SPATIAL AND TEMPORAL PATTERNS OF CORAL COMMUNITY STRUCTURE AT BAKER AND HOWLAND ISLANDS

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I certify that we have read this thesis and that, in our opinion, it is satisfactory in scope and quality as a thesis for the degree of Bachelor of Science in Global Environmental Science.

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To my parents and my siblings.

Your endless support and inspiration kept me going through this journey. Thank you for always believing in me.

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ABSTRACT

Baker and Howland islands are located in the Central Pacific and preserve some of the most pristine coral reef ecosystems in the world. Due to their remote location, the islands have had minimal human contact, but they are still under threat. Surveys conducted by the Ecosystem Sciences Division of the National Oceanic Atmospheric Administration Pacific Islands Fisheries Science Center indicate that benthic composition and structure vary across space and time. Baker and Howland experienced mass coral bleaching following the 2009–2010 El Niño Southern Oscillation event that resulted in increased sea surface temperatures. This study has examined the coral reef community structure for the years 2012, 2015, and 2017 to assess changes in abundance and spatial distribution of the main benthic taxa in order to provide a general overview of the current status of the coral reef ecosystem surrounding these islands. Three different depth strata were used to understand the composition of the forereef communities. This study focuses on the main functional groups of coral, coralline algae, and macroalgae. Benthic composition varied with depth, as some species thrive with more sunlight while others can survive at lower light levels. The results of this study describe how the benthic cover of the reef has changed, specifically an overall decrease in coral cover and coralline algae and macroalgae equaling or exceeding coral cover. Analyzing the changes of the reef in the past five years will give insight on how the reef might change in the future if sea surface temperatures and widespread bleaching continue to occur.

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1.0 INTRODUCTION

1.1 Location

Baker and Howland islands are part of the Pacific Remote Island Marine National Monument (PRIMNM) located in the Central Pacific (Figure 1). The islands are located on the Tokelau submarine ridge. Howland Island (0°48' N, 176°37' W) is situated 66 km northwest of Baker and 68 km north of the equator, while Baker Island (0°12' N, 176°29' W) is 53 km north of the equator (Maragos *et al.* 2008). The islands have never been permanently inhabited, due to their remoteness and arid conditions. Both Baker and Howland were established as National Wildlife Refuges in 1974 by the US Fish and Wildlife Service and as part of the Pacific Remote Island Marine National Monument in 2009 (Boyle *et al.* 2017; Maragos *et al.* 2008; USFW 2007).

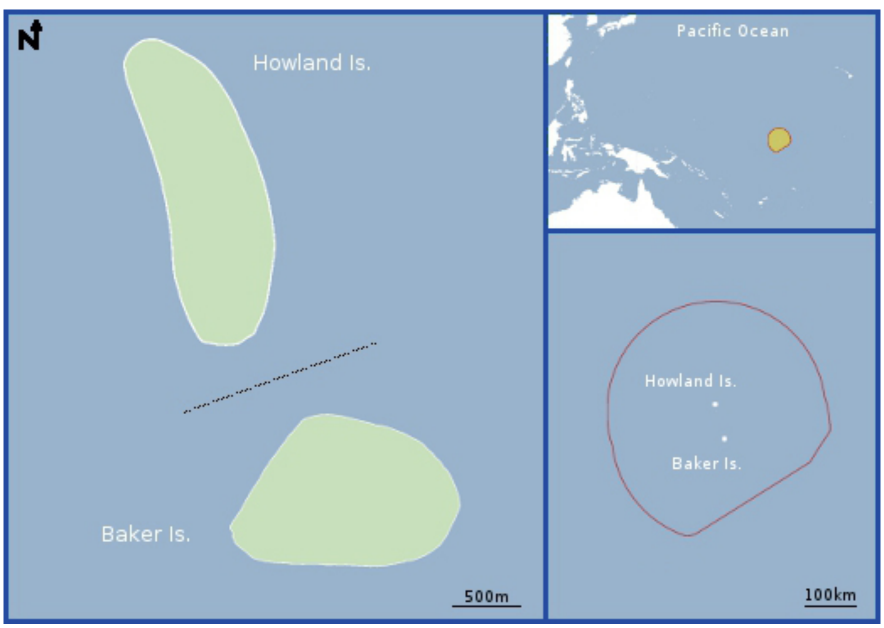

Figure 1. Baker and Howland islands; top right panel: location in the Central Pacific Ocean; bottom right panel: proximity of the two islands. (Image source: Pacific Islands Ocean Observing System (PacIOOS).

1.2 Climate and Geology/Oceanography

The seafloor surrounding the PRIA has provided evidence that Howland was formed about 70–72 million years ago (Maragos *et al.* 2008). Since Baker and Howland are so close in proximity, scientists have hypothesized that the islands formed around the same time period. The reefs surrounding the islands developed while the islands themselves were still forming from volcanic activity. As the islands gradually subsided, the reef continued to grow upward to remain near the sea surface for light availability.

Relatively small, low reef islands, Baker has an elevation of only 8 m and land area of 2.1 km^2 while Howland has an elevation of 3 m and a land area of 2.6 km^2 (Maragos *et al.* 2008). Since the islands have no ridges rising from the deep ocean, but are just isolated peaks, their flanks of the islands have a very steep slope, between 30°–40° and reach a depth of about 1,000 m. There are areas of both islands with low slopes that lead to shallow terraces at depths of 7–17 m (Maragos *et al.* 2008). In addition, Howland Island has more terraces at multiple depths on the northeast, northwest, and south sides of the island (Maragos *et al.* 2008).

Fringing reefs encircle Baker and Howland, but due to the orientation of each island, at different locations; Baker is extended in an east-west direction, while Howland is in a north south direction (Figure 1) (Maragos *et al.* 2008). Baker Island has steep reef slopes that reach large depths on the west, north, and south sides of the island. On the eastern side, a reef terrace extends from 3–20 m depth, where it then plunges to great depths (Maragos *et al.* 2008). Howland has the broad reef terrace on the north and south ends of the island. There is a minor fringing reef crest along the western side of Howland followed by a steep slope to great depths. Howland experiences strong currents, onshore winds, and swells that make it difficult to study the reef (Maragos *et al.* 2008).

Located in close proximity to the equator, Baker and Howland experience westward flowing surface currents and eastward flowing subsurface countercurrents caused by the easterly Trade Winds (Maragos *et al.* 2008). The Equatorial Undercurrent (EUC) and the South Equatorial Current (SEC) are two major ocean currents that affect the islands. The EUC flows eastward and carries cold nutrient rich water directly below the SEC that flows westward with slightly weaker and warmer currents (Maragos *et al.* 2008).

Baker and Howland generally have consistently warm sea surface temperatures of about 28°C due to the equatorial western warm pool in the Pacific (Maragos *et al.* 2008). There is little seasonal variation in sea surface temperatures. El Niño Southern Oscillation (ENSO) events have the ability to alter the sea surface temperatures, currents, and winds of Baker and Howland. When the trade winds weaken during an ENSO event, the islands experience warmer than average sea surface temperatures, occasionally resulting in coral bleaching (Maragos *et al.* 2008).

1.3 Background

1.3.1 U. S. Acquiring of the Islands

Baker Island was first discovered by an American whaling ship in 1832 but was not claimed by the United States until 1838 (Maragos *et al.* 2008). Baker received its name from the captain of the whaling ship, Michael Baker. Howland Island was discovered and named by George Netcher, a New England whaler, in 1842.

Both Baker and Howland were claimed by the United States for guano extraction through the Guano Islands Act of 1856 (Maragos *et al.* 2008). Guano consists of seabird droppings high in phosphates. At the time, the phosphates were widely used in agriculture, as commercial fertilizer, and for the military, in explosives. Captain Baker sold his rights to Baker in 1855 to the American Guano Company while Howland was claimed by two guano companies, the American Guano Company and a firm owned by Arthur Benson (Maragos *et al.* 2008). The two islands were also claimed by the United Kingdom from 1886 to 1934 (Maragos *et al.* 2008). With both countries mining guano from the islands, the deposits were largely exhausted by the end of the nineteenth century. Without the guano, there was no use for the islands and they were abandoned. The mining of guano had a large impact on Baker and Howland by modifying the land surface and lagoons.

