Environmental Effects on Spatial Distribution of *Montipora dilatata* in Kaneohe Bay

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Abstract

The Hawaiian Islands are home to many invasive species that are continuously being introduced through import ships and large vessels. The interactions and impacts these species have on the native ecology of marine organisms in Kaneohe Bay are a main concern for the coral communities dispersed within the patch reefs of the Bay. The need for conservation of the rare coral *Montipora dilatata*, was brought to the attention of the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) as itsabundance and distribution within the bay was decreasing and threatened by invasive algae. This concern has prompted NOAA to designate *M. dilatata* as a Species of Concern (SOC), and to investigate abiotic and biotic factors within the bay that may be jeopardizing these populations. Using GIS and previous data, patch reefs known to have *M. dilatata* colonies were surveyed to measure sedimentation, current flow, and macroalgae cover to assess their potential relationships to colony distribution. This study revealed that their appears to be impacts of current flow from incoming and outgoing tides and sedimentation on the distribution of *M. dilatata* colonies. Future research is necessary to further explore the environmental parameters of *M. dilitata* distribution in patch reefs in the northern section of the bay in order to effectively map and spatially manage *M. dilatata*.

Introduction

In 2004, the scleractinian coral, *Montipora dilatata* was placed on the NOAA National Marine Fisheries Services “Species of Concern” (SOC) list (NOAA 2007) due to its limited abundance and recent declines in Kaneohe Bay, Oahu. *Montipora dilatata* is thought to be one of the rarest coral species in the Pacific (Veron 2000). A distinct chocolate-purple color and branched morphology converging into flat tops was once thought to be characteristic of this species (NOAA 2004). However, in recent years it has been discovered that variable morphologies can be found within a single colony (Forsman *et al*. 2010) (Figure 1). This species has been identified in Kaneohe Bay, O’ahu and Maro Reef in the Northwestern Hawaiian Islands (Forsman et al. 2010) and very few colonies have been found in recent surveys (NOAA 2007).

Kaneohe Bay is also home to many introduced species of macroalgae that are negatively affecting the native corals in the bay by engulfing them and providing little shelter for native organisms (Russell and Balazs, 2009). Two of these invasive species are *Gracilaria salicornia* and *Eucheuma/Kappaphycus*, which are found abundantly throughout the bay and provide an alternative food source for marine organisms such as green sea turtles and sea urchins (Russell and Balazs, 2009). *Tripneustes gratilla* have been deployed on several reefs in the bay by Hawaii Department of Land and Natural Resources in an ongoing effort to manage alien algae and prevent their growth around *Montipora dilatata* colonies. In an effort to document macroalgae influence on *M. dilatata* growth, percent cover of these invasive species was quantified to assess their relationship to colony distribution.

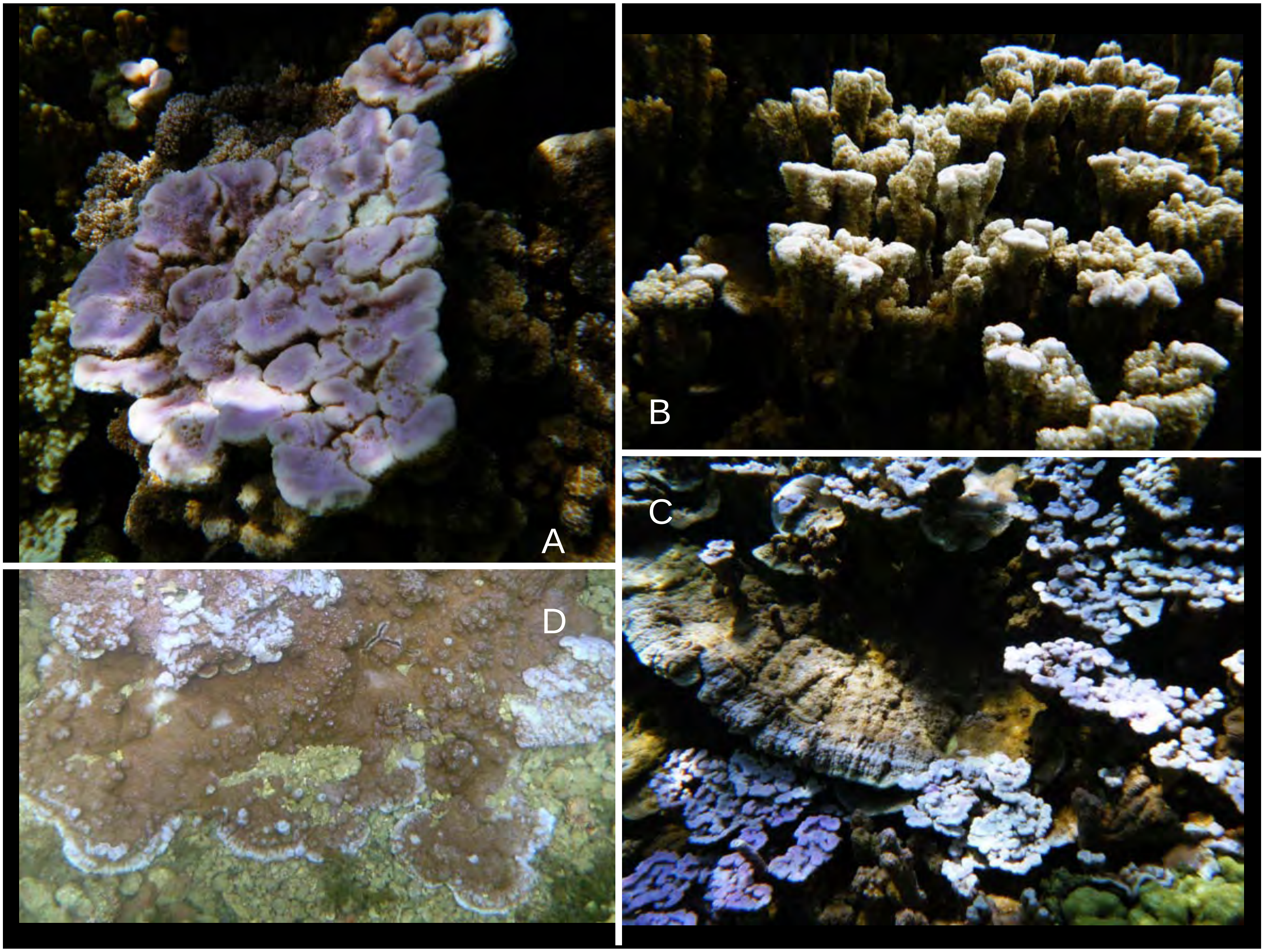

Figure 1: Differing morphological traits of *Montipora dilatata*: A) a branched colony of *M. dilatata*; branch heads generally have a distinctive flat tip, B) Branches and polyps from the side view may come in shades of brown as well as purple, C) Plating colonies have a ruffled edge, D) Encrusting colonies have short branches sporadically throughout the colony; colony edges are generally a lighter purple or white color while the center of the colony is a purple-brown.

Geographic Information System (GIS) has become an increasingly useful technique in the scientific community and more recently in the marine environment. GIS is particularly useful for mapping cities and community structure on land (Breman 2010) and is now being applied to reef ecosystems. By combining satellite imagery and infrared laser technology (Wedding et al. 2008) GIS may also incorporate LiDAR bathymetery to view a reef system on a spatial scale. From these spatial approaches, conclusions can be made to further understanding of important relationships and impacts that shape ocean ecosystems (Wright 2007, Graham 2006).

In order to predict areas of possible habitats for the NOAA Species of Concern, GIS technology was used to map population distributions and abundance of *M. dilatata* in Kaneohe Bay. Several reefs in Kaneohe Bay were studied extensively to look for conditions that may affect habitat preference for this species.

