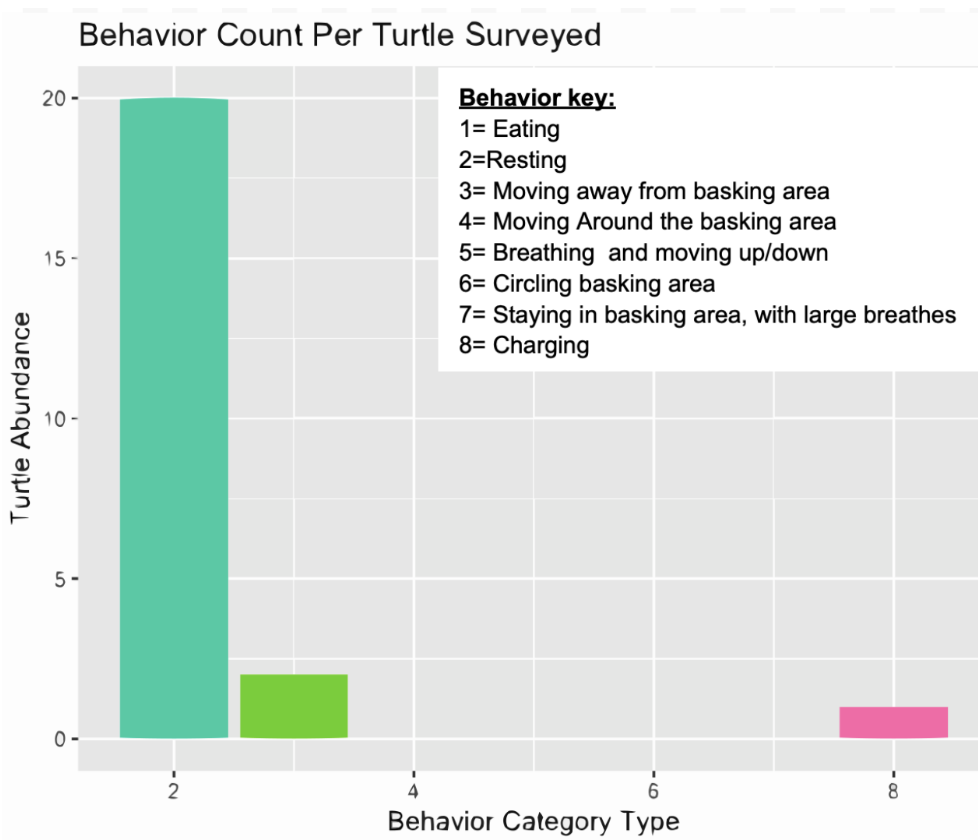
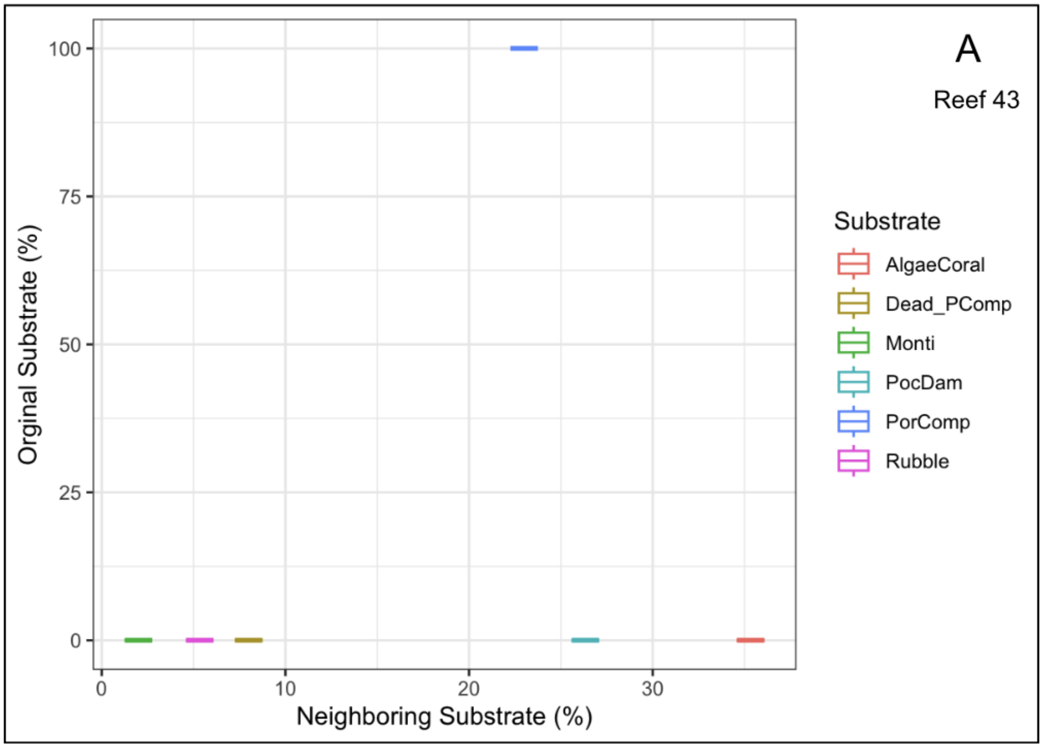