1.3.2 Occupation of the Islands

For a brief period from 1935 to 1944, Baker and Howland were occupied by military personnel and a group recognized as Hui Panala'au (USFW 2007; Maragos *et al.* 2008). The group consisted of high school graduates of the Hawaiian Kamehameha Schools. In 1937, an airfield was constructed at Howland to assist the military personnel stationed on the island (USFW 2007; Maragos *et al.* 2008). In Amelia Earhart's attempt to fly around the world, she was scheduled to stop at Howland to refuel, but disappeared en route. An attack on Howland in the midst of World War II by the Japanese military killed two of the Hawaiians residing there, leading to the evacuation of all civilians from the two islands in 1942 (Maragos *et al.* 2008). Baker and Howland gave the U.S. an advantage in the war, with their proximity to Japan and Japanese occupied islands and atolls. An airstrip was constructed at Baker Island in 1943 to further assist in the war efforts (USFW 2007; Maragos *et al.* 2008).

With the end of the war, Baker and Howland were abandoned by the military by March of 1944 (Maragos *et al.* 2008). The military construction on Baker and Howland has had a lasting effect on the islands. Alien species such as weeds and rats were introduced. Seabird populations were nearly destroyed with the introduced rat predator. Channels were created in the reef by the military to allow small boats to easily access the island before the airstrips were built. Further damage to the reef came from toxic waste and iron debris.

1.4 Objectives of Study

The overarching goal of this study is to describe the status of the benthic composition of the reefs at Baker and Howland islands. The geographic proximity of Baker and Howland has allowed for comparison of the main benthic taxa found at different depths and different locations around the islands. The secondary goal of this study is to determine how the reefs have changed recently by using data collected from 2012–2017. By comparing and observing changes of the reefs at Baker and Howland over the past five years it is possible to predict which main benthic taxa species are more resilient and how the reef composition may transform over coming years.

2.0 METHODS

Benthic images were taken of the reefs surrounding Howland and Baker by the Ecosystem Sciences Division of the National Oceanic Atmospheric Administration Pacific Islands Fisheries Science Center. The images were obtained during the Pacific Reef Assessment and Monitoring Program (RAMP) cruise to the Pacific Remote Island Marine National Monument, for the years 2012, 2015, and 2017. The benthic survey images were then annotated using CoralNet (Beijbom *et al*. 2015).

2.1 REA Surveys

In order to measure the percent cover of the reef habitat of the islands, the Rapid Ecological Assessment (REA) survey method was used. REA surveys provide high-resolution images that allow fine-scale analysis of the benthic community composition. The sites for the REA survey are selected with a depth-stratified random approach (Swanson *et al.* in review). At each REA site, 30 images are collected using a digital camera mounted on a monopod (Figure 2). The images are taken along two 18 m transect lines (Swanson *et al.* in review). The divers move along the transect lines and take photos ranging in three different depth strata. Shallow depth is classified as 0–6 m, mid depth as 6–18 m and deep depth stratum is 18–30 m (Swanson *et al.* in review). The survey design is such that the survey effort allocation is proportional to the amount of hard-bottom within each depth stratum. Due to the steep slopes found at Baker and Howland, more sites are found in the mid depth stratum. Table 1 shows the number of sites surveyed at each depth stratum for the three years RAMP cruises were completed. The number of sites REA surveys completed depended on the amount of time allotted for each island in the Pacific Remote Islands Area during the RAMP cruises. Once all of the photos are collected by the benthic and fish team, they are uploaded to CoralNet.

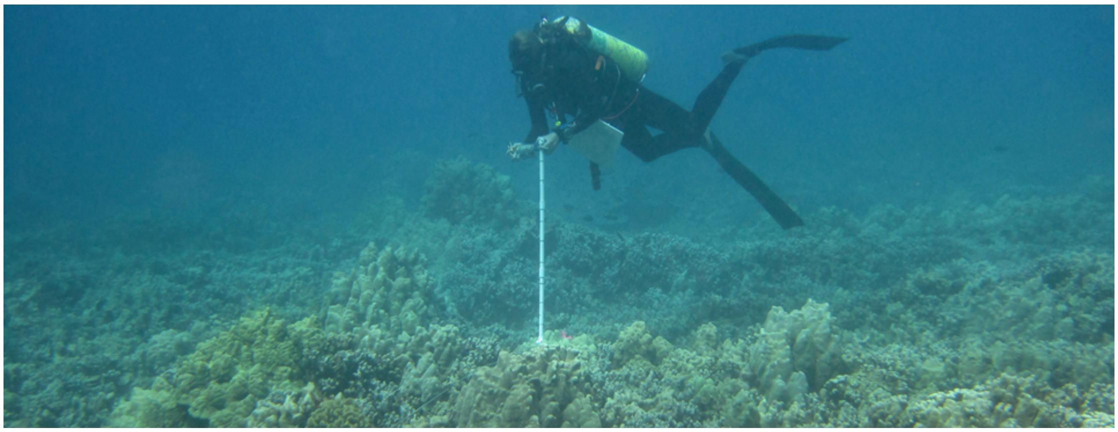

Figure 2. An example of a diver collecting benthic images. The device used in the photoquadrat surveys is a monopod made of one meter of PVC. An underwater camera in water safe housing is used to capture images. Photo courtesy of NOAA.

Table 1. Number of REA survey sites completed for each of the three depth strata at Baker and Howland islands

	SHALLOW	MID	DEEP	TOTAL
Baker 2012	5	12	7	24
Howland 2012	10	15	12	37
Baker 2015	15	22	14	51
Howland 2015	22	19	15	56
Baker 2017	9	8	6	23
Howland 2017	7	7	6	20

2.2 CoralNet

CoralNet is a web-based annotation tool that allows accurate and consistent image analysis of benthic communities. Every image will have ten points randomly placed over the image, by the CoralNet software, to analyze (Beijbom *et al.* 2015). The analyst identifies which benthic category lies directly beneath the point's cross-hair.

Images are annotated using a level of taxonomic resolution identified as Tier 3b, which classifies coral and macroalgal taxa to the genus and morphology functional-group-levels (e.g. *Acropora* branching, *Montipora* encrusting/non-encrusting; *Peyssonelia,* blue-green macroalgae, green algae) (Lozada-Misa *et al.* 2017). All of the categories are listed in a grid at the bottom of the screen, and there are 94 categories total (Figure 3). In order to keep the grid concise, abbreviations are used for the categories. Once all points are confirmed and a category is selected and entered into the cells on the right of the screen, the image is fully annotated. In order to consistently and accurately annotate the images for my study, I had to complete training and a number of calibration exercises to learn the genera and species typically found in the Pacific Remote Islands.

When annotating an image and a point is difficult to identify, first it should be discussed with a colleague and if still unsure it should be classified as Unknown. If a point is placed in a dark spot on the image and difficult to identify, it should be classified as Shade/Shadow. A number of categories are available to choose from used to classify points that land on benthic organisms including: mobile fauna, giant clam, and unclassified sessile invertebrate to name a few. There are also categories available if a point lands on a part of the seafloor consisting of plain substrate or sand. Figure 4 demonstrates what an image might consist of.

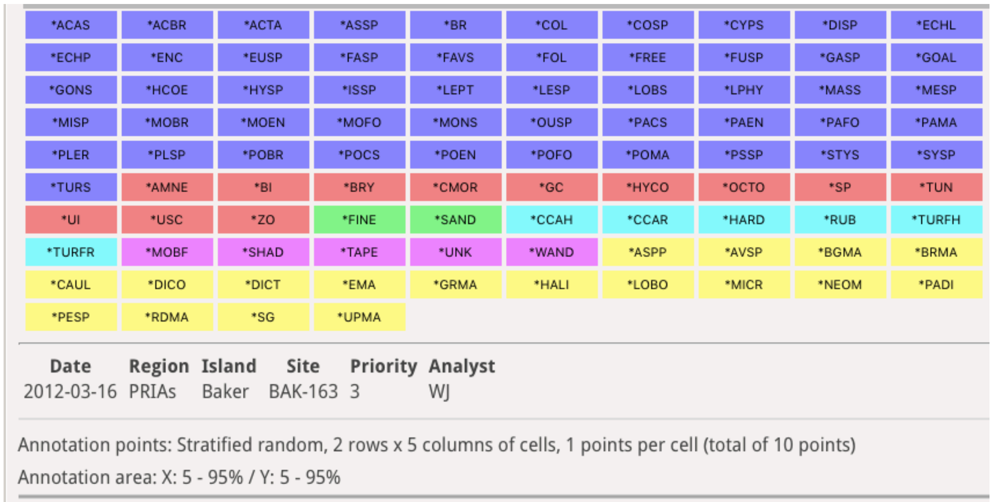

Figure 3. The abbreviations for the category choices for every image. Images obtained from coralnet.ucsd.edu.