Methods and Materials

Snorkel surveys were conducted in Kaneohe Bay, and included patch reefs 12, 24, 43, 44, 54 (Figure 3). In teams of three, 50 meter transects were laid and five $0.25m^2$ quadrats were taken at random points within 10 meter intervals. The beginning and end point of each transect was marked using GPS and mapped with ARCGIS.

Quadrats were centered over the transect line, with the lower edge of the quadrat placed atop a randomly generated point (Figure 2B). Photographs of these quadrats were taken and within each, the percent cover of total macroalgae, *Euchema/Kappaphycus* and *Gracilaria salicornis* was recorded. Depth was measured at the randomly generated points on the transect from the highest point on the reef to the water's surface.

An apparatus was constructed to measure the turbidity and flow and placed at the zero meter mark on the transect (Figure 2A) for a period of 48 hours. The apparatus consisted of a suspended falcon tube secured to fishing line and stabilized with several zip ties 0.25 meters above the reef. A plaster cube (to measure relative water motion) was fastened below the sediment trap and a balloon kept the apparatus afloat and provided aid in finding the traps for collection. The locations for deployment of this apparatus were recorded using GPS.

Upon collection of the falcon tubes, caps were fastened. Sediment was filtered on a pre-weighed, 30μm mesh coffee filter and dried for 12 hours before being weighed to compare sedimentation rates among patch reefs. Plaster cubes were weighed before being deployed and a control for the cubes was generated by placing a single cube in a bucket of seawater for 48 hours. All cubes were weighed after drying for 24 hours. The weight loss of the control cube was subtracted from the weight loss of the experimental cubes and the rate of dissolution was calculated based on this final weight.

To record temperature, HOBO data loggers were deployed on patch reefs 43 and 44 (Figure 2C). Four of these devices were placed from north to south on reef 44 using predetermined GPS points. The remaining two HOBO data loggers were placed on reef 43. Snorkelers started at the center of the reef, tied the HOBO to sturdy substrate and marked the location with GPS. Using a compass, the snorkel team swam directly south to the reef edge, secured the HOBO, and marked the end point using GPS.

Temperature, flow rates and sedimentation rates were compared to the known distributions of *Montipora dilatata* colonies using ARCGIS maps.

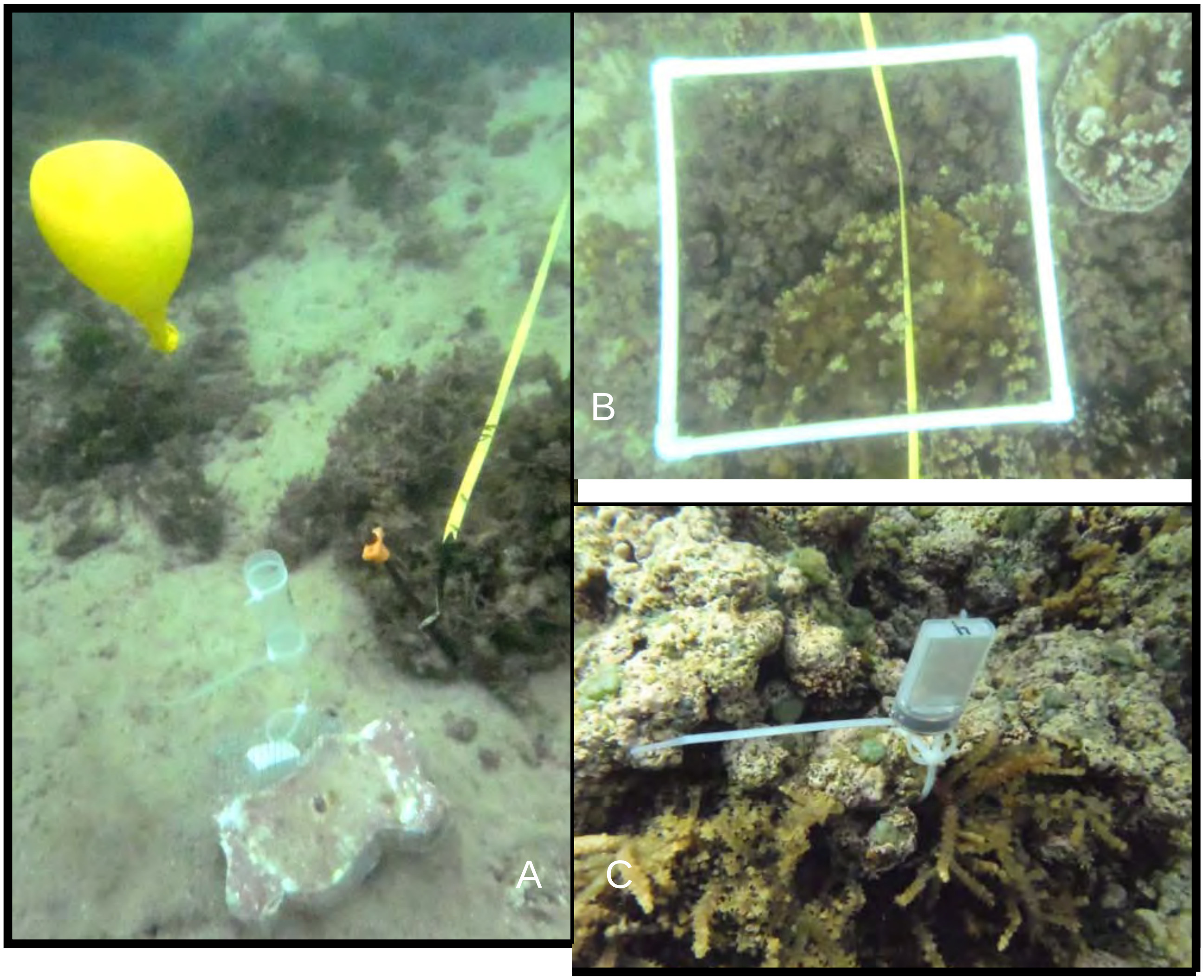

Figure 2: A) Apparatus consisting of a balloon for flotation, a falcon tube acting as a sediment trap, a plaster cube to measure flow and a brick acting as a weight B) $0.25m^2$ quadrats were placed at random points on a 50m transect, percent cover of macroalgae was recorded within each quadrat C) HOBO data loggers were zip tied to sturdy coral rubble on reefs 43 and 44 and recorded data every 5 minutes for 7 days.