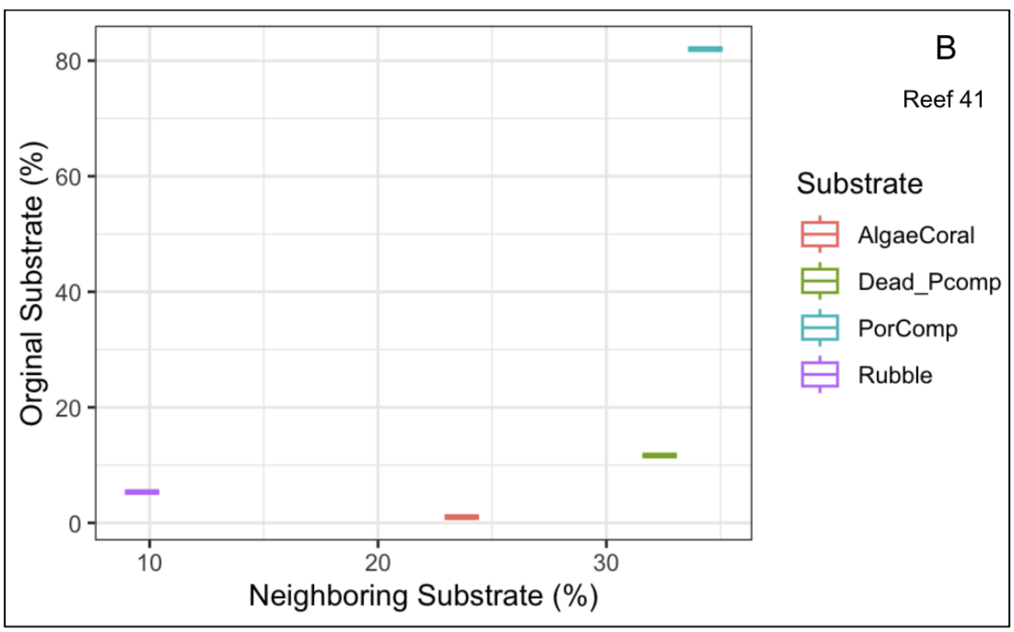