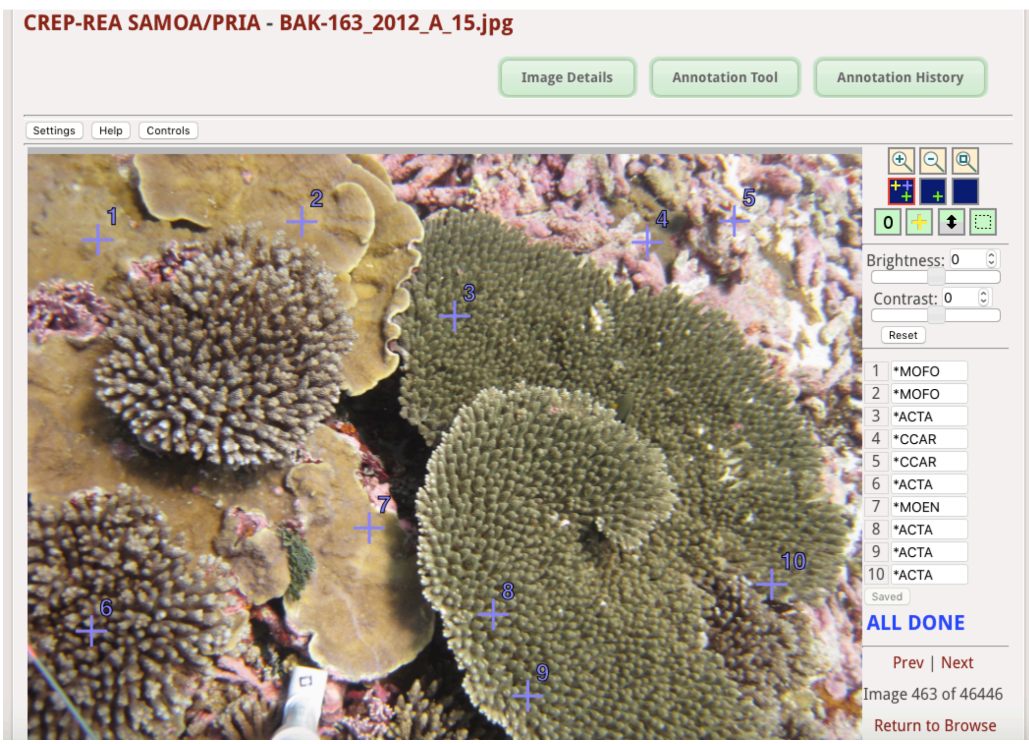

Figure 4. A fully annotated photo from Baker Island 2012. Images obtained from coralnet.ucsd.edu.

2.3 Calculations

Once all of the images from each year, 2012, 2015, and 2017, were completely annotated, the full annotations for both Baker and Howland were downloaded from CoralNet. The data is organized in an excel file displaying the site at which the image was taken, the label of every point on each image, the annotator, and the date it was annotated.

The data was reorganized using a pivot table to display the site and how many categories were selected for the entire site. The end of the table has a grand total, which is usually 300 due to the typical 30 images and 10 points per image, for every site. The grand total was modified to exclude points that were labeled Wand or Tape, due to those points not being part of the benthic cover and unavoidably being captured when taking the images.

With the new grand total, the categories were collapsed into basic functional groups including coral, coralline algae (CCA), macroalgae, turf, corallimorph, and other. It is important to note that for simplicity of this project the macroalgae functional group included fleshy macroalgae, calcified macroalgae (*Halimeda*), encrusting macroalgae, and blue-green macroalgae. The specific taxa found in each functional group can be found in Appendix 1. These groups were chosen based on their significance to the benthic cover as seen by the annotations. The group "turf" includes points annotated that have a carpet-like algae that covers a hard surface (Lozada-Misa *et al.* 2017). The categories grouped in "other" included some marine organisms that are not part of the benthic composition or were not seen often in the images, and therefore the number of annotated points for those categories was small compared to other categories such as specific corals, coralline algae, and macroalgae.

To determine the benthic cover of every site, the percent cover of the six groups was calculated. This was done by adding up all of the points annotated in those groups, dividing it by the total amount of points annotated for that site and multiplying it by 100. For both Baker and Howland, the sites were arranged into year and depth strata. The average percent cover was taken for each year, 2012, 2015, and 2017, and for each depth strata, shallow, mid depth, and deep for all of the six groups. Finally, the standard deviation was calculated to find the standard error, which was a measure of the dispersion of the data. A number of non-parametric tests were run to determine any significant differences in the functional groups by depth for each year as well as any significant differences between Baker and Howland for each functional group at each depth strata for each year.

To obtain a more detailed understanding of the reef composition for 2017, the cover for specific taxa that exhibited the highest counts for the coral and macroalgae functional groups was determined. Average percent cover for each depth strata means were estimated for each functional group as well as specific taxa including *Acropora, Montipora, Pocillopora Porites,* encrusting macroalgae, and *Halimeda* (e.g. the average percent cover of *Acropora* at shallow depth).

3.0 RESULTS

3.1 Current Status of the Reefs

The first part of the results identifies reef composition using the latest data collected, in 2017, to determine the current status of the reef.

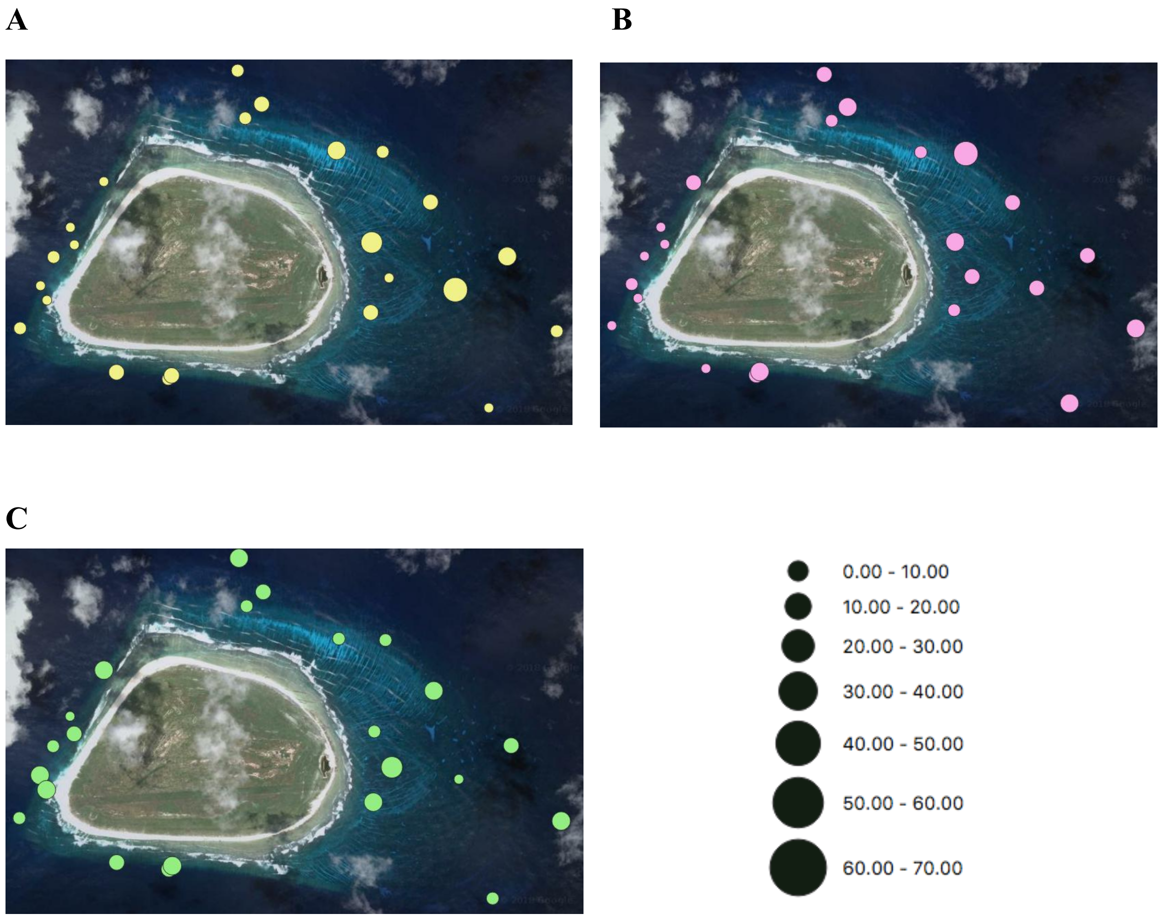

*Figure 5. Bubble plots display the REA sites for Baker Island 2017 and the average percent cover of coral (**A**), coralline algae (**B**), and macroalgae (**C**) found at each REA site.*

Figure 5 shows the abundance of each main functional group at each REA site surveyed in 2017. There were more REA sites for Baker on the east and west sides of the island, due to the fringing reef terraces found there. For all three functional groups, coral, coralline algae, and macroalgae, the greatest abundance was found on the east side of the island, where the reef is shallow and well lit. Coral cover was very low on the north, south, and west sides of the island, while coralline algae and macroalgae cover was greater on the west side. Although more coralline algae were found on the west side than coral, the abundance was relatively low compared to macroalgae. The abundance of macroalgae around Baker Island was relatively consistent.