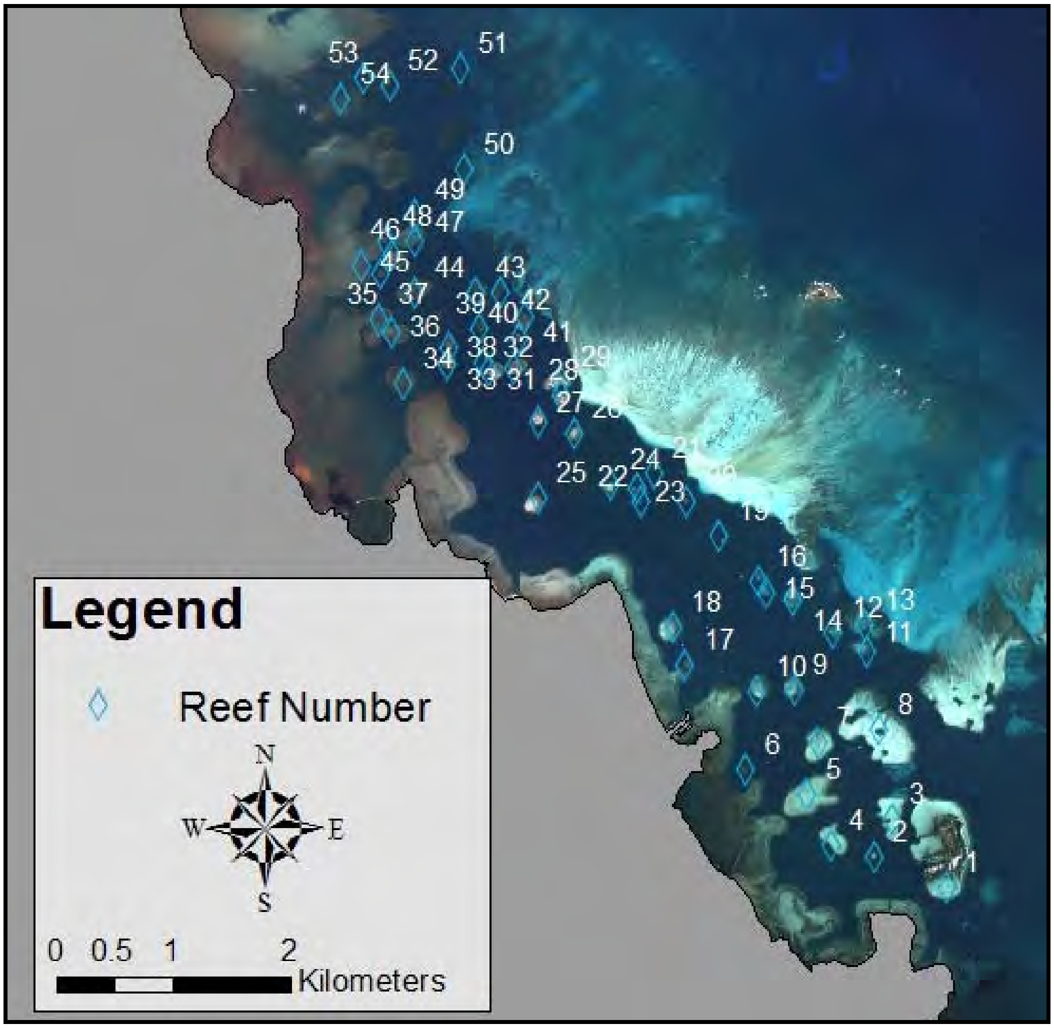

Figure 3: 2012 Map of Kaneohe Bay, Hawaii including patch reefs and corresponding numbers (from Roy, 1970). Study sites were on reefs 54, 44, 43, 24 and 12.

Results:

Reef 54 showed the highest amount of water motion as assessed by dissolution of the plaster cubes, with a weight loss of 0.413 g/hr. Reef 24 had the lowest amount of weight change, with a dissolution rate of 0.219 g/hr. The average weight loss among all flow cubes was 0.299 g/hr.

Currents at Reef 12 were observed to move from east to west for incoming tides and west to east during outgoing tides (Figure 4) (Bathen 1968). Macroalgae cover on Reef 12 was below 10%, while sediment rates were constant between 0.06-0.09g in 48 hours, and dissolution rates were 0.26 – 0.30 g/hr (Figure 5).

The currents at Reef 24 flowed from north to south during incoming tides (Figure 6). It was also observed that current flowed over the Sandbar and towards Reef 24 for both incoming and outgoing tide (Figures 14; 15). Dissolution rates ranged from 0.31-0.35 g/hr on the northern portion of the reef and from 0- 0.25 g/hr on the southern portion of the reef (Figure 7C). Sedimentation rates on this reef ranged between 0.17 to 0.28 g (Figure 7B) and grain size of sediments on this reef were noticeably larger (Figure 18) than that of reefs located further north. Macroalgae cover on this reef was less than 10% (Figure 7A).

Reefs 43 and 44 were located on opposite sides of the channel. Currents around Reef 44 were observed to approach the reef from the southwestern edge of the reef for both incoming and outgoing tide while currents at Reef 43 ran in opposite directions for incoming and outgoing tides (Figure 8). HOBO data loggers were placed on Reefs 44 and 43 to record temperature differences between the reefs. Reef 44 was observed to be 1-2^{o}F warmer on average than Reef 43 (Figure 11). Reef 43 was observed to have intermediate dissolution rates over the entire reef (0.26-0.35g/hr), low sedimentation (0.05-0.06g) and the highest amount of macroalgae was observed on the northern edge of the reef (Figure 9). On Reef 44, macroalgae was observed in highest percentage cover at the southern edges, which coincided with the highest rates of sedimentation (0.17-0.48g) (Figure 10 A;B). Dissolution rates remained intermediate over the southern portion of the reef (Figure 10C).

Reef 54 was observed to have constant currents for both incoming and outgoing tides (Figure 12). The largest cover of macroalgae was observed in the central and southern portions of the reef which coincided with the highest sedimentation rates (0.17-0.48g) (Figure 13A,B). Sedimentation rates were also noted to be higher at reef edges (Figure 16). Dissolution rates were observed to be higher in the central portion of the reef (Figure 13C; 15).

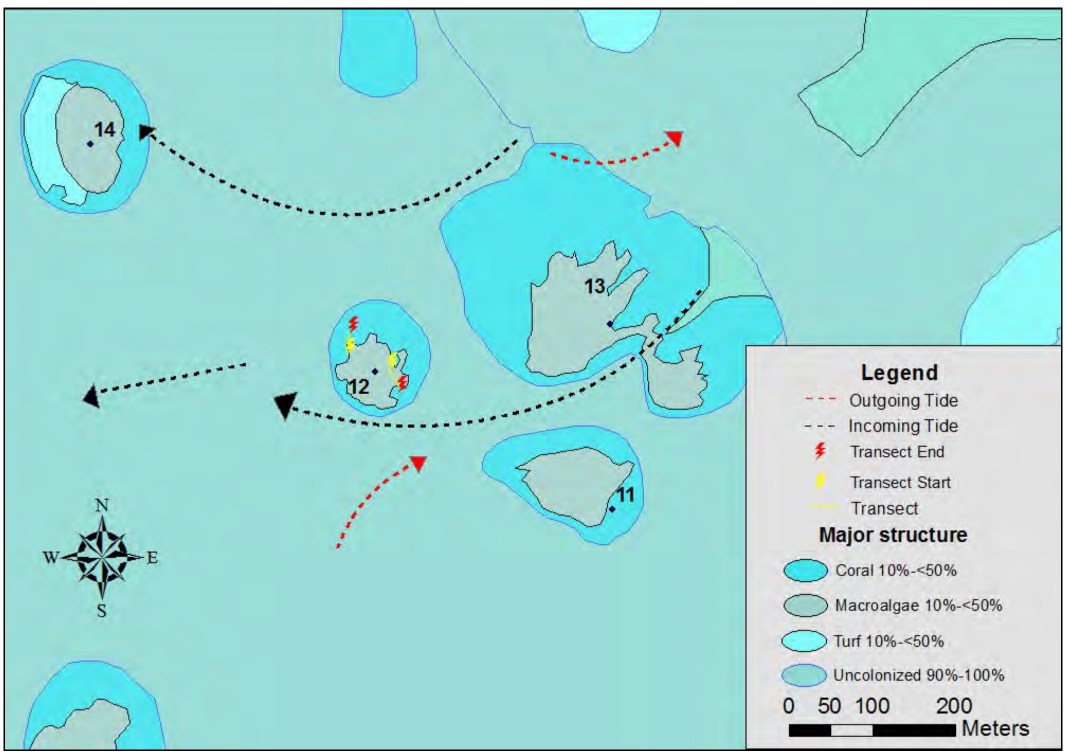

Figure 4: ArcGIS map of Reef 12 showing tide movements (digitized from Bathen 1968) transects and coral/algae cover.

