Montipora dilatata

Environmental Influences on Morphological Patterns

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Abstract:

The Hawaiian reef coral, *Montipora dilatata*, is one of the rarest coral species in the Pacific (Veron, 2000) and has often been confused with other *Montipora* species (Forsman et al., 2010). In the summer of 2011, the University of Hawai'i Manoa Biology 403 course surveyed nine known colonies of *M. dilatata* on three different patch reefs in North Kane'ohe Bay, O'ahu, Hawai'i in order to gather pertinent information on its exact habitat. The intentions of this study were to hopefully provide information to NOAA so *M. dilatata* could one day be reproduced and transplanted to a suitable habitat. Surveying the different colonies included planting sediment traps and water-flow plaster balls, as well as measuring length, width, height, perimeter, and the water depth at which each colony grows. Water depth was the only ecological parameter which depicted a significant impact on morphological patterns along with the location of each reef. Moreover, Reef 44 was hypothesized to be the optimal habitat for *M. dilatata* to thrive because of its shallow depth and low water flow environment. The colonies at Reef 44 were the largest of the nine colonies that were surveyed, which may also be an indicator of a healthy environment.

Introduction:

The Hawaiian reef coral, *Montipora dilatata*, a National Oceanic Atmospheric Administration (NOAA) National Marine Fisheries Services (NMFS) Species of Concern (SOC), is thought to be one of the rarest coral species in the Pacific (Veron, 2000). It has only been found in Kane'ohe Bay, O'ahu and tentatively on Maro reef (*M. c.f. dilatata*) in the Northwestern Hawaiian Islands (Forsman *et al.*, 2010). This species was once very abundant in Kane'ohe Bay, but extensive surveys in 2000 identified only three colonies (NOAA, 2007). *Montipora* morphology, like many coral genera, can be quite variable. Colonies may exhibit any combination of morphology from encrusting to plates, knobs, and branching (Figure 3). The most common morphology is irregular branch-like up-growths up to 100 mm thick, which become flattened near their ends. Colonies are typically purple or chocolate brown and are restricted to shallow, calm environments such as lagoons and bays.

Montipora dilatata is very sensitive to thermal stress. It was the first species to bleach during the 1996 epidemic in Kane'ohe Bay and the last to recover (Jokiel and Brown, 2004). The main threats to *M. dilatata* are 1) vulnerability to coral bleaching due to high temperatures,

2) freshwater kills and exposure at extreme low tides, 3) habitat degradation and modification as a result of sedimentation, pollution, alien alga species and invasive green alga, 4) limited distribution, and 5) damage by anchors, fish pots, swimmers, and divers (NOAA, 2007). In August 2006, NMFS Pacific Island Regional Office (PIRO) Protected Resources Division held its first Species of Concern workshop in Honolulu, Hawai'i for species in the Pacific Islands region. The purpose of the workshop was to gather pertinent researchers and resource managers to share their knowledge, which provided overall information on the species, their habitat, threats, and conservation ideas. One main issue that was presented is being able to determine whether or not colonies from various sites in Kane'ohe Bay are in fact *M. dilatata*, a hybrid species, or a different species of *Montipora* (NOAA, 2007).

The positive identification of *M. dilatata* in the field has confounded researchers due to its phenotypic plasticity (Forsman *et al.*, 2009). This wide range of morphological variation is thought to be linked with interspecific hybridization (Forsman *et al.*, 2010). In the field, *M. dilatata* is often confused with *Montipora flabellata* because of its vivid, fluorescent blue color (Studer, 1901; Vaughn 1907) and *Montipora turgescens* because of its encrusting structure and lavender to brown hue (Barlow *et al.*, 2011). Until recently, the taxonomy of scleractinian corals was strictly based on skeletal morphology. Further genetic investigation would allow for proper identification of the *Montipora* genera at a species level. Furthermore, additional research is needed to verify morphological differences within *M. dilatata*. This study provides data and uses results from previous scientific experiments to further explain a significant relationship between ecological parameters (e.g. water depth, sedimentation rate, and water flow) and morphological patterns in *M. dilatata*.

This study focuses on 1) the morphological differences (e.g. branching, plating, encrusting, and other formations) of the positively identified colonies of *M. dilatata* found between the surveyed patch reefs in North Kane'ohe Bay and 2) the influence water depth, sedimentation rate, and the rate of the water flow have on those morphological features.

Materials and Methods:

In 2010, 43 colonies of *M. dilatata* were classified by the summer Biology 403 course in Kane'ohe Bay, O'ahu. This year, three reefs with three colonies each were surveyed based on the properly identified colonies found in last year's data. The reefs chosen were 44, 47, and 54 (Figure 1). At each of these colonies, various parameters including the GPS coordinates, colony height, maximum width and length, perimeter, water depth of the colony, sedimentation rate, and water flow were recorded and input into an excel spreadsheet. Also, the morphologies (branching, plating, and encrusting) of each colony were observed, photographed, and documented. The latitude and longitude were taken using a Garmin *etrex* while the height, width, length, perimeter, and water depth were all recorded using a 50 m transect. The sedimentation rate was calculated by planting a plastic tube attached to a wire flag as close as possible to the colony and the ground (Figure 2C). It was then left for 7 to 10 days (Rogers, 1990). The water flow was estimated by placing three separate plaster balls made in a 5:1 ratio (plaster: water) at approximately the same water depth at various spots around each colony for 2 days (Figure 2A).