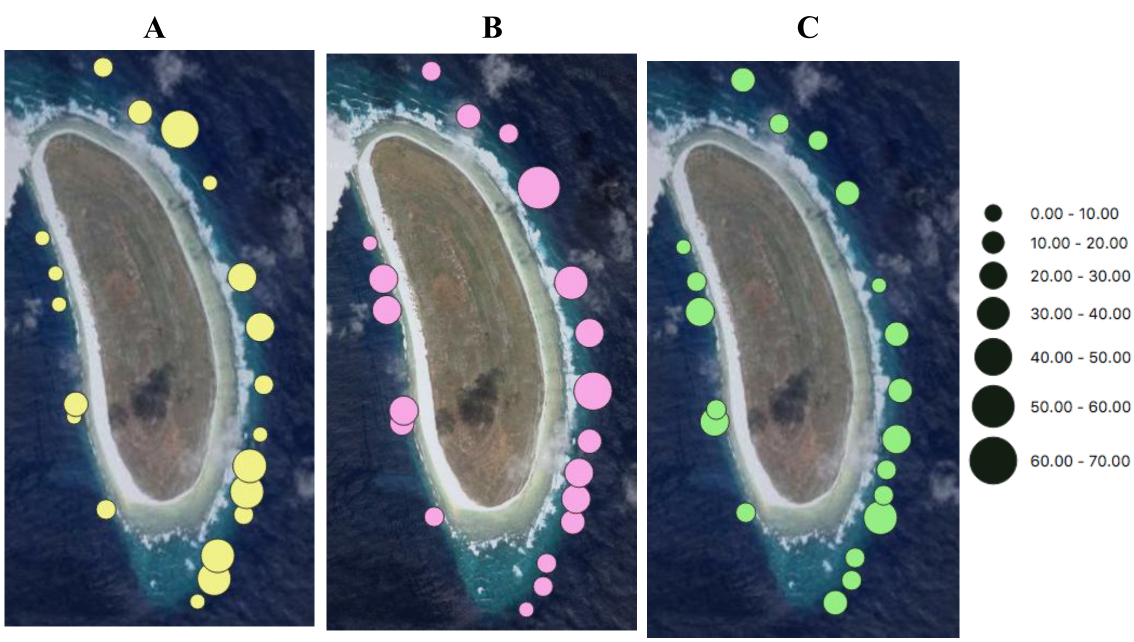

*Figure 6. Bubble plots display the REA sites for Howland Island 2017 and the average percent cover of coral (**A**), coralline algae (**B**), and macroalgae (**C**) found at each REA site.*

Figure 6 shows a greater abundance of REA sites found along the east side of Howland where shallow, well-lit reef terraces are found. The coral and macroalgae bubble plots show abundance increasing toward the tips of the island. There is notably less REA sites and abundance of all three functional groups on the west side of the island, likely do to the strong currents, swells, and winds that limit surveying (Maragos *et* al.

2008). Coralline algae had significantly larger abundances than coral and macroalgae at a number of REA sites.

Figure 5 and Figure 6 focus on where and how much coral, coralline algae, and macroalgae were found around Baker and Howland. To obtain an overall understanding of the reef composition, the average percent cover is divided into the three depth strata where surveys were completed.

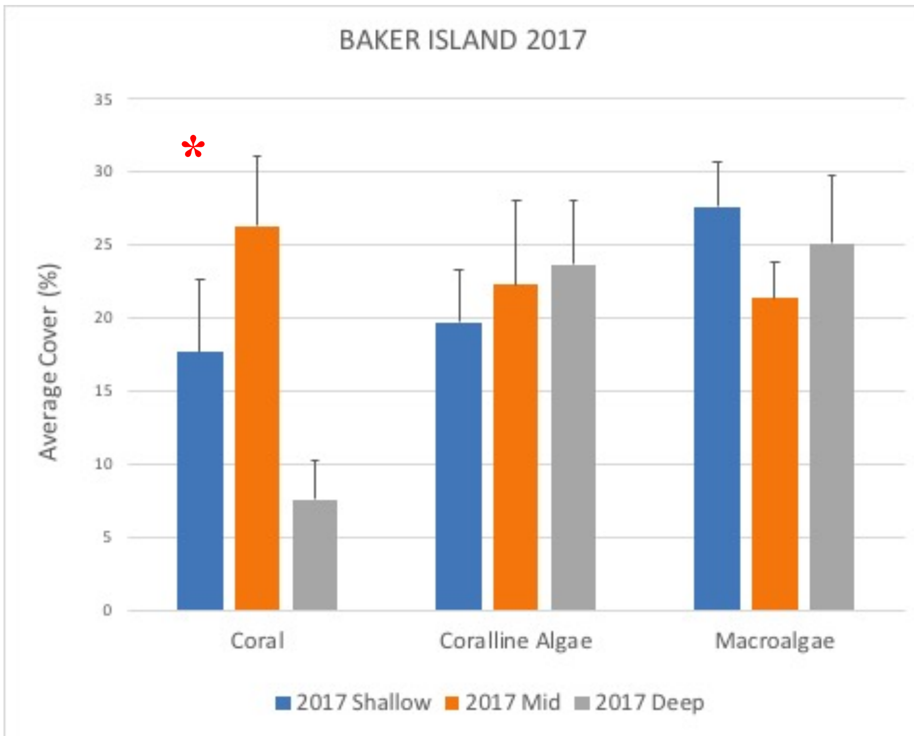

Figure 7. The average percent cover for the three main functional groups that compose the benthic cover at Baker Island at the three different depth strata. The red asterisk indicates that there is a significant difference of coral cover relative to depth.

Figure 7 shows macroalgae represented the greatest percent cover at Baker Island in the shallow and deep strata, while scleractinian corals in the mid depth. The average percent coral cover was significantly lower at the deep stratum. Coralline algae and macroalgae cover did not differ significantly with depth.

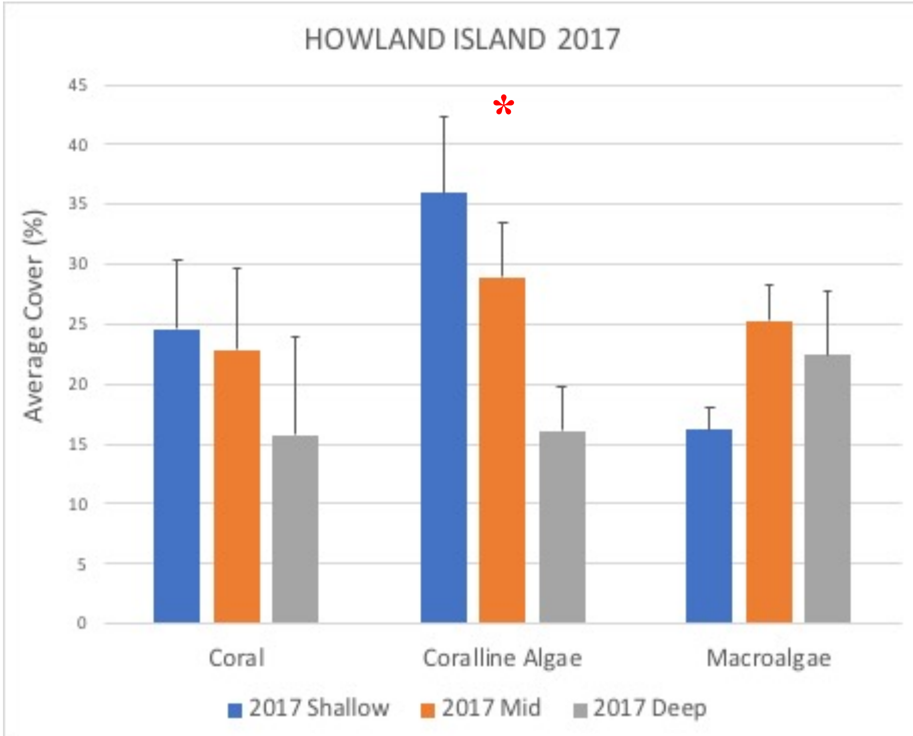

Figure 8. The average percent cover for the three main functional groups that compose the benthic cover of Howland at the three different depth strata. The red asterisk indicates that there is a significant difference of coralline algae cover relative to depth.