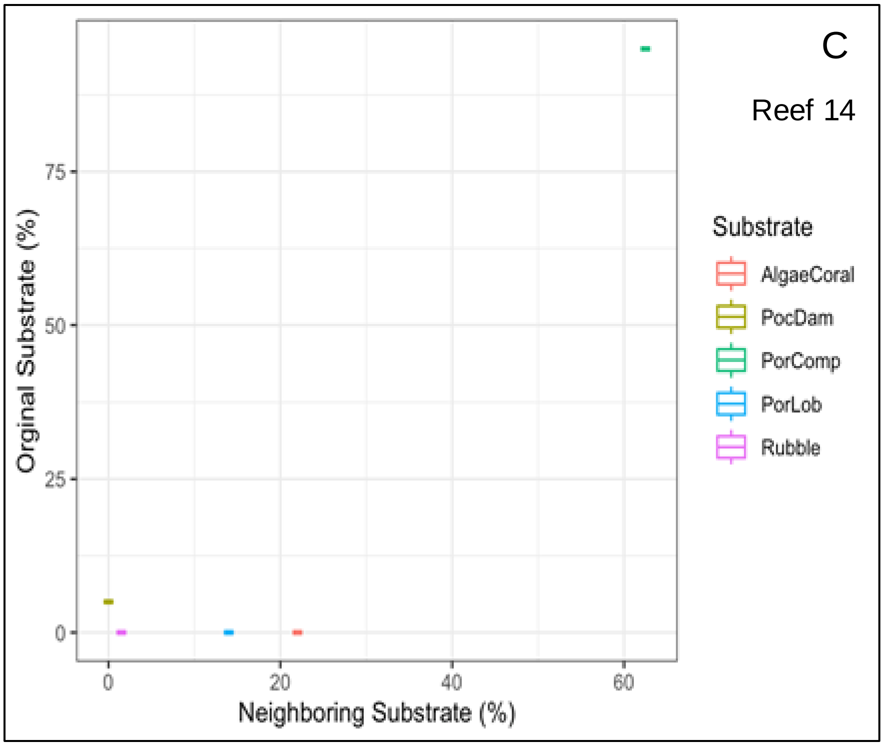
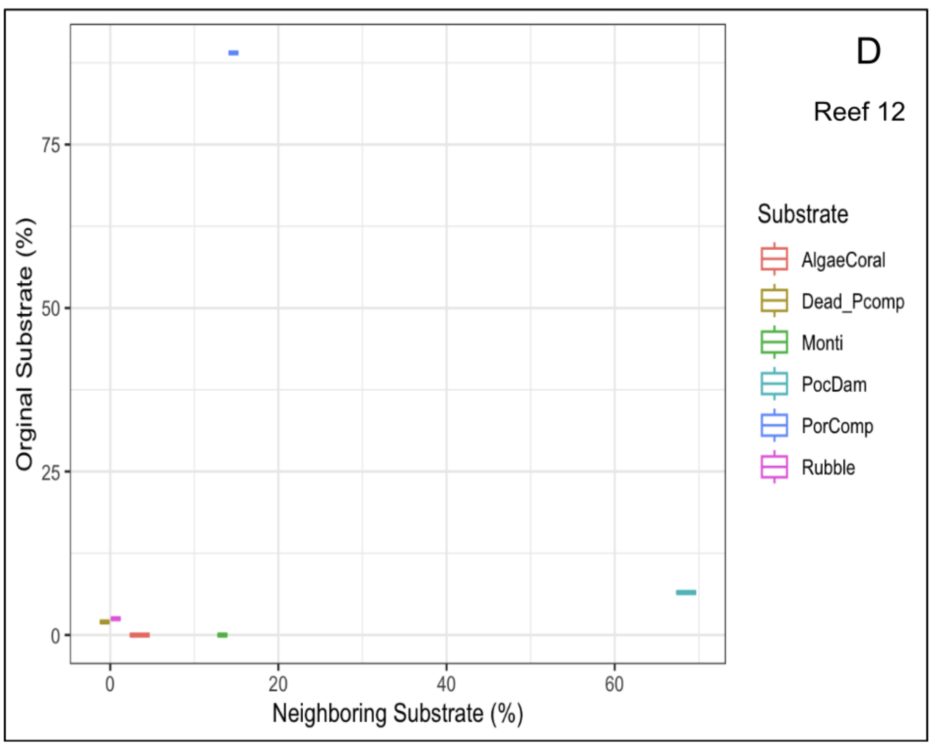