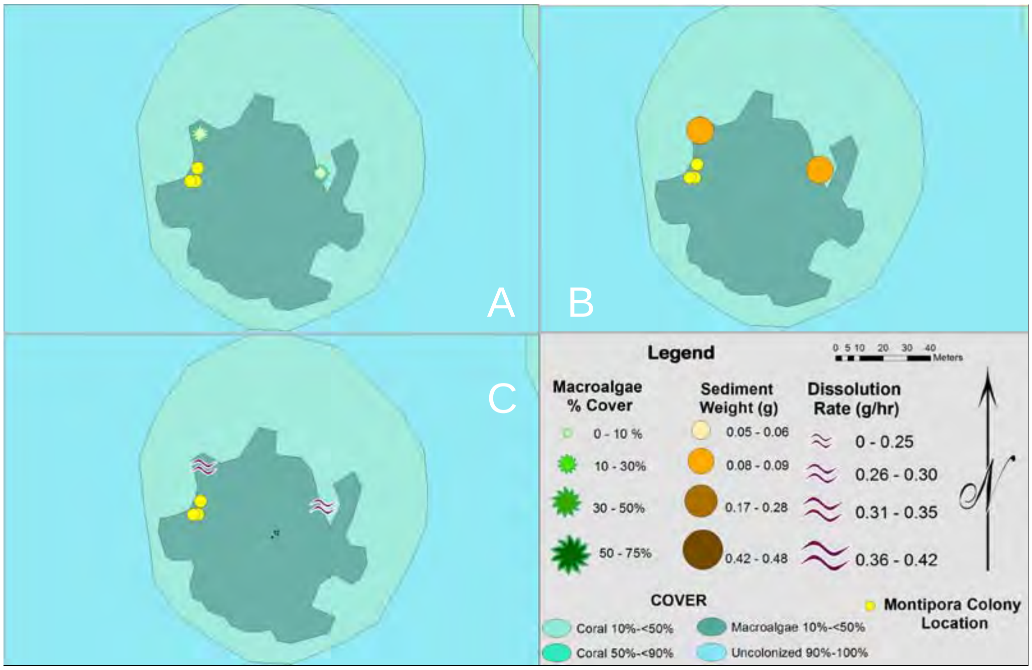

Figure 5: ArcGIS map of Reef 12 showing A) average percent cover of macroalgae in areas transects were taken B) Sediment weight collected from each sample site C) dissolution rates of collected plaster balls.

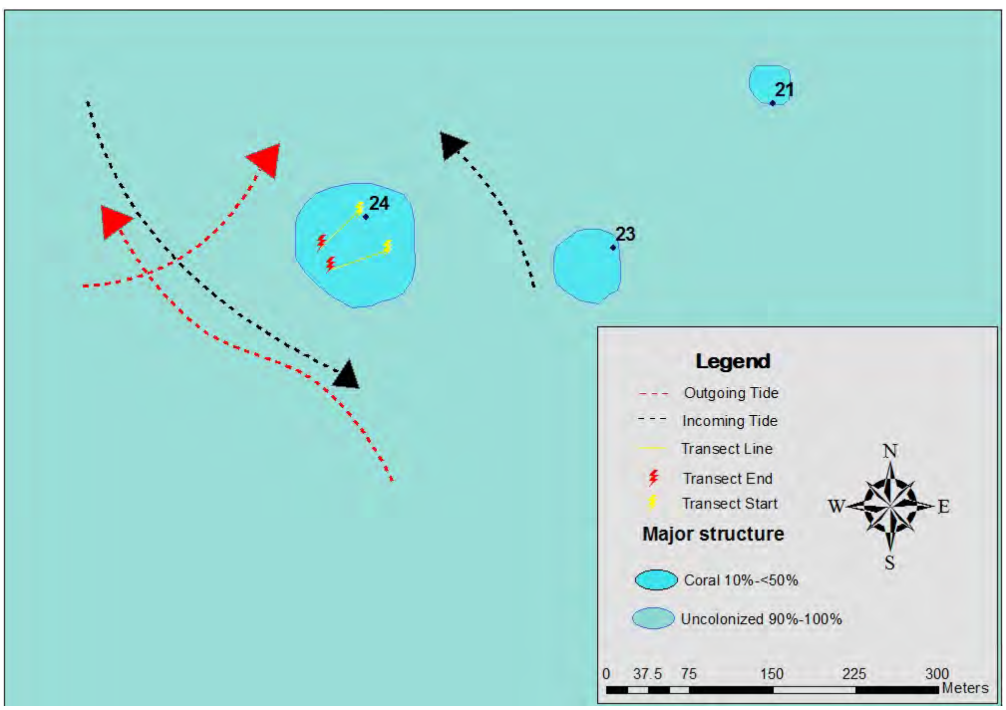

Figure 6: ArcGIS map of Reef 24 showing tide movements (digitized from Bathen 1968) transects and coral/algae cover.

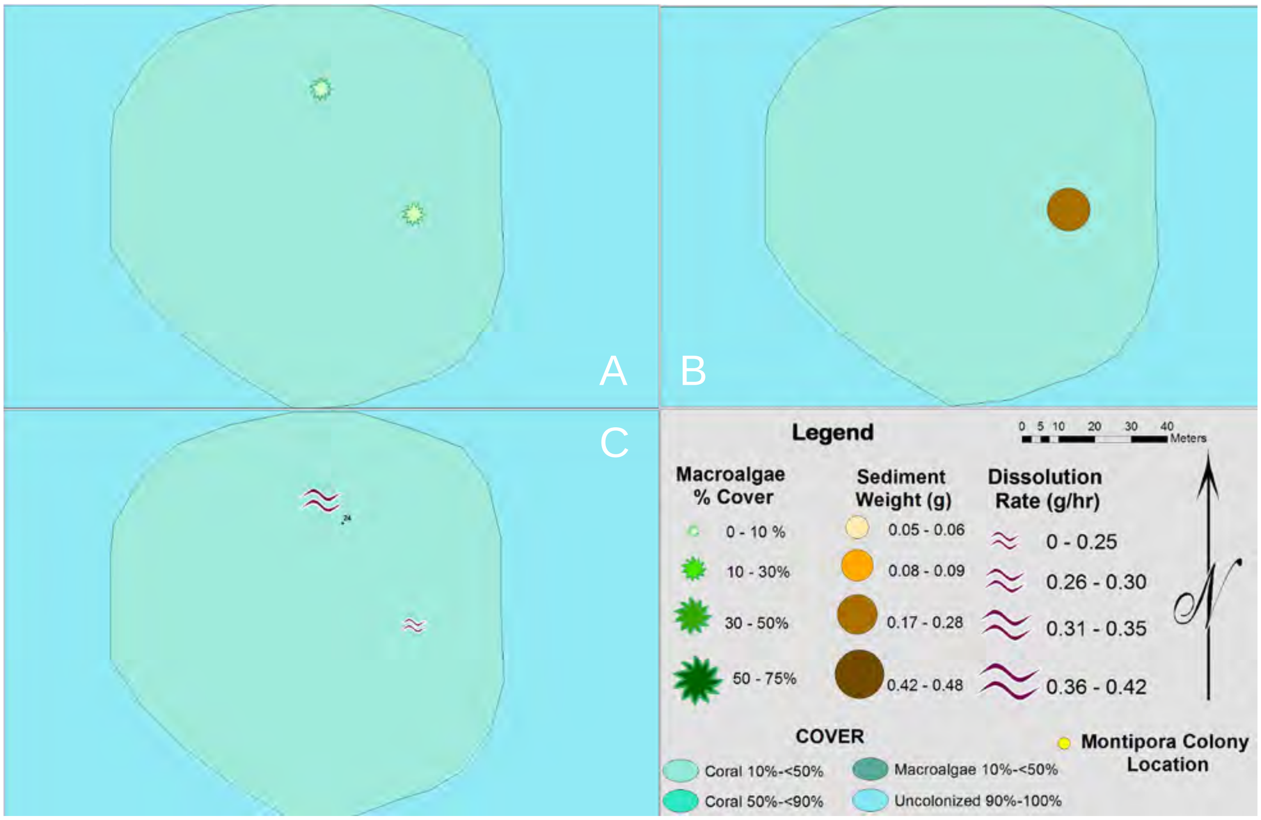

Figure 7: ArcGIS map of Reef 24 showing A) average percent cover of macroalgae in areas transects were taken B) Sediment weight collected from each sample site C) dissolution rates of collected plaster balls