In comparison, on Howland Island coralline algae cover was significantly lower at the deep stratum, while coral and macroalgae did not vary significantly with depth (Figure 8). Overall, Howland Island overall had more coral and coralline algae cover than Baker Island; comparatively Baker Island had a higher abundance of macroalgae.

For an enhanced understanding of benthic composition, the average percent cover of each specific taxon for both Baker and Howland is listed in Table 2.

Table 2. Benthic cover for the most abundant coral and macroalgae taxa at Baker and Howland islands. The four coral taxa include Acropora*,* Montipora*,* Pocillopora*, and* Porites*, and the two macroalgae taxa are encrusting macroalgae and* Halimeda*. The total percent for coral is the average percent of coral cover for Baker and Howland for each three depths in 2017. The same system was applied to macroalgae. All numbers for the taxa are calculated as the average percent at each depth.*

BAKER

Depth 2017	Coral					Macroalgae		
	Total %	*Acropora*	*Montipora*	*Pocillopora*	*Porites*	Total %	Encrusting macroalgae	*Halimeda*
Shallow	17.66	64.85	20.39	4.27	0.27	27.62	77.10	12.30
Mid	26.29	86.20	4.39	0.93	3.73	21.34	93.44	3.47
Deep	7.59	5.01	0.90	9.54	11.13	25.12	86.93	6.38

HOWLAND

Depth 2017	Coral					Macroalgae		
	Total %	*Acropora*	*Montipora*	*Pocillopora*	*Porites*	Total %	Encrusting macroalgae	*Halimeda*
Shallow	24.59	22.99	62.35	4.49	7.31	16.20	82.19	7.59
Mid	22.84	47.38	26.09	6.51	10.11	25.32	82.94	4.62
Deep	15.77	33.21	2.13	17.48	19.84	22.43	91.84	5.44

The Baker Island data shows that the coral taxa with the greatest abundance in the shallow and mid depth were *Acropora* and *Porites* in the deep stratum*.* For the shallow stratum, 17.66% of the benthos was classified as coral; 64.85% of that consisted of *Acropora* of which counts of *Acropora* branching were notably greater than the table colonies. *Porites* had the lowest average percent cover in the shallow stratum, with only 0.27% being classified as branching, encrusting, foliose, or massive. The mid depth for Baker had the highest coral abundance, with 26.29% of the benthic cover being classified as coral. *Acropora* comprised a substantial portion (86.20%), while *Pocillopora* had the least percent cover at only 0.93%. Baker Island's deep stratum had a total average percent of 7.59% coral cover. *Porites* had the highest abundance, with 11.13% cover, while *Montipora* had the lowest cover of 0.90%. *Montipora* had the second highest average percent cover in the shallow and mid depth strata, and the decline in cover in the deep stratum is notable (Table 2).

The macroalgae at Baker Island consisted mainly of encrusting macroalgae (EMA) and *Halimeda.* In every depth stratum, EMA had the highest abundance, but it was very substantial in mid depth where it represented 93.44% of the macroalgal cover. *Halimeda* abundance was highest in the shallow and lowest at the mid depth.

The Howland Island coral composition was slightly different than Baker. The total average percent coral cover was substantially higher in the shallow and deep strata. *Acropora* was not as abundant at Howland, but it was still the most abundant coral taxon in the mid and deep depth strata. With *Acropora* cover notably lower, the other three taxa had a higher abundance in every depth strata compared to Baker Island. In the shallow depth stratum, *Montipora* was the most abundant, representing 62.35% of the coral cover (Table 2).

The macroalgae composition for Howland Island looked similar to that of Baker in the mid and deep strata. The total average percent cover of macroalgae in the shallow depth for Howland was sizably lower than Baker Island where the shallow depth stratum had the most abundant cover of macroalgae. The two main taxa for Howland were the same as Baker: EMA and *Halimeda.* At Baker, the mid depth stratum had a substantial cover of EMA, while at Howland the deep stratum had the most significant cover. Of the 22.43% of the benthic cover classified as macroalgae in the deep stratum, 91.84% of that cover was EMA. *Halimeda* cover in the shallow stratum at Howland was lower than Baker, but that was still the depth strata with the highest abundance of *Halimeda.*

3.2 Comparison Between Baker and Howland

The second part of the results was configured to compare each main functional group, coral, coralline algae, and macroalgae, by year and to examine the difference in both islands. Benthic cover patterns for coral, coralline algae, and macroalgae was variable for space and time for both islands.

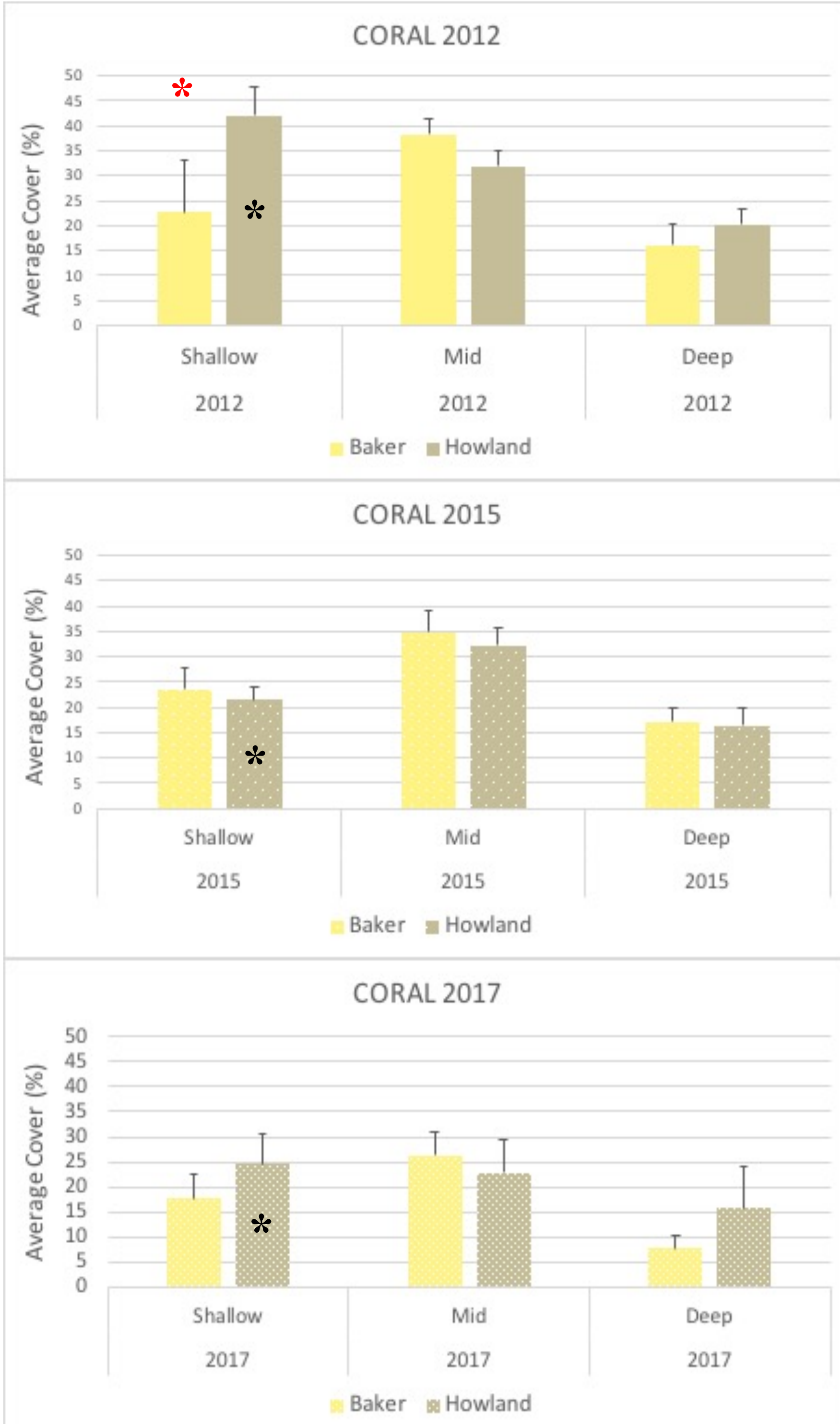

Figure 9. Spatial and temporal patterns of mean coral cover at Baker and Howland islands. Significant differences between islands are indicated by a red asterisk ($p<0.05$). Black asterisk indicates significant temporal differences ($p<0.05$).