Figure 6 (a-e) : Substrate percent coverage of each of the 5 reefs surveyed for substrate percent coverage. Original substrate % coverage represents substrate where *Chelonia mydas* are present, and Neighboring substrate % coverage represents where no *Chelonia mydas* were present.


A
Reef 43
Orginal Substrate (%)
100
75
50
25
0
0
10
20
30
Neighboring Substrate (%)
Substrate
AlgaeCoral
Dead_PComp
Monti
PocDam
PorComp
Rubble


B
Reef 41
Orginal Substrate (%)
80
60
40
20
0
10
20
30
Neighboring Substrate (%)
Substrate
AlgaeCoral
Dead_Pcomp
PorComp
Rubble


C
Reef 14
Orginal Substrate (%)
Neighboring Substrate (%)
Substrate
AlgaeCoral
PocDam
PorComp
PorLob
Rubble
0
25
50
75
0
20
40
60


D
Reef 12
Orginal Substrate (%)
Neighboring Substrate (%)
Substrate
AlgaeCoral
Dead_Pcomp
Monti
PocDam
PorComp
Rubble
0
25
50
75
0
20
40
60

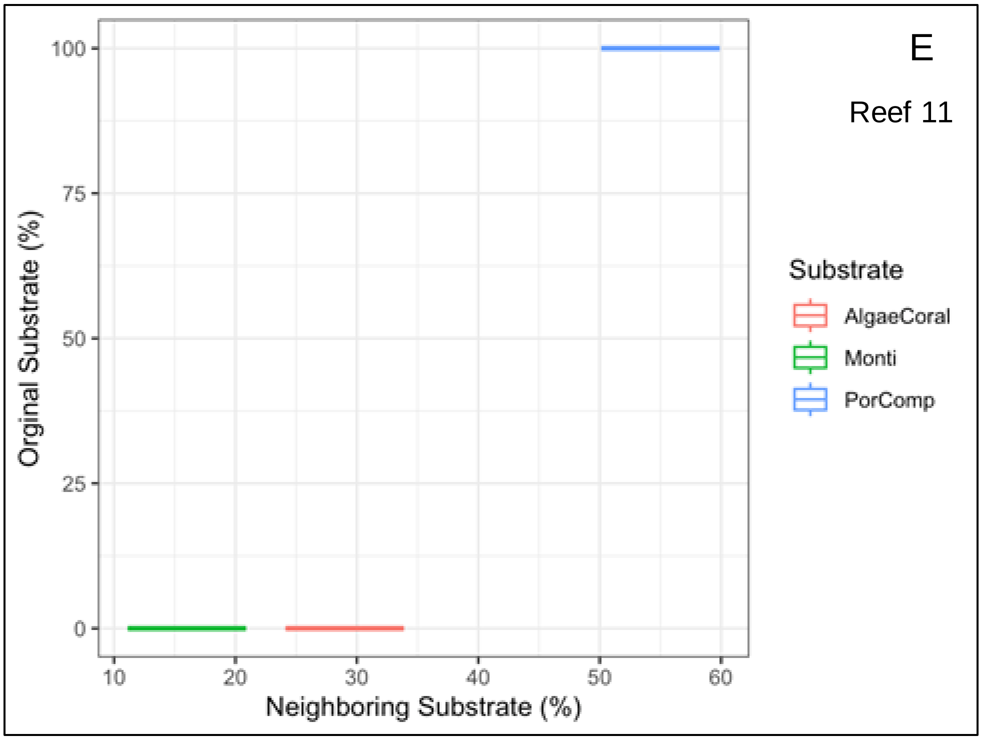


Figure 7: Example of Original Q1 and Neighboring Q1 of substrate images

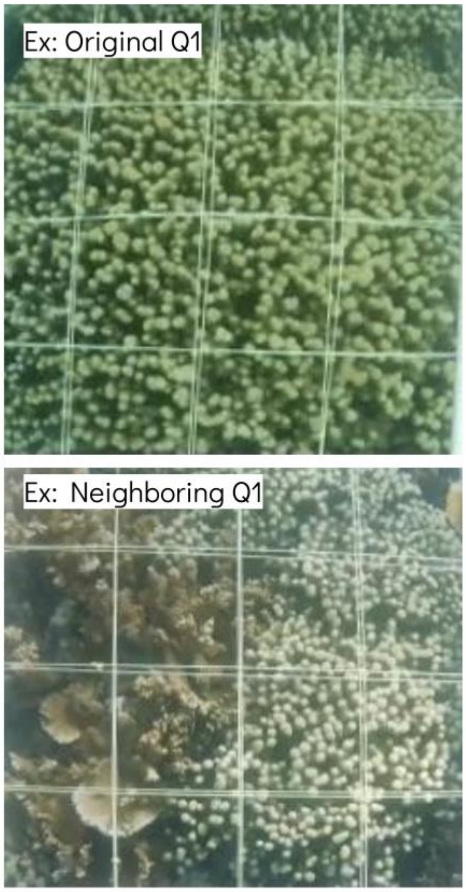


Figure 8: Example of *Chelonia mydas* inhibiting a basking cove.