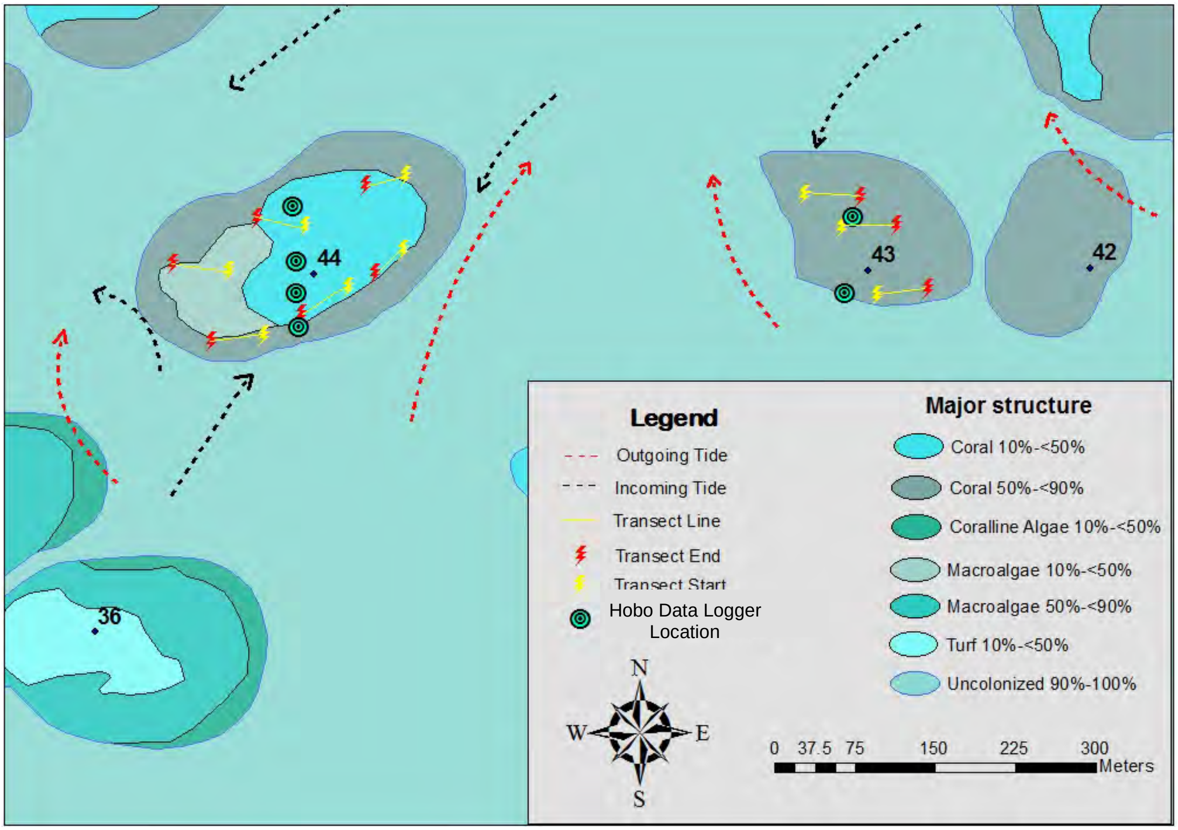

Figure 8: ArcGIS map of Reefs 43 and 44 showing tide movements (digitized from Bathen 1968), transects, HOBO data logger placements and coral/algae cover.

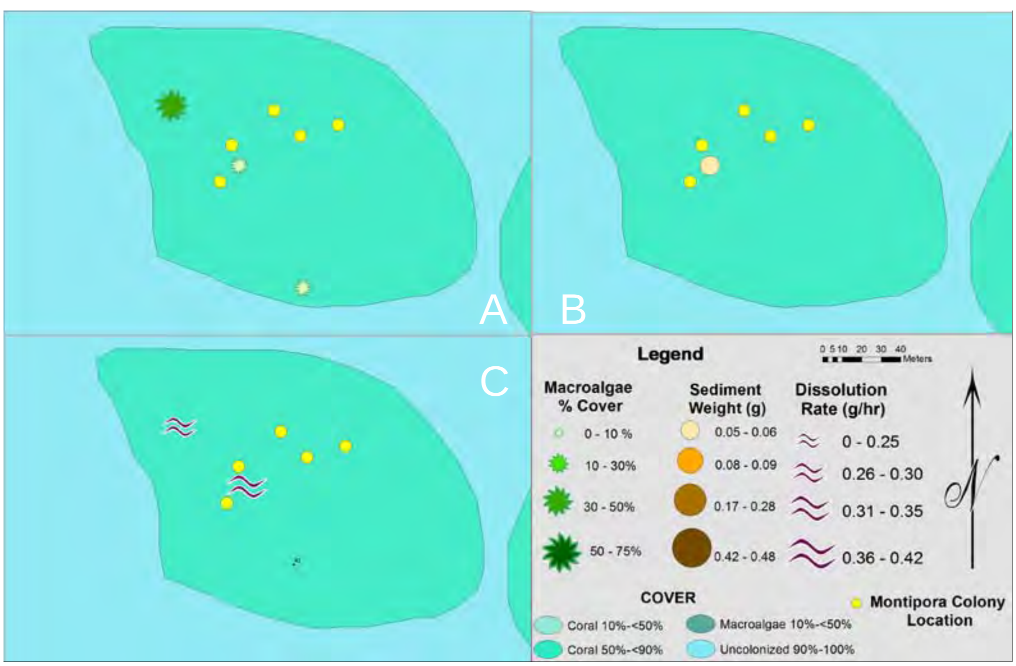

Figure 9: ArcGIS map of Reef 43 showing A) average percent cover of macroalgae in areas transects were taken B) Sediment weight collected from each sample site C) dissolution rates of collected plaster balls

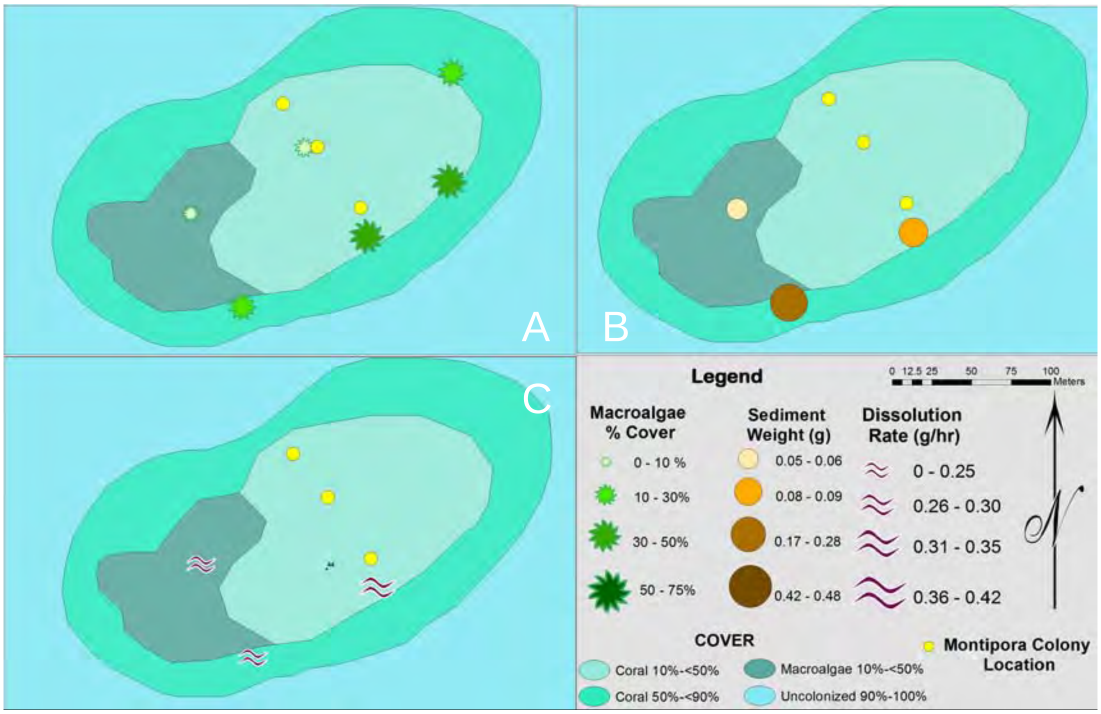

Figure 10: ArcGIS map of Reef 44 showing A) average percent cover of macroalgae in areas transects were taken B) Sediment weight collected from each sample site C) dissolution rates of collected plaster balls.