A control plaster ball was placed into a bucket with no water flow to measure the weight loss of the plaster when in a no-flow environment. This was done because it is known that plaster is water-soluble and will dissolve even when water flow is not a factor. The dry weight of each plaster ball, including the control, was recorded before placing them on the colonies. Once they were picked up, all of the plaster balls were dried, weighed, and recorded. In order to find the rate of the water flow, the difference between the before and after weights of the plaster balls were compared. In addition, once the sedimentation traps were capped and picked up, the sedimentation rate was then calculated by weighing the wet and dry weights of the sediment that was captured in each trap. The dry weight was weighed 24 hours after the wet weight was recorded. Water depth measurements were taken at a different time of day and a different tide level. Thus, to standardize the raw data, the time that the water depth was recorded at each location was documented. Then, using a Hawai'i marine tide and moon phase calendar for 2011, the different water depths were homogenized to calculate the water depth at a 0.0 m tide.

With the different environmental data that was collected (e.g., sedimentation rate, flow rate, width, length, perimeter, and water depth), statistical regressions were run to explore the relationship between the environmental parameters on the morphological features of the different colonies. Similarly, a one-way ANOVA was done to compare the morphology and reef location of each *M. dilatata* colony. Moreover, various graphs also illustrating these spatial relationships were generated. Five different maps were produced using ArcGIS, in order to demonstrate 1) the GPS location of each reef (Figure 1), 2) the percent morphology of each colony (Figure 4), 3) the benthic habitat and percent morphology of each reef (Figure 5), 4) the area of each colony which was calculated by using the formula πr^2 (Figure 6), and 5) the abundance and perimeter of each colony, which also includes all *M. c.f. dilatata* that were surveyed throughout Kane'ohe Bay (Figure 7).

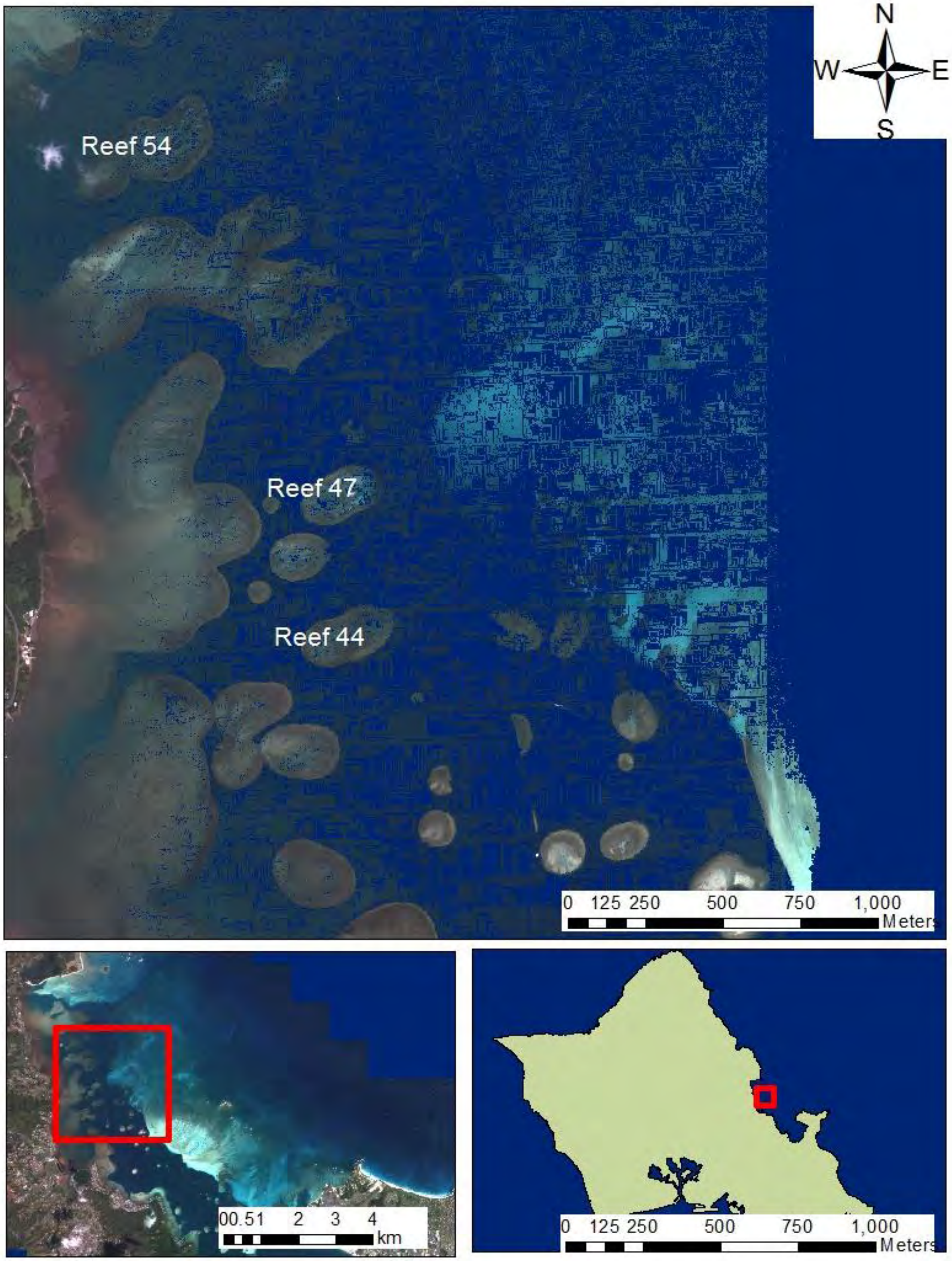

Figure 1: The GPS location of the three surveyed reefs in Kane'ohe Bay, O'ahu, Hawai'i.