Results

Although the research was looking at behavior and preference of substrate, we recorded abundance at each survey because it was an important part of our other hypotheses. We compared the abundance between 4 regions, North offshore, North onshore, South offshore, and South on shore. In Figure 3 we compare the raw count of Green turtles (*Chelonia mydas*) in both the Northern regions compared to both Southern Region. We found that out of 23 turtles, there were 15 recorded in North Bay making up 65%, and South Bay only having 8 counts which is 35%. We used a Kruskal Wallis test to assess the evenness of distribution between the two populations. The test showed the p-value = 0.028932, meaning there was a significant difference in abundance between the two regions. Specifically, the northern region had the most abundant of turtles. We then compared all 4 regions of abundance, as you can see in Figure 4. There is a visible difference in abundance, the north offshore has a much higher abundance on the boxplot. I used a Multiple comparison Kruskal Wallis test to compare each region to each other. The only significant difference was found when comparing North offshore with South onshore, also with North offshore and North onshore. There was not a significant difference between the north offshore abundance compared to the south offshore, due to the south offshore having a bit larger abundance. Using a Kruskal Wallis to compare the 4 regions to each other, we found the p-value = 0.001272 meaning there was a significant difference in distribution. Showing that once again there is a significantly more abundance in Northern Offshore which is Reef 43 and Reef 41.

For the behavior results, we used the behavior key to identify every behavior of the 23 Green turtles (*Chelonia mydas*) surveys. In Figure 5 you can see the distribution of behavior throughout all surveys. The most common behavior identified was resting 90% while foraging was 10%. I consider the two behaviors ‘moving away from cove’ and ‘charging’ under foraging because the turtles were simply moving around and not displaying any new behavior. To summarize the movement, I classified it as foraging. There was one count of hostile charging behavior, but this was an outlier compared to the overall amount of resting. I used a chi-square test to test if the observed data were significant compared to the expected. The p-value 3.337e-07 showed that the data were significant and that resting was the majority count.

The substrate data were only applicable for 5 out of the 9 reefs surveyed. We used reefs 41 and 43 for the northern region, and Reef 14, reef12, and reed 11 for the southern region. As you can see in Figure 6 a-e, we used a scatter plot for each reef to display the % coverage of substrate in all the total neighboring quadrats compared to all the original quadrats. Each reef's total surveys were accumulated so the original percent coverage made up the % coverage of the quadrats used in total. The same was done for neighboring quadrat images per reef. Looking at the reefs in the northern regions figures 6 a-b, show an increased amount of *Porites compressa* in both original quadrats. There was more of a variety in the substrate in the neighboring percent coverage, but still a high percentage in *Porites compressa* in the neighboring. There was a similar result found in the southern region of the bay as you can see in figure 6 c-e. Similarly, the northern region the *Porites compressa* count was higher in Green turtles (*Chelonia mydas*) present compared to none. We used a Spearman rank test individually for each reef to determine the relationship strength or association between the various substrates. Each test was found to have almost the same results. For each reef, the p-values were the following: Reef 41; p-value = 0.8047, Reef 41; p-value = 0.3333, Reef 14; p-value =0.7177, Reef 12; p-value =0.5452, and for Reef 11; p-value =0.5452. Each P-value found for all 5 reefs indicated that the data found was not significant. For the Spearman rank test, the rho indicates if there is going to be a positive or negative correlation between the substrates. All the rho for the 5 reefs showed no association and were neither positive nor negative. The rho values were the following: Reef 43 ; rho = 0.1309307 , Reef 41 ; rho = 0.3333 , Reef 14 ; rho = 0.2236068 , Reef 12 ; rho = 0.3134678 , and for Reef 11 ; rho = 0.3134678 . Each of the 5 rho values is neither positive nor negative and extremely difficult to determine the relationship between the substrates. The p-value was also nonsignificant, showing that there wasn't a significant difference between the substrates. Although we can see that *Porites compressa* had high percentages in both original and neighboring, the test proves it's not significant. The rho also indicates each reef's substrates did not have an association between them or a monotonic relation. There was neither a positive nor negative correlation for each reef. Due to the high abundance of *Porites compressa* present in both neighboring and original images, we used a paired t-test for the 2 reefs in the northern region and 3 reefs in the southern region. This test was used to determine what was the % difference in coverage between Orginal *Porites compressa* and neighboring *Porites compressa*.