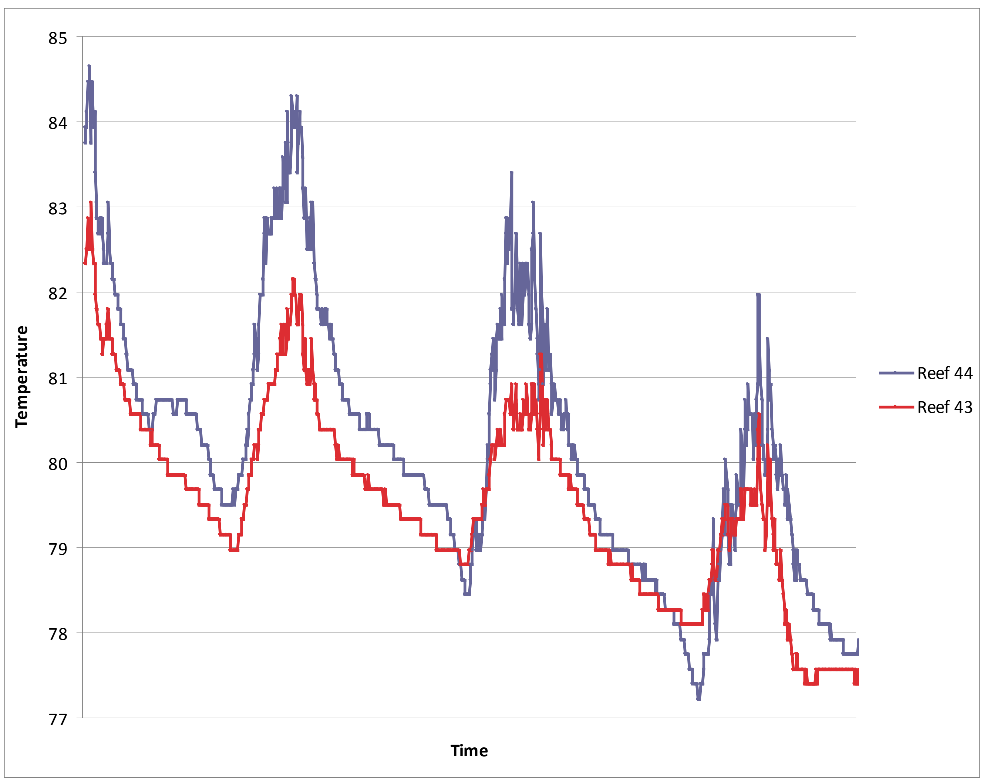

Figure 11: Temperature data (F) recorded from the HOBO data loggers from Reefs 43 and 44 from 6/15/2012 until 6/18/2012. Time is measured in days with noon approximated near the spikes.

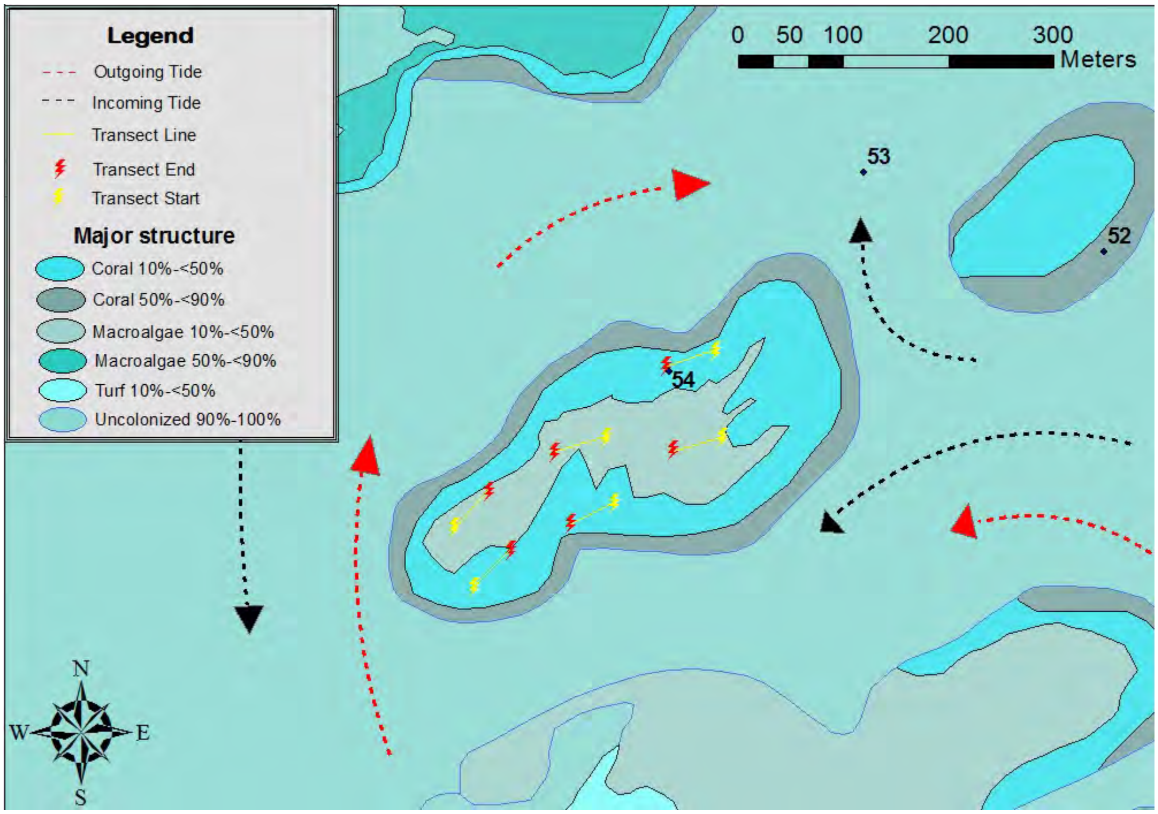

Figure 12: ArcGIS map of Reef 54 showing tide movements (digitized from Bathen 1968) transects and coral/algae cover.