Overall, the spatial coral composition for Baker and Howland were similar, except for the 2012 shallow stratum which was significantly higher at Baker (Figure 9). The temporal variations show that Howland Island's shallow stratum was significantly different over the three years data was collected. From 2012 to 2015 the percent coral cover of Howland's shallow stratum notably decreased, then slightly increased from 2015 to 2017. In all three depth strata, Baker saw the most substantial decrease in percent coral cover between 2015 and 2017, however it was not significant. In comparison, Howland saw a slight decrease in the mid and deep depths. For all three years data was collected, Baker consistently had the highest percent coral cover in the mid depth stratum, creating a dome shaped trend. Howland Island had a slightly different trend with the greatest percent coral cover in the shallow stratum and cover decreasing with depth for the years 2012 and 2017. For both Baker and Howland, the shallow and mid strata had the most coral cover consistently over time.

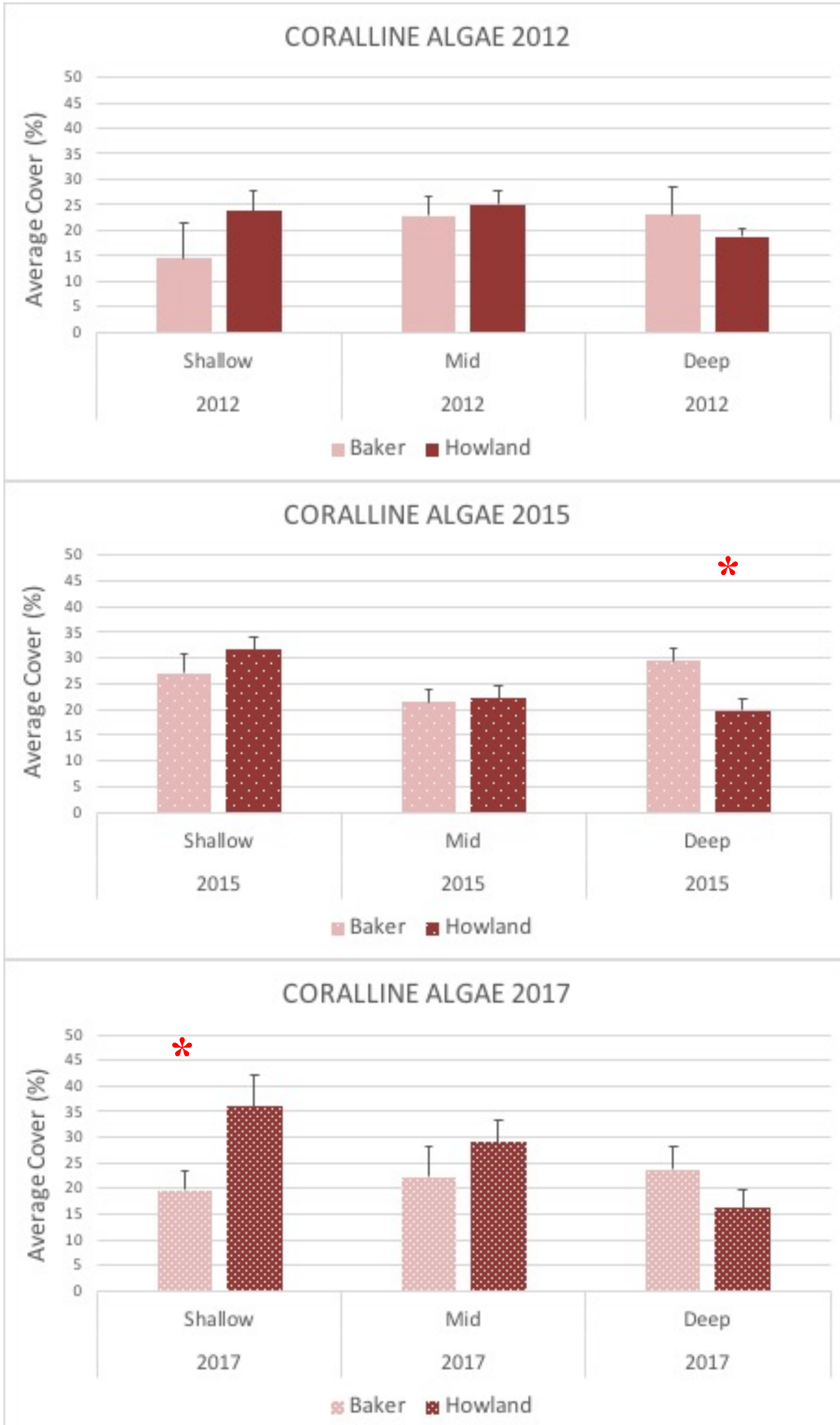

Figure 10. Spatial and temporal patterns of mean coralline algae cover at Baker and Howland islands. Significant differences ($p<0.05$) between islands are indicated by a red asterisk.

The patterns observed in the spatial and temporal crustose coralline algae (CCA) composition for Baker and Howland were not as obvious as those observed for coral composition (Figure 10). CCA cover was similar for both islands except in the 2015 deep stratum and 2017 shallow stratum. In the 2015 deep stratum cover at Baker was significantly greater than at Howland and in the 2017 shallow stratum cover was significantly greater at Howland Island. The average percent cover of CCA was the lowest in 2012, increased in 2015 and decreased in most depth strata for both islands in 2017. Howland Island consistently had a larger percent cover in the shallow and mid depth strata for all three years, while Baker did in the deep stratum. The percent cover for both the shallow and mid depth were very similar for Howland, while the percent cover for the mid and deep depths were very similar for Baker. Comparing the strata specific cover between 2012 to 2015, there was a large increase in the percent cover in the shallow, a slight decrease in mid, and an increase in cover of the deep of both Baker and Howland islands. In 2017, we start to see a shift towards decreasing CCA cover in most depth strata for both islands except for Howland's shallow and mid depth. It is important to note the increase in percent cover for Howland Island's shallow depth from 2012 to 2017, however it was not significant. In addition, Baker Island's mid depth cover has remained very similar in all three years data was collected. Despite variations in temporal changes of CCA cover, no depth strata for each island had significant differences.