For South Bay, the test showed that P-value = 0.008079 and Mean difference = 62, meaning the data were significant and that original *Porites compressa* was 62% higher in coverage compared to neighboring *Porites compressa*. Similar results were also found in the northern region where the P-value = 0.001566 and Mean difference = 61.6667. This also indicates that there the data were significant and had 61.6% higher *Porites compressa* in original coves compared to neighboring. This indicates that even with no relationship between the substrate, there still is a higher percent coverage of *Porites compressa* where Green turtles (*Chelonia mydas*) are present.

Discussion

There are multiple reasons that we observed a higher abundance of Green turtles (*Chelonia mydas*) in the northern offshore region compared to the other regions. Firstly, the reefs in the northern offshore region are very close to feeding pastors. According to Dennis. J Russel's previous study was done on Green turtles' diet, a common behavior of the turtles in the bay is resting by feeding pastures (Russel, 2015. The northern offshore region is the closest reef to a seagrass-feeding pasture. This could be one of the multiple reasons there was a larger abundance in the northern region. It is also a calmer region of the bay with less boat activity, making it perfect conditions for basking and eating without a threat from predators. The increased abundance in this region could also be due to the mating season starting in the middle of April (Balazs, 1980). Boat crew members observed many turtles mating throughout the bay, although I did not observe any, I did notice an increase in turtles per survey in the northern region. This could indicate that turtles chose that area of the bay to feel safe with each other. It is not surprising that there was a lower abundance seen in the Northern onshore, this is due to the water quality being low, and the deteriorated coral. Due to the location of the northern onshore reefs, pollutant runoff could be increased due to the stream. There was also a low abundance in both southern regions, and I believe this is due to the increased boat activity in this region. Throughout my survey trips, I would observe multiple signs that indicated boat drivers to watch out for Green turtles (*Chelonia mydas*).

Out of the 23 Green turtles (*Chelonia mydas*) surveyed majority 90% were identified to be resting. We had predicted this originally, due to a study done by Richard Brill in 1995. This paper indicated that one of the most common behaviors turtles exhibited in the patch reefs was resting. Although most would assume it was grazing or eating, they usually chose to sleep in patch reefs near their feeding pastures. The majority of the abundance was in the northern offshore near the feeding pastures, and the statistics show that the data were significant. Meaning turtles have a higher chance of exhibiting resting behavior in the bay. There were two more behaviors observed that did not include resting. 3 turtles exhibited different behaviors, 2 were moving around the basking site and one charged at me while I was swimming. The moving around behavior could be due to human presence disturbing them. The turtles are very timid and aren't as used to humans as Green turtles in other locations around the island such as Ala Moana. The two turtles were most likely curious about why my research partner and I were swimming around. But both turtles exhibiting that behavior didn't show any significance compared to the number of turtles resting. For the single instant of the turtle charging, we believe it was due to the hostility due to the start of mating season. The mating season begins mid-April (Balazs, 1980), and after having crew members observe mating, I was hyper-aware of this turtle activity. Although we did not observe any mating, the hostile charging could be stress-induced because of the increased breeding in the area.