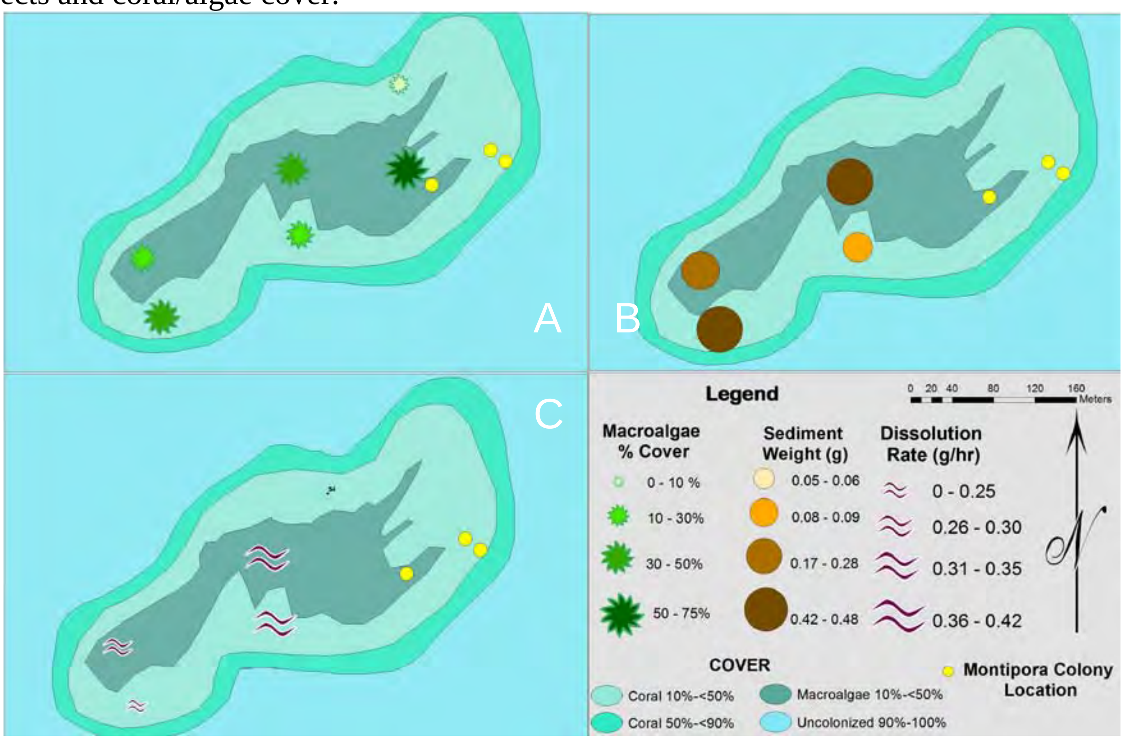

Figure 13: ArcGIS map of Reef 54 showing A) average percent cover of macroalgae in areas transects were taken B) Sediment weight collected from each sample site C) dissolution rates of collected plaster balls.

Figure 14: Incoming tide map of Kaneohe Bay using Google Earth, digitized from Bathen 1968

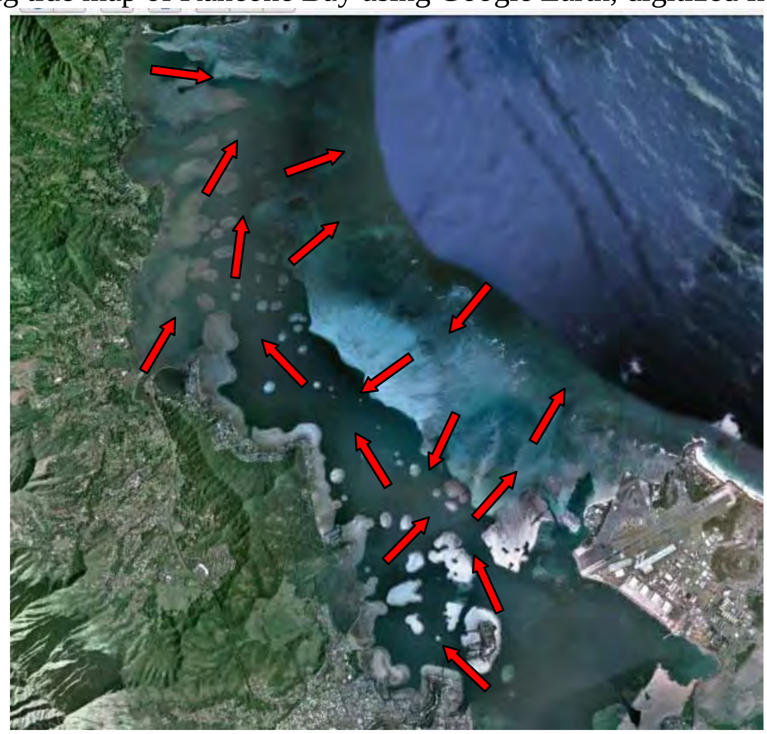

Figure 15: Outgoing tide map of Kaneohe Bay using Google Earth, digitized from Bathen 1968.

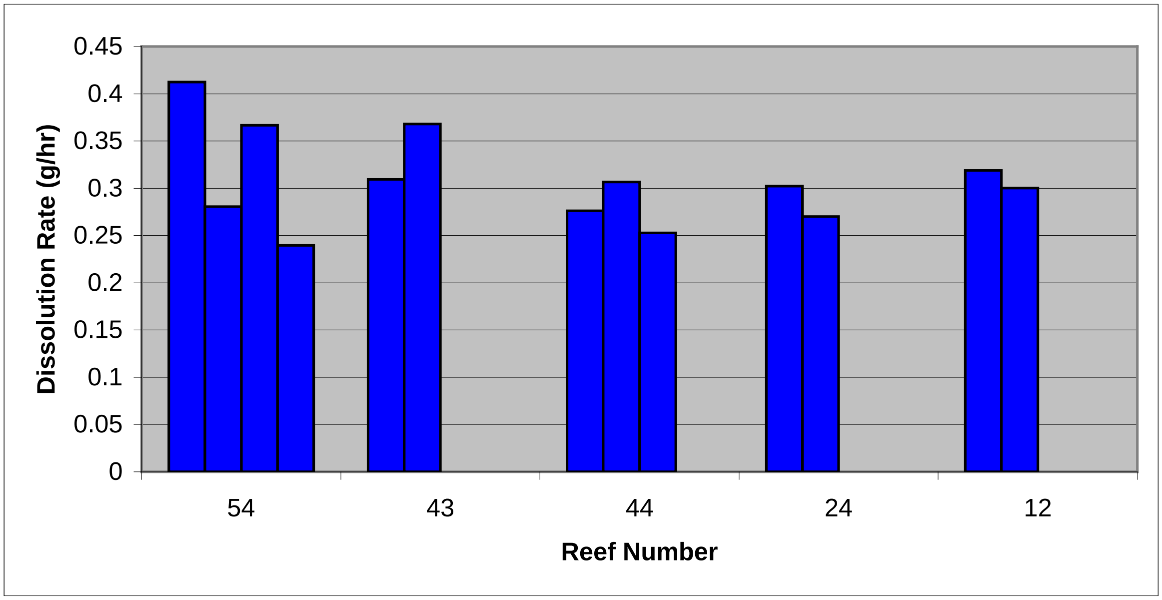

Figure 16: Dissolution rates of the plaster cubes set out on Reefs 54, 43, 44, 24, and 12. Each column represents the rate of dissolution for the plaster cubes found at each reef. Columns are arranged based on plaster cube locations within each reef starting with North on the left and ending with cubes from the South of the reef on the right.