Figure 2: A) The placement of three plaster balls on Colony 15 on Reef 54; B) the placement of a sediment trap next to Colony 14 on Reef 44; C) placing a sediment trap on Colony 14 of Reef 44; D) measuring the maximum width of Colony 30 on Reef 47; E) measuring the perimeter on Colony 12 of Reef 44; F) taking macro pictures of Colony 16 on Reef 44.

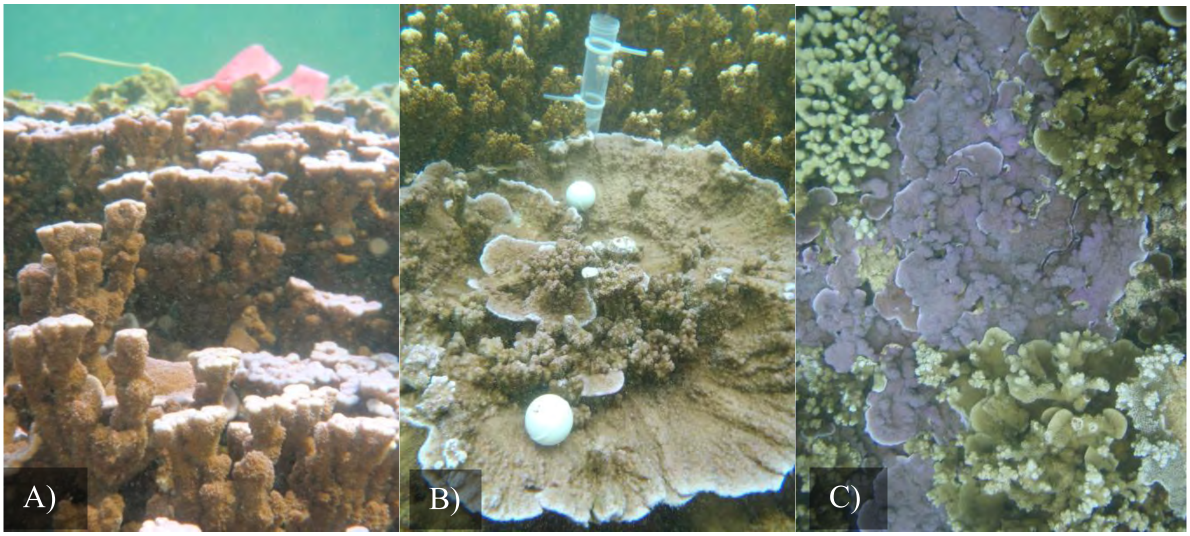

Figure 3: A) Branching, B) Plating, and C) Encrusting morphology of *M. dilatata*.

Results:

In North Kane'ohe Bay, O'ahu, Hawai'i, three known colonies of *Montipora dilatata*, on three different patch reefs (Reefs 44, 47, and 54) were studied (Figure 1). Colonies 12, 14, and 16 were surveyed on Reef 44; Colonies 3, 15, and 30 on Reef 47; and Colonies 1, 3, and 15 on Reef 54 (Appendix 1). At these colonies, water depth, sedimentation rate, and flow rate were measured and recorded (Table 2).

The average water depth was the deepest at Reef 54 (90.33cm) of the surveyed reefs. Conversely, Reef 44 (14.33 cm) had the shallowest water depth at the surveyed *M. dilatata* colonies during the observation period. A one-way ANOVA was used to test the relationship between water depth and the surveyed colonies at different reef locations (Reef 44, 47, and 54). Differences among water depth were significantly different between reef locations ($F_{(2,8)}= 7.76$, $P< 0.05$) (Table 2).

The greatest average amount of plaster lost on the three reefs was at Reef 54 (13.49 g/day). On the other hand, the least average amount of plaster lost was at Reef 44 (13.1 g/day). However, the control plaster ball weight loss was 6.11 g/day in a saltwater control; thus, this amount (6.11 g) was added to the end plaster ball weight to determine the corrected weight loss (Table 2). On Reef 54, colony 3 exhibited a flow ball weight loss of 13.19 g/day, which was the greatest amount lost and occurred on a colony with the least amount of branching morphology (Table 3, Figure 9). A one-way ANOVA was used to test the relationship between plaster ball weight loss and the surveyed colonies at different reef locations (Reef 44, 47, and 54). Differences among plaster ball loss were not significantly different between reef locations ($F_{(2,8)}$= 0.99, P >0.05).

The largest average sedimentation rate was observed at Reef 54 (0.067 g/day) while the smallest average sedimentation rate was measured at Reef 47 (0.051 g/day) (Table 2, Figure 10). A one-way ANOVA was used to test the relationship between sedimentation rate and the surveyed colonies at different reef locations (Reef 44, 47, and 54). Sedimentation rates between surveyed reef sites were not significantly different ($F_{(2,8)}$= 0.06, P >0.05).