Although the Spearman rank correlation test showed that each of the 5 reefs surveyed for coral substrate had no association between its substrates. Due to no positive or negative association, we are unable to determine the relationship between the substrates. They simply do not have a monotonic relationship with one another. Porites compressa was predicted to be the majority due to its high abundance across the entire bay from a study conducted in 1995(Hunter, 1995). There were high amounts of *Porites compressa* found in both neighboring and original reefs. After performing the paired t-test, we observed that both South Bay and North Bay have 62% higher coverage of *Porites compressa* in their turtle-present coves compared to no turtles present. There was no difference between the regions, indicating the turtles don't have a preference in either region. They are just more abundant in northern regions. The results also indicate that even though the *Porites compressa* is present in no turtles, it does have a higher percent coverage when they are present. Due to the results showing no positive nor negative correlation between the substrates, we can conclude the high percent of *Porites compressa* is just due to it being highly abundant in the bay. There is no statistical proof that turtles are preferring a certain substrate over others. It is unknown still if they have a preference or if they just chose what is more readily available.

We are unable to determine substrate preference, but with what we know about abundance, we can infer that due to higher abundance in the Northern region, those patch reefs may be less susceptible to coral deterioration. Due to Green turtles (*Chelonia mydas*) being the most abundant herbivore/grazer in the bay (Mcdermind, 2007, we can infer that their abundance could lessen algae coverage on the northern region reefs. The patch reefs rely on the mutualistic relationship between substrate and turtle, to increase its protection against algae. The abundance of the turtle plays a key role in which region is most protected, while behavior indicates the motive of a turtle. Turtles observed resting are most likely sleeping near food for easy access. Although there is no substrate preference, we know the 62% higher *Porites compressa* in turtles present indicates that it could be subjected to less threat from algae. Because it is the most common coral species in the bay, there is no data that concludes it is less threatened by turtles present, but we do know they sleep where they eat. Turtle abundance will play a key role in continuing to save the patch reefs, just more research needs to be done to observe conditions for the Green turtles (*Chelonia mydas*) in the bay. The results overall show that the expected outcome was correct.

Conclusion

In conclusion, my research shows an increased abundance in the northern region, with the majority of behavior resting. Although there is no evidence that substrates in the patch reefs have a strong relationship with each other, there is an increased amount of *Porites compressa* in Green turtles (*Chelonia mydas*) present. The data concludes that it would be extremely difficult to base restrictions of patch reef uses based of substrates. It is most logical to base restrictions based of region of the bay where turtles are most abundant or least abundant. Both of my hypotheses about behavior and substrate percent coverage were accepted. The prediction that the most common behavior would be resting was proven to be true. As well as the prediction that *Porites compressa* will have a higher percent coverage where turtles are present was correct. There were multiple limitations to my research that played a role in my results. Firstly, the number of reefs surveyed, I would have preferred to use more reefs in the northern offshore because of the increased turtle abundance. Another limitation was the time of year and the day of the week. As stated, before the data were collected at the beginning of the mating season and throughout the rainy season, this could have skewed the results because it does not look at the annual behavior and abundance. My biggest limitation was the dependency on my fellow research partners. Due to so many statistics being recorded such as abundance, behavior, and quadrats images, my team had to hold a lot of gear. We also had to hold an emergency buoy because of our movement along the perimeter of the reefs. With so much equipment it was hard when someone missed survey day, due to the lack of help. The increase in equipment per person could have altered the ability to take images. Another limitation of the photograph of substrate was if the turtle was too fast or too deep, we were unable to record the substrate for that individual. The substrate images used were from reefs that had applicable substrate data. Implications for the goal of this project were to determine if turtles have a preferred substrate selection within their basking coves. The data did reveal higher Porites compressa, but with no association between the other substrates. Although the substrate has no association this information is important because we now know what coral species Green turtles (*Chelonia mydas*) are targeting. Implications for the gap in my research would be it was only conducted once a week, which could affect when and where the turtles were present. More research needs to be done to fill in the gaps. Such as determining algae abundance, determining driving factors of turtle abundance, and researching into other common behaviors in the patch reefs. For future studies, I would encourage researching algae coverage in turtle-present coves compared to no turtle-present. This way we can conclude if the Green turtles (*Chelonia mydas*) are grazing in their coves.

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