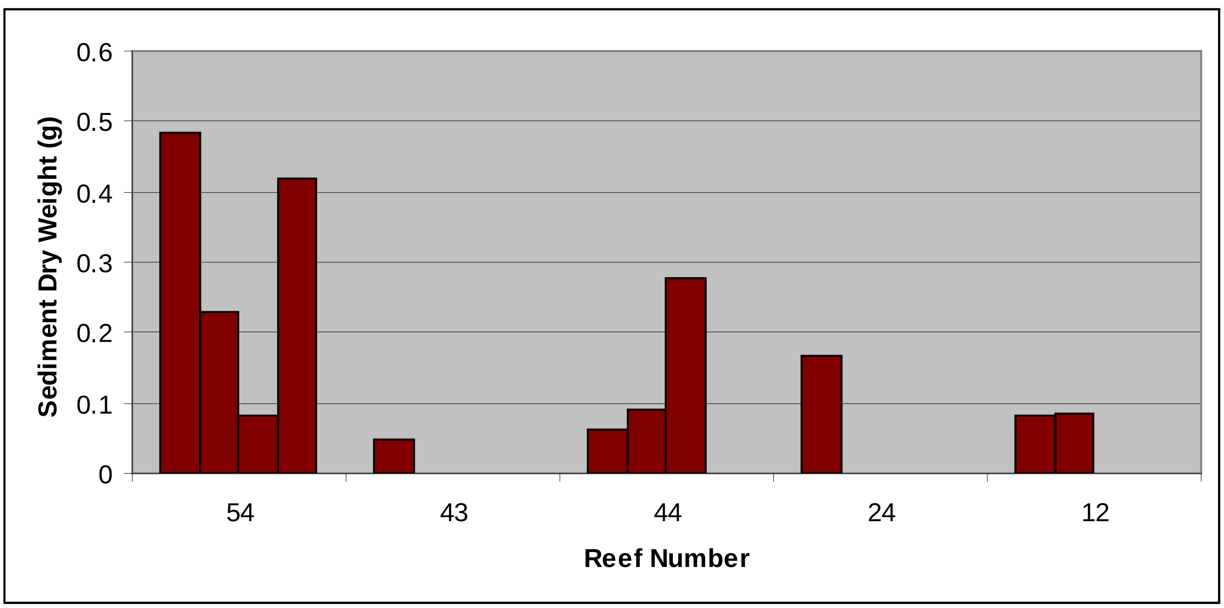

Figure 17: Dry weight of sediment collected from Reefs 54, 43, 44, 24, and 12. Columns are arranged based on falcon tube locations within each reef starting with northern-most tube placement on the left and ending with tubes from the south of the reef on the right.

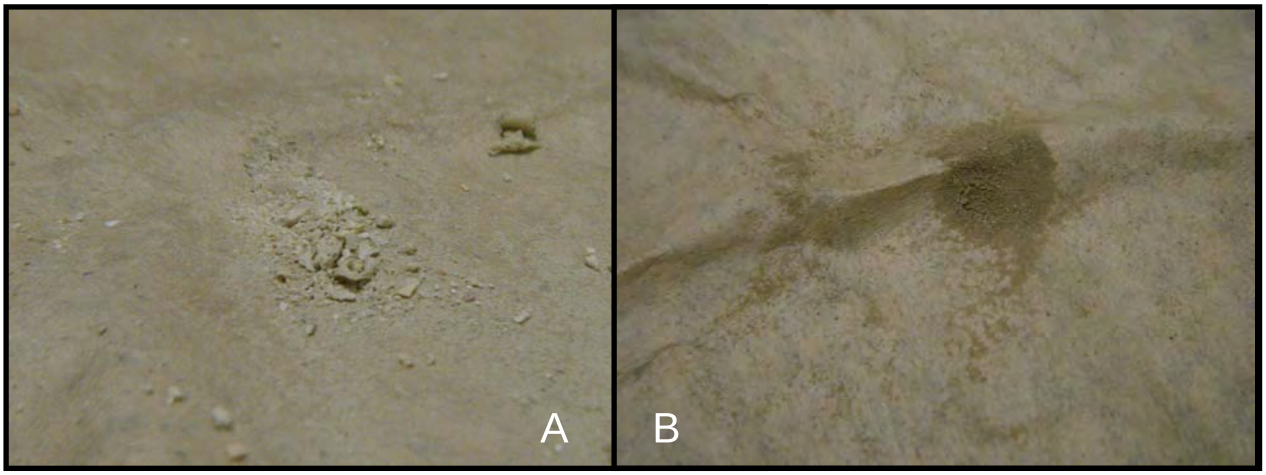

Figure 18: Sediment collected from Reef 24 and Reef 54: A) Sediments collected at Reef 24 were noticeably larger and lighter in color, closer to the consistency of sand, B) Sediments collected from Reef 54 and other northern reefs were very fine and had a similar consistency to the mud throughout Kaneohe Bay.

Discussion and Conclusion:

The research objective was to map and identify the spatial patterns of the SOC *Montipora dilatata* in Kaneohe Bay and study the environmental variables that were driving those patterns in abundance and distribution of this coral. Temperature, tidal flow direction, relative water motion, and sedimentation rate were measured in order to determine which patch reefs were ideal environments for *M. dilatata,* and to further an understanding of the environmental variables driving spatial patterns. Initial observations of reefs in Kaneohe Bay revealed possible trends between locations of *M. dilatata* colonies in respect to sedimentation, flow and invasive algae cover.

Although no significant results were found between reefs, trends emerged when looking at individual patch reefs. For example, there appeared to be a higher flow from the southern side of Reef 54 through the center where *M. dilatata* colonies were not observed and *Eucheuma/Kappaphycus,* as well as sedimentation, was most abundant. On Reef 44, there was a higher flow on the southern side as well as more macroalgae. On smaller reefs such as 12, a more consistent flow over the entire reef was observed.

In addition to flow cubes, sediment traps were deployed in the same apparatus to measure the sedimentation rates among different reefs. It was hypothesized that differences in sedimentation rates could be a crucial factor when determining where *M. dilatata* will settle and thrive. Short-term sediment deposition decreases photosynthetic efficiency and, if not removed, corals may bleach and/or die (Piniak 2007). Although many of the sediment traps were not recovered, a correlation between increasing flow rate and sediment abundance was observed. For example, the south side of Reef 44 had the highest sedimentation rates, high flow rates, and no observed *M. dilatata* colonies. Although the center southernmost sediment trap on Reef 44 was dropped prior to capping, there was a noticeably higher amount of sediment compared to all others. This agrees with the hypothesis that most sedimentation occurs at the sides of the reef that are exposed to and face the currents. All of the colonies that were observed were in the northern portion of the reef that displayed much lower flow rates and lower amounts of sedimentation. In addition, the largest *M. dilatata* colony occurs on the north side of patch reef 44 and the smallest on the south. A trend was also observed in the size of sediments within reefs, but sediment size between reefs was highly variable. Reef 24, which is closest to the Sandbar, has larger sand grains than Reefs 44 and 54 which have mostly terrigenous clay sediment. It was also noted that no *M. dilatata* colonies were observed on any of the patch reefs directly west of the Sandbar where currents are constantly flowing in the same direction.

Although temperature data between Reefs 43 and 44 was compared, complete results were unable to be obtained because of low HOBO recovery rates. The two data loggers obtained were noted to have bite marks, and it was speculated that turtles or octopi may have been attracted to the objects. Reef 44 had a higher temperature at peak hours of the day than Reef 43, and night temperatures were similar.

For future studies, a more in depth approach should be taken to further quantify these environmental factors that may affect the distribution of *M. dilatata.* There was a visible difference in sedimentation and flow rates over these reefs, but some limited time and materials on each reef affected the completeness of our results. The first set of apparatuses was constructed with too much air in the balloons which caused many to break off in the waves. In addition, some sediment traps potentially would tip at low tide because the balloon did not hold them vertically in the water column. Lastly, some flow cubes experienced a far greater flow and dissolved completely in 48 hours. There is an apparent link between the sedimentation flow over reefs and algal cover, however further research needs to be done to clarify these environmental effects.

This ongoing study quantifies the spatial patterns of *M. dilatata* and will support spatial management of this species. The locations of all new and existing colonies have been documented using GPS so that NOAA Species of Concern managers can better understand the implications and effects that current, sedimentation, and temperature have on the distribution and abundance of *M. dilatata*. Since sedimentation may not have an adverse effect on the survivorship of invasive macroalgae due to fast growth observed in species such as *Eucheuma/Kappaphycus,* managers could partner with organizations such as Division of Aquatic Resources (DAR) to remove encroaching algae to create space for new *M. dilatata* recruits to settle.

Future research on the fine scale variation of sedimentation rates in specific reefs as well as further studies on the sedimentation flux between patch reef systems would provide a complete picture of the source and sink locations of terrigenous sediment in Kaneohe Bay. This information would support the best management practices on individual patch reefs and would facilitate management of the Species of Concern from a broader land to sea perspective.

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