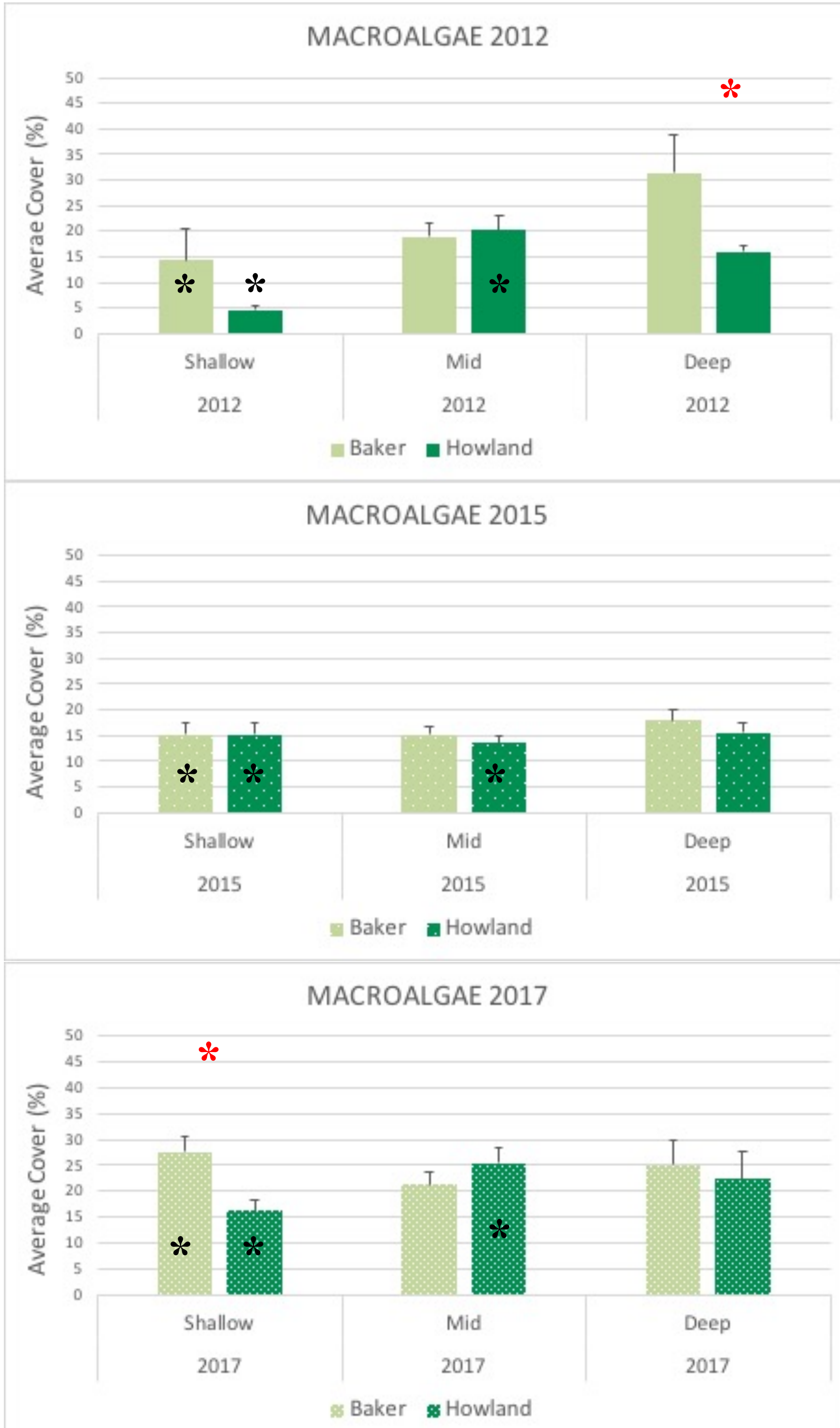

Figure 11. Spatial and temporal patterns of mean macroalgae cover at Baker and Howland islands. Significant differences between islands are indicated by a red asterisk (p<0.05). Black asterisk shows significant temporal differences (p<0.05).

Figure 11 illustrates macroalgae cover; some patterns to note are as follows. Macroalgal cover varied greatly over all depths for both islands from 2012 to 2017. In 2012, the lowest percent cover for both islands was found in the shallow depth, while the highest for Baker Island was in the deep stratum and Howland in the mid depth stratum. Baker Island had a significantly greater average percent cover than Howland in the 2012 deep stratum and the 2017 shallow stratum (Figure 11). Howland Island's shallow and mid depth strata had a significant change in macroalgae cover over the three years data was collected. The percent cover for Howland in the shallow depth was substantially low in 2012, and we saw a large increase in 2015. Howland Island's mid depth stratum has a significant increase from 2015 to 2017. Baker Island's shallow stratum had significant temporal variations with a large increase in macroalgae cover from 2015 to 2017. Baker Island had a decrease in percent cover in the mid depth from 2012 to 2015 and a notable decrease in the cover of the deep stratum, however these were not significant. In 2015, both Baker and Howland had very similar macroalgae cover at every depth. From 2015 to 2017, there was an increase in cover at all three depths for both islands. For all years, macroalgae cover was the greatest in 2017 for both islands across all depth, except for Baker's cover in the deep strata in 2012. Overall, macroalgae cover was variable, never consistently high or low.

4.0 DISCUSSION

Baker and Howland were islands used in the World War II campaign, but since then they have remained relativity free from of human contact. The changes being observed to the reef are due to natural occurring disturbances, not direct anthropogenic disturbances. However, the benthic cover of Baker and Howland islands has varied over space and time.

4.1 Spatial and Temporal Comparisons

Despite some of the noted differences, the statistical tests indicate that cover varies greatly within depth strata and that is the reason there are not many differences across space and time.

Overall, coral cover only significantly decreased for Howland Island in the shallow stratum and cover was relatively similar for both islands except 2012 in the shallow stratum. Corals are sensitive to changes in temperature and different species of coral respond differently to temperature variations. For example, branching corals such as *Acropora* and *Pocillopora* are fast growing but are more sensitive to elevated temperature (Vargas-Ángel *et al*. 2011; Marshall & Schuttenberg, 2006).

A study at Baker and Howland conducted in 2006 shows that Baker's coral composition had a greater configuration of *Acropora* branching and turf algae, while Howland had more coralline algae and small compact corals, such as *Pocillopora* (Vroom *et al.* 2010). Table 2 shows that Baker has a greater composition of *Acropora* in the shallow and mid depth strata than Howland. However, there was a decline in *Acropora* composition in the shallow and mid strata from 2015 to 2017 at Howland, and an increase at the same strata for Baker. *Acropora* cover at Howland in 2017 was already less than Baker, but competition for space and light along with temperature change might have had a more substantial impact at Howland Island (Vroom *et al.* 2010). This shows that since 2006, Baker has maintained a higher composition of branching *Acropora*. In contrast, Vroom *et al.* (2010) found that Howland had a higher composition of *Pocillopora,* which was still present in all three depth strata in 2017. *Pocillopora* cover has decreased over time at Baker Island, particularly in the shallow and mid depth strata from 2015 to 2017. The cover of *Acropora* and *Pocillopora,* two species susceptible to thermal bleaching, is almost the opposite at Baker and Howland islands. The overall reef composition of Baker and Howland has changed over time but looking at specific coral genera shows that each island still maintains higher composition of the same coral taxa since 2006 (Vroom *et al.* 2010).

A study documenting the effects of the 2009–2010 El Niño event at Baker and Howland indicated that *Montipora* was overall the most resistant taxon to bleaching (Vargas-Ángel *et al.* 2011). For both Baker and Howland, *Montipora* composition only declined in the shallow stratum from 2015 to 2017. This could be partially due to morphology, as massive species are more tolerant to changes in temperature (Vargas-Ángel *et al.* 2011). Other factor such as disease and physiology can affect bleaching in addition to thermal stress.

Due to the irregular cover patterns over space and time for coralline algae and macroalgae, causes of the change in reef composition are difficult to pinpoint. Overall, spatial and temporal coralline algae composition was relatively similar for both islands, except for 2015 deep stratum and 2017 shallow stratum. Trends in macroalgae composition are not as clear as trends in coral and coralline algae composition. In the deep strata for 2012 and the shallow stratum for 2017 Baker Island had a significantly higher average percent cover of macroalgae than Howland. Both coralline algae and macroalgae are dependent on sunlight and there might be competition for space in the shallow and mid depth strata. Coralline algae cover at Howland was consistently highest in the shallow and mid depth strata for all three survey years, where light easily reaches the seafloor. Coralline algae and macroalgae cover could increase after coral bleaching events caused by thermal stress. The competition for space is lowered when corals bleach and/or die due to changes in temperature.

Macroalgae composition was studied in further detail to determine the specific taxa with the greatest abundance. The macroalgae composition for Baker and Howland is composed heavily of encrusting macroalgae, which can consist of either calcified like the red alga *Peyssonnelia,* or uncalcified like the brown alga *Lobophora* (Lozada-Misa *et al.* 2017). Such a high composition of encrusting macroalgae is rare and sea surface temperatures might be the reason (Vroom *et al.* 2010). A survey of the reef at Baker and Howland in 2006 revealed that the most dominant macroalga was the brown alga *Lobophora* (Vroom *et al.* 2010). However, composition of encrusting macroalgae from 2015 to 2017 remained similar except for a slight decrease in the shallow depth stratum at both Baker and Howland. *Halimeda* is the second most abundant taxa, but the average percent cover is far less than encrusting macroalgae. *Halimeda* composition had a very large increase from 2015 to 2017 in every depth strata for Howland and a substantial increase in the mid and shallow depth strata for Baker. As shown in Table 2, Baker Island has a greater average percent cover of *Halimeda* in the shallow and deep strata, which is corresponding to Vroom *et al.* (2010) study from 2006.

Although Baker and Howland are in close proximity to one another and have similar geomorphology, a comparison of the benthic community has shown that they are distinct in their coral, coralline algae, and macroalgae composition. Differences in the community structure might result from physical forces, habitat location around the island, and size of reef terraces (Vroom *et al. 2010)*.