Of the confirmed colonies of *M. dilatata* (Figure 4), the GPS location using latitude and longitude, perimeter, area, and percent morphology were recorded. From this collected data, colonies of *M. dilatata* on Reef 44 (35,853.43 cm^2) had the largest average area, and colonies of *M. dilatata* on Reef 47 (5,741.26 cm^2) had the smallest average area (in comparison to surveyed sites) (Table 2, Figure 6). The highest average percentage of branching morphology was seen on Reef 44 (70.83%); the highest average percentage of plating morphology was observed on Reef 47 (58.33%), and the highest average percentage of encrusting morphology was recorded on Reef 54 (50.0%) (Table 1, Figure 5). A one-way ANOVA analysis showed no significant relationship between reef location and morphology (branching: $F_{(2,8)}$= 4.71, P >0.05; plating: $F_{(2,8)}$= 0.40, P >0.05; encrusting: $F_{(2,8)}$= 1.70, P >0.05) (Figure 8).

Measured ecological parameters were compared to morphological patterns to determine a significant relationship. Using a simple linear regression analysis, the sedimentation rate between the surveyed reefs showed no significant relationship with the branching morphology (H_0: r^2=0; df= 8, r^2 =0.014; P> 0.05), plating morphology (H_0: r^2=0; df= 8, r^2=0.024, P >0.05), or encrusting morphology (r^2=0.154, P >0.05). Also, plaster ball weight loss between surveyed reefs depicted no significant relationship between branching (r^2=0.043, P >0.05), plating (r^2=0.024, P >0.05), or encrusting (H_0: r^2=0; df= 8, r^2=0.009, P >0.05) morphologies. Lastly, water depth between surveyed reefs showed no significant relationship with plating (H_0: r^2=0; df= 8, r^2=0.12, P >0.05) or encrusting (H_0: r^2=0; df= 8, r^2=0.04, P >0.05) morphologies of *M. dilatata*, while a regression analysis showed a significant relationship between water depth and branching morphology among all surveyed reefs (H_0: r^2=0; df= 8, r^2=0.56, P <0.05).

Appendix 1: The reef and colony number, GPS location, perimeter, and water depth for surveyed *M. dilatata* colonies. The colonies that have been properly identified as *M. dilatata* have been categorized with a Yes status, and the colonies that are potential colonies (*M. cf. dilatata*) have been recorded with a Potential status.

Reef	Colony	Latitude	Longitude	Perimeter (cm)	Depth (cm)	Status
44	16	21.4774	-157.83170	535	23	Yes
44	14	21.4777	-157.83218	875	43	Yes
44	12	21.4770	-157.83168	500	-23	Yes
54	1	21.4915	-157.83658	730	72	Yes
54	3	21.4916	-157.83672	541	83	Yes
54	15	21.4913	-157.83727	178	116	Yes
47	3	21.4809	-157.83267	199	90	Yes
47	15	21.4817	-157.83289	346	60	Yes
47	30	21.4812	-157.83500	107	90	Yes
52	21	21.4926	-157.83467	68	56	Potential
52	13	21.4928	-157.83459	381	118	Potential
52	14	21.4934	-157.83443	140	183	Potential
52	18	21.4933	-157.83463	151	186	Potential
52	19	21.4933	-157.83463	119	203	Potential
52	20	21.4932	-157.83467	68	205	Potential
52	12	21.4931	-157.83482	171	196	Potential
52	15	21.4931	-157.83406	476	195	Potential
52	16	21.4931	-157.83411	198	-87	Potential
52	11	21.4932	-157.83470	75	203	Potential
12	119	21.45074	-157.79736	40	n/a	Potential

12	120	21.45113	-157.79785	17	n/a	Potential
12	146	21.45073	-157.79799	11	157	Potential
12	147	21.45067	-157.79796	36	145	Potential
12	148	21.4503	-157.79764	60	148	Potential
12	149	21.45044	-157.79756	52	21	Potential
12	151	21.4506	-157.79762	30	24	Potential
12	152	21.45075	-157.79765	52	128	Potential
12	153	21.45073	-157.79762	12	126	Potential
12	118	21.45062	-157.79805	46	n/a	Potential
12	119	21.45061	-157.79759	70	119	Potential
12	120	21.45077	-157.79761	68	115	Potential
12	121	21.45089	-157.79774	90	123	Potential
12	123	21.45111	-157.79788	71	87	Potential
15	1	21.4536	-157.8073	19	97	Potential
15	2	21.53218	-157.80298	35	160	Potential
15	3	21.4536	-157.80302	45	109	Potential
15	4	21.45382	-157.80315	107	95	Potential
15	5	21.45388	-157.80305	93	95	Potential
15	6	21.44943	-157.79608	30	100	Potential
11	1	21.4497	-157.79617	93	150	Potential
11	2	21.44942	-157.79575	51	100	Potential
11	3	21.44946	-157.79565	35	96	Potential
11	4	21.4989	-157.79553	48	110	Potential
11	5	21.44907	-157.79568	21	126	Potential
11	6	21.44947	-157.79593	123	132	Potential
11	7	21.44951	-157.79538	37	102	Potential
11	8	21.44969	-157.79568	75	150	Potential
11	9	21.44961	-157.79564	62	150	Potential
11	10	21.44943	-157.79608	58	110	Potential
11	11	21.44938	-157.79599	70	100	Potential

Table 1: The average of the coral colony percent morphology observed per reef.

Reef	Plating (%)	Branching (%)	Encrusting (%)
44	37.5	70.83	0
54	29.17	26.83	50
47	58.33	22.5	20.83

Table 2: The average of the coral colony perimeter, area, height, and water depth per reef along with the average of the weight loss of the plaster ball per reef and the average sedimentation rate of each reef. The weight loss and sedimentation rate are measured in grams per day.

Reef	Perimeter (cm)	Area (cm^2)	Colony Height (cm)	Depth (cm)	Plaster Ball Weight Loss (g/day)	Sedimentation Rate (g/day)
44	636.67	35853.43	243.33	14.33	13.1	0.062
54	483	11839.88	186	90.33	13.49	0.067
47	217.33	5741.261	100.33	80	13.27	0.051

Table 3: Flow ball weight loss average per colony compared to branching morphology.

Reef	Colony	Flow Ball Weight Loss (g)	% Branching
44	16	N/A	87.5
44	14	25.91	62.5
44	12	25.55	62.5
47	3	25.73	15
47	15	25.66	37.5
47	30	N/A	15
54	1	N/A	62.5
54	3	26.37	3
54	15	26.31	15

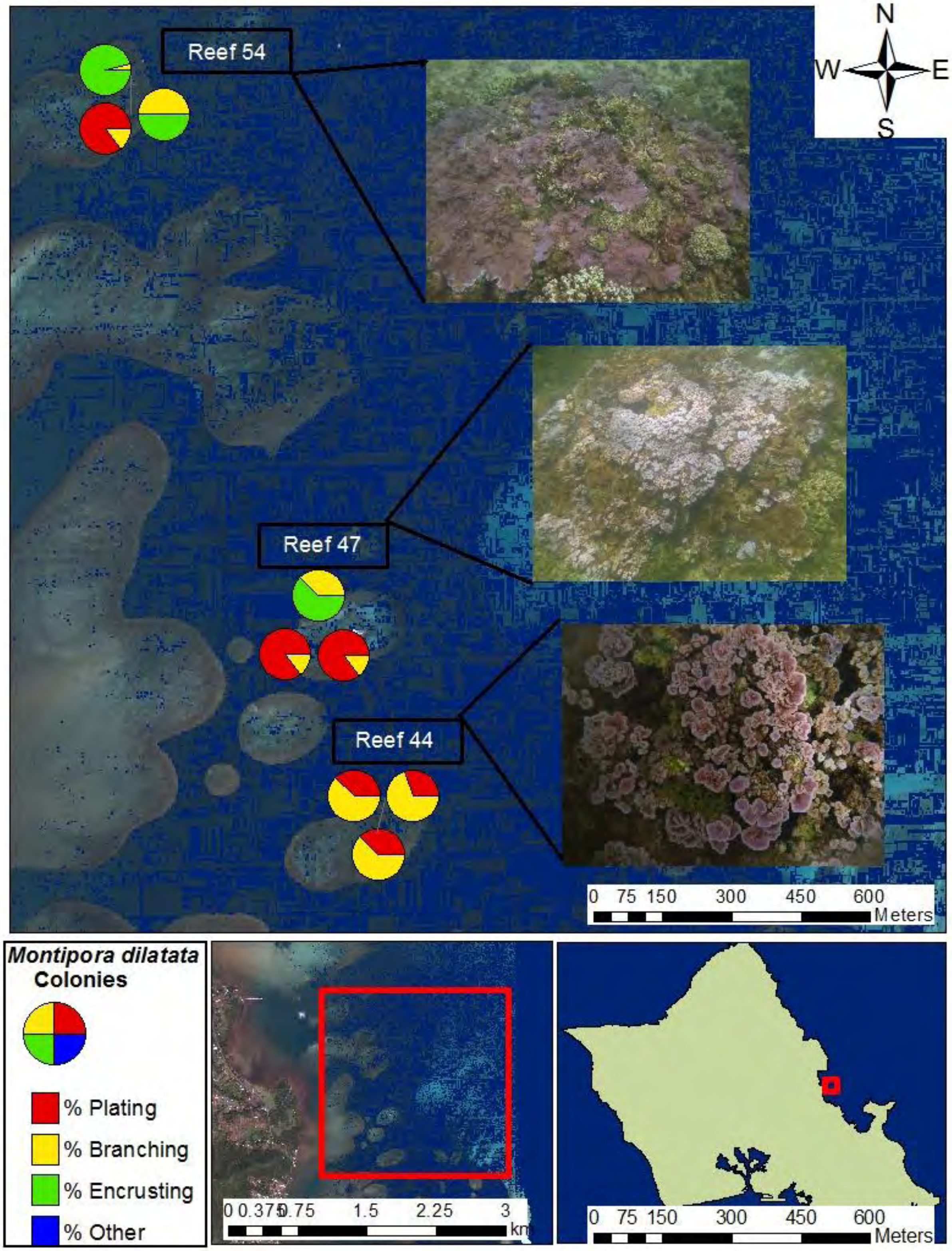

Figure 4: A pie chart map depicting the percent morphology of each colony of *M. dilatata* in Kane'ohe Bay, O'ahu, Hawai'i.

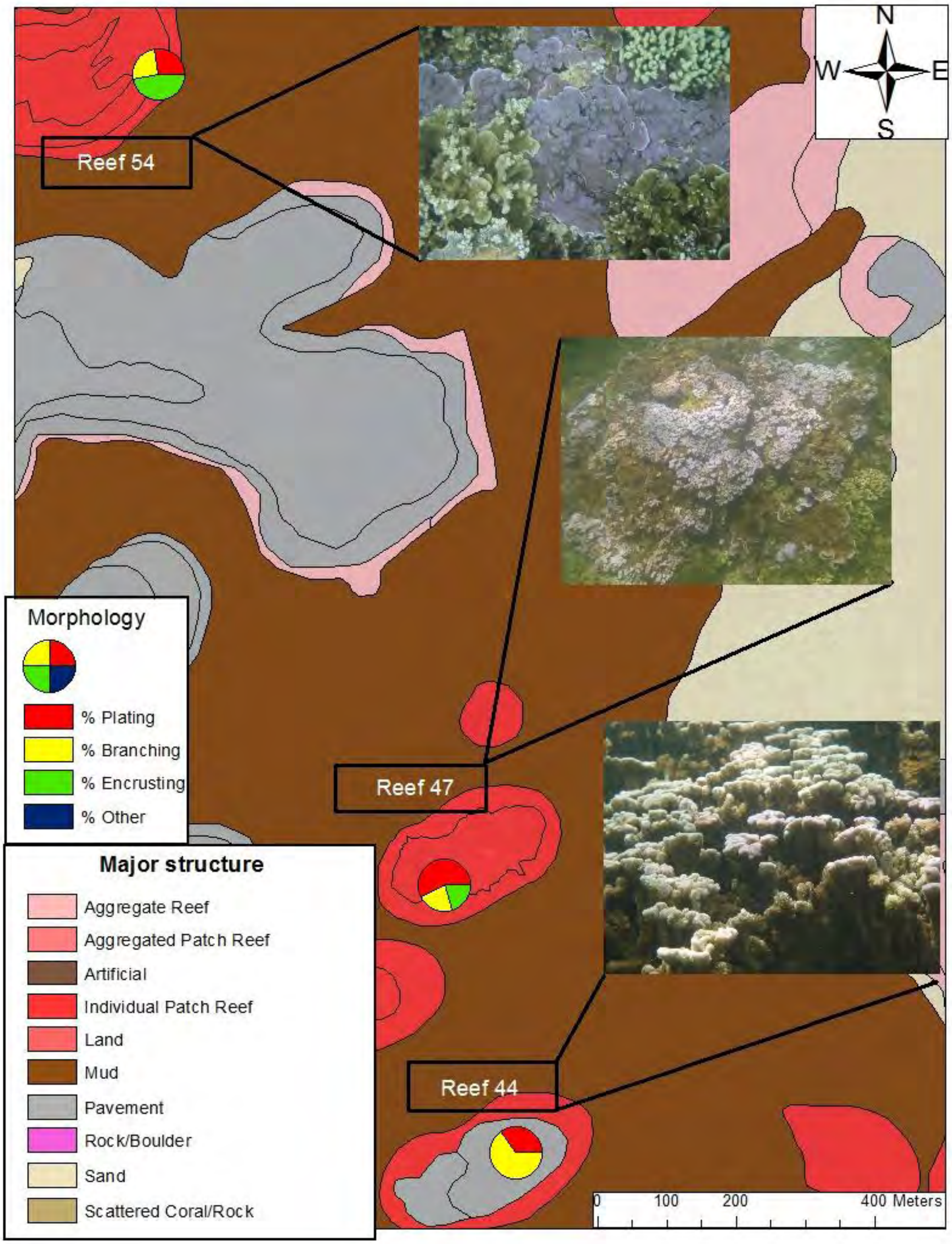

Figure 5: The benthic habitat map of Kane'ohe Bay with the average percent morphology of *M. dilatata* at each surveyed reef displayed as a pie chart.

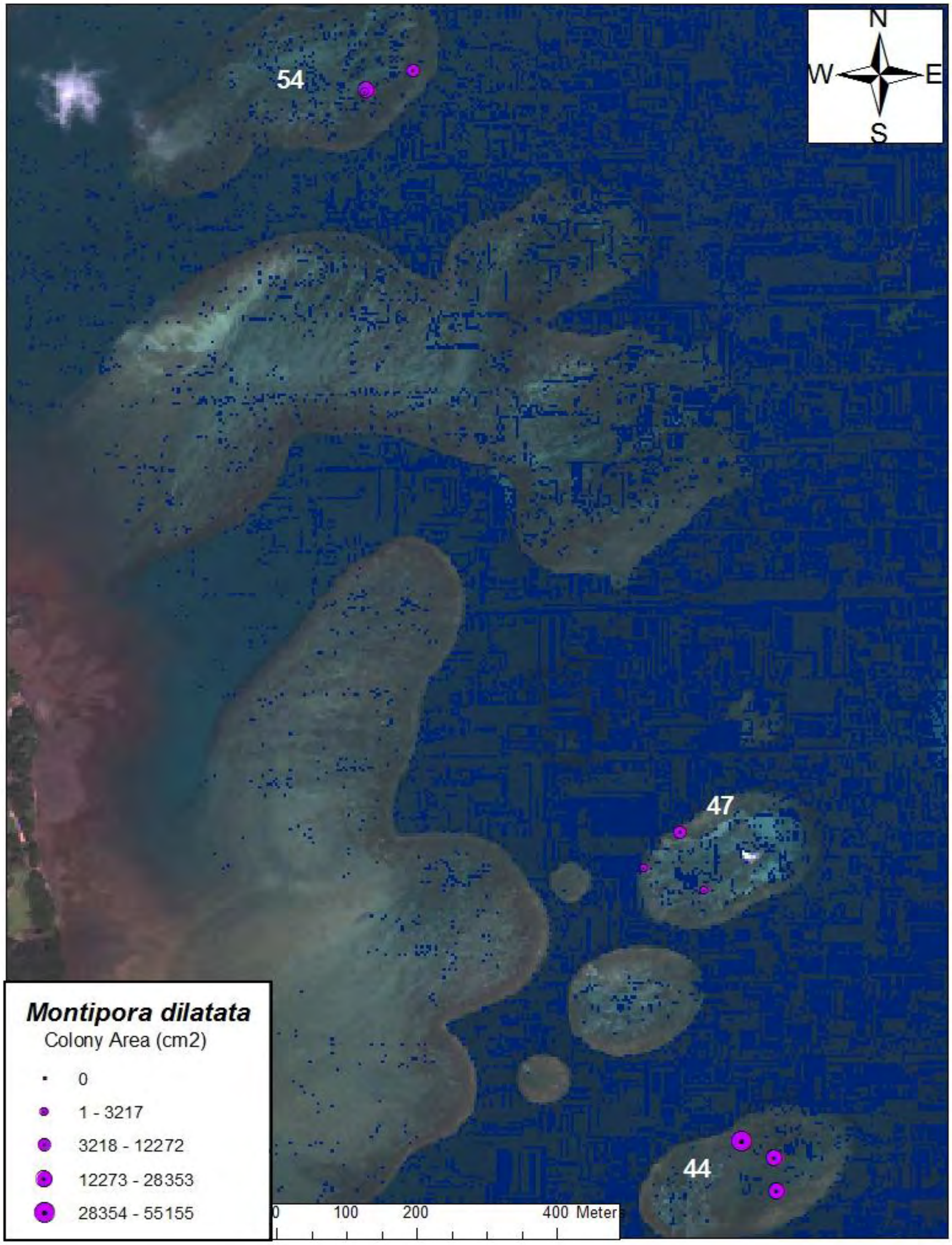

Figure 6: A dot density map displaying the area of each surveyed colony of *M. dilatata* in cm^2 in Kane'ohe Bay, O'ahu, Hawai'i.

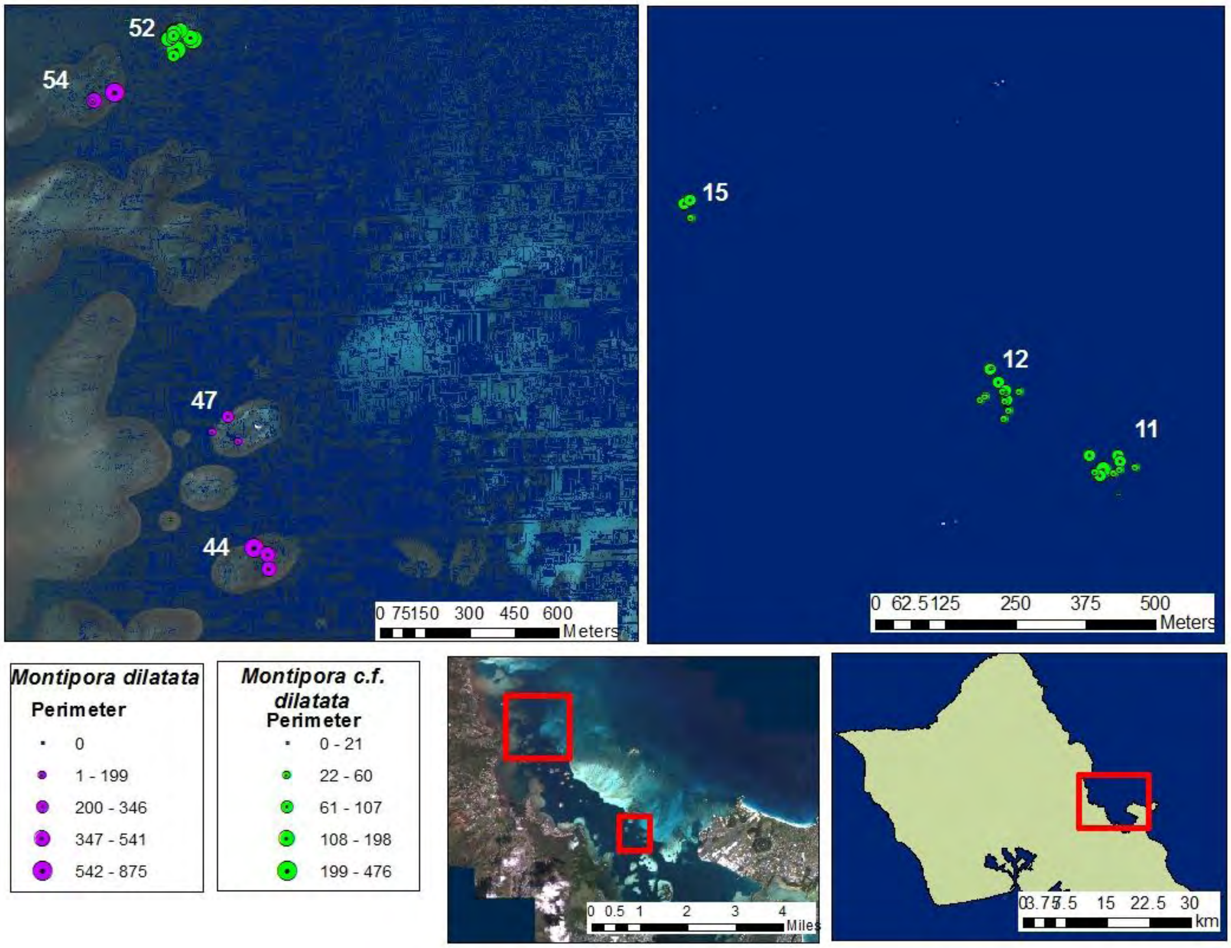

Figure 7: A dot density map illustrating the abundance and perimeter (cm) of each surveyed colony including all *M. c.f. dilatata* colonies. The purple dots represent positively identified colonies of *M. dilatata* while green dots symbolize potential colonies of *M. dilatata*.

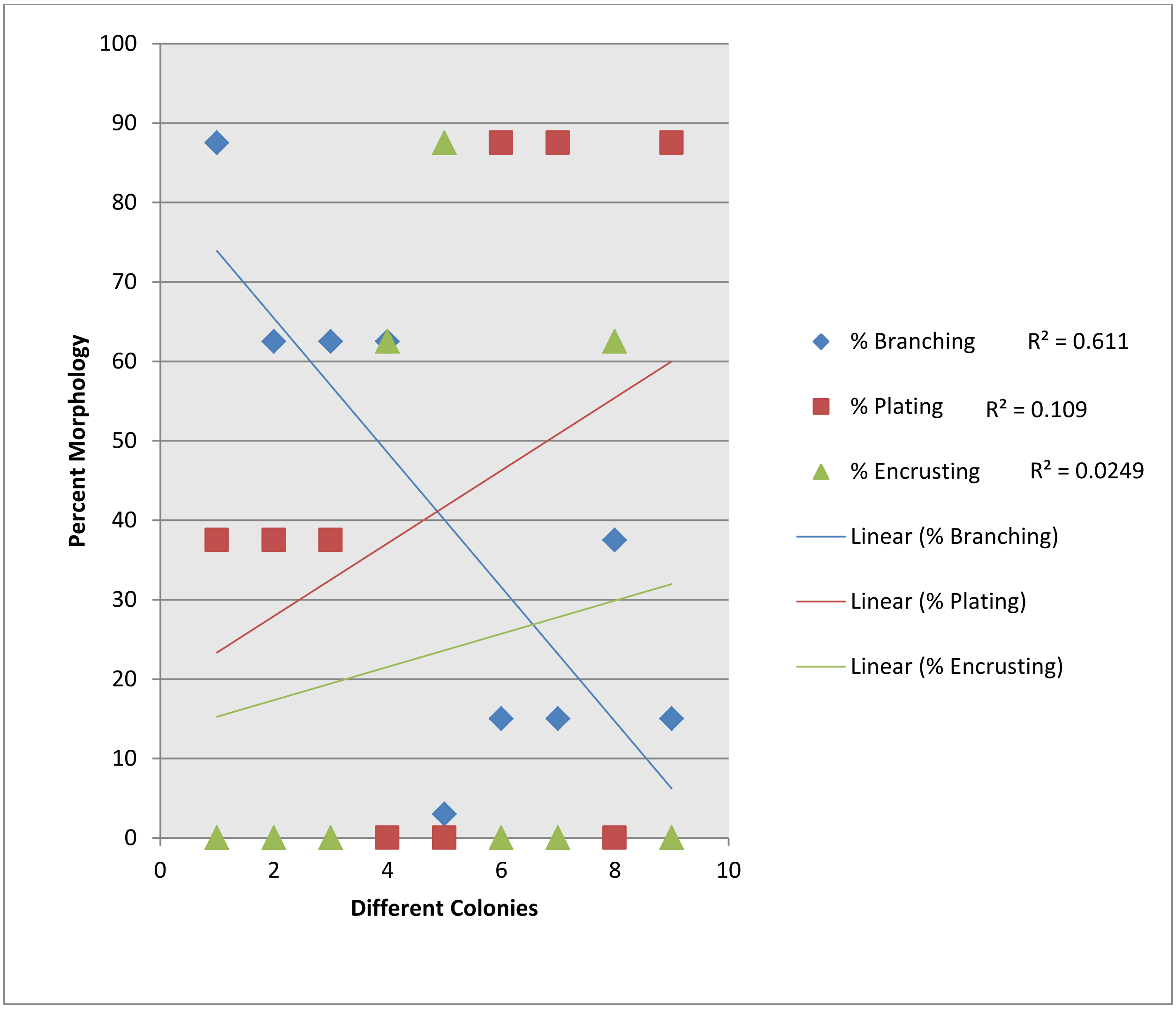

Figure 8: The relationship of morphology between the surveyed colonies of *M. dilatata*. The green triangles illustrate encrusting morphologies, the blue diamonds represent branching morphologies, and the red squares depict plating morphologies. This graph was made using a simple linear regression analysis.