4.2 El Niño Events

Due to the isolation of Baker and Howland and the fact that the islands are only surveyed by NOAA every three years, it is difficult to determine definite causes of the changes in reef. The natural disturbances, such as El Niño events causing extended periods of thermal stress and a decrease in primary productivity, are events we know have occurred even without being present at the islands (NOAA Coral Reef Watch Program, 2018). Therefore, these events, combined with typical reef competition and predation, are the likely cause of any major changes in the reef composition.

The El Niño event in 2009–2010 caused widespread coral bleaching at Baker and Howland, but mortality was not catastrophic (Vargas-Ángel *et al.* 2011). Surveys in 2012 showed few changes and suggested that the reef was already starting to recover (Brainard *et al.* 2018; Vargas-Ángel *et al.* 2011). This could be due to the fact that thermal anomalies may have not been as severe and/or prolonged as other locations and times. Another possibility the bleaching event was not catastrophic could be that the El Niño was quickly followed by a La Niña, which brought temperatures back to normal including the topographic upwelling at Baker and Howland that caused phytoplankton blooms (Brainard *et al.* 2018).

However, the major changes observed in the data from 2017 are the result of another El Niño event in 2015–2016 (Brainard *et al.* 2018). Distinct changes in the benthic cover at Baker and Howland islands can be observed from 2015 to 2017 (Brainard *et al.* 2018). The 2015–2016 El Niño event was not stronger than the 2009–2010 event, they were both considered moderate, but the lack of primary production following the 2015–2016 El Niño resulted in 'desertification' conditions hindering coral recovery (Brainard *et al.* 2018). In addition, the 2015–2016 El Niño occurred during a year with record high surface temperatures (Heron *et al.* 2016). The 2015–2016 El Niño was a primary factor of the most significant coral bleaching event on record, resulting in a decrease in coral cover from 2015 to 2017 at Baker and Howland islands (Brainard *et al.* 2018). Jarvis Island, located about 1830 km east of Baker and Howland islands, experienced substantially larger sea surface temperature anomalies during both the 2009–2010 and 2015–2016 El Niño events (Brainard *et al.* 2018). Catastrophic coral mortality and an island wide coral cover decline of > 95% occurred at Jarvis Island following the 2015–2016 El Niño event, while there was only moderate impact and a 23–31% loss in coral cover at Baker and Howland islands (Brainard *et al.* 2018).

Not only did the 20152016 El Niño event have an effect on Baker and Howland and nearby islands in the Pacific, but it triggered a pan-tropical coral bleaching episode (Hughes *et al.* 2017). In 2016, the Great Barrier Reef suffered extensive and severe bleaching, especially in the northern region of the reef. The weakening of the Leeuwin Current, which transports warm tropical waters south, from El Niño conditions resulted in latitudinal gradients in bleaching of Australia and offshore atolls in the Indian Ocean and Coral Sea (Hughes *et al.* 2017). Bunaken National Park, located in Indonesia, includes several islands that also suffered coral mortality from the 2015–2016 El Niño event (Ampou *et al.* 2017). A substantial sea level fall at the beginning of the El Niño period led to corals to be exposed above water and led to mortality (Ampou *et al.* 2017). The rapid fall in sea level in Indonesia had a significant effect on the reef before any ocean warming bleaching occurred (Ampou *et al.* 2017). Looking at reefs affected all over the world from thermal stress and sea level variation shows that even the most protected and pristine coral reef areas are highly susceptible to severe heat stress, sea level variations, and loss of coral cover. Baker and Howland island's remote location and protected waters do give an advantage as opposed to reefs such as the Great Barrier Reef and those in Indonesia that suffer from pollution and fishing in addition to thermal stress and sea level variations.

Increases in sea surface temperatures are becoming a more commonplace in recent years (Heron *et al.* 2016). Thermal stress to the reef community in the Central Pacific is slowly intensifying and climate models suggest that by the middle of this century coral bleaching events will occur more frequently until they occur annually (Hoegh-Guldberg, 2011; Heron *et al.* 2016). Mounting evidence leads researchers to believe that corals and other organisms of benthic composition will not be able to adapt with the changing ocean (Hoegh-Guldberg, 2011).

5.0 CONCLUSION

Despite the similarities in geomorphology and the proximity in Baker and Howland, they support slightly different reef communities. The composition of coral, crustose coralline algae, and macroalgae varies between the islands, which has been consistent over time despite changes to the reef composition. Baker Island has maintained a greater abundance of macroalgae while Howland Island has maintained a greater abundance of crustose coralline algae. Looking at the temporal variations for the three main functional groups revealed that average percent cover of coralline algae and macroalgae is often equaling or exceeding that of the scleractinian coral. Spatial variations of the reef show that most of the main functional groups making up the benthic composition are found in the shallow and mid depth strata, likely due to light availability.

This knowledge of spatial and temporal patterns in the coral reef community at Baker and Howland islands has revealed that although the specific coral genera with the highest average percent composition of the reef have remained stable, over time, coral cover has decreased. This is believed to be as a result of the 2015–2016 El Niño and increasing thermal stress to the reefs.

Coral reefs are reaching their bleaching threshold more often as sea surface temperatures increases from more intense El Niño events that reflect an anthropogenic influenced trend. Baker and Howland, islands with minimal human contact, appear to have thus far been unaffected by the global sea surface warming, but might start to see the effects of anthropogenic impacts on the reef composition in the near future.

APPENDIX

APPENDIX 1: List of Specific Taxa Included in Each of the Six Main Functional Groups.

Main Functional Groups	Specific Taxa Included in Group
Coral Group	*Acanthastrea* (ACAS)
	Acropora – branching (ACBR)
	Acropora – table (ACTA)
	Astreopora (ASSP)
	Branching hard coral (BR)
	Columnar hard coral (COL)
	Coscinaraea (COSP)
	Echinophyllia (ECHL)
	Echinopora (ECHP)
	Encrusting hard coral (ENC)
	Euphyllia (EUSP)
	Favia (FASP)
	Favites (FAVS)
	Foliose hard coral (FOL)
	Free-living hard coral (FREE)
	Fungia (FUSP)
	Goniopora/Alveopora (GOAL)
	Goniastrea (GONS)
	Hydnophora (HYSP)
	Isopora (ISSP)
	Leptastrea (LEPT)
	Leptoseris (LESP)
	Lobophyllia (LOBS)
	Massive hard coral (MASS)
	Merulina (MESP)
	Millepora (MISP)
	Montipora – branching (MOBR)
	Montipora – encrusting (MOEN)
	Montipora – foliose (MOFO)
	Montastraea (MONS)

	Pachyseris (PACS)
	Pavona – encrusting (PAEN)
	Pavona – foliose (PAFO)
	Pavona – massive (PAMA)
	Platygyra (PLSP)
	Porites – branching (POBR)
	Pocillopora (POCS)
	Porites – encrusting (POEN)
	Porites – foliose (POFO)
	Porites – massive (POMA)
	Psammocora (PSSP)
	Stylophora (STYS)
Crustose Coralline Algae Group	Crustose coralline algae on hard substrate (CCAH)
	Crustose coralline algae on rubble substrate (CCAR)
Macroalgae Group	*Asparagopsis* (ASPP)
	Blue-green macroalgae (BGMA)
	Brown macroalgae (BRMA)
	Caulerpa (CAUL)
	Dictyopteris and Dictyota (DICO)
	Dictyosphaeria (DICT)
	Encrusting macroalgae (EMA)
	Green macroalgae (GRMA)
	Halimeda (HALI)
	Lobophora (LOBO)
	Microdictyon (MICR)
	Padina (PADI)
	Peyssonnelia (PESP)
	Red macroalgae (RDMA)
	Upright macroalgae (UPMA)
Turf Algae Group	Hard substrate (HARD)
	Turf growing on hard substrate (TURFH)
	Turf growing on rubble substrate (TURFR)
Corallimorph Group	Corallimorph (CMOR)
Other Group	Fine substrate (FINE)
	Giant clam (GC)
	Mobile fauna (MOBF)

	Octocorals (OCTO)
	Rubble substrate (RUB)
	Sand (SAND)
	Shadow (SHAD)
	Sponge (SP)
	Tunicate (TUN)
	Unclassified sessile invertebrate (UI)
	Unclassified/Unknown (UNK)
	Zoanthids (ZO)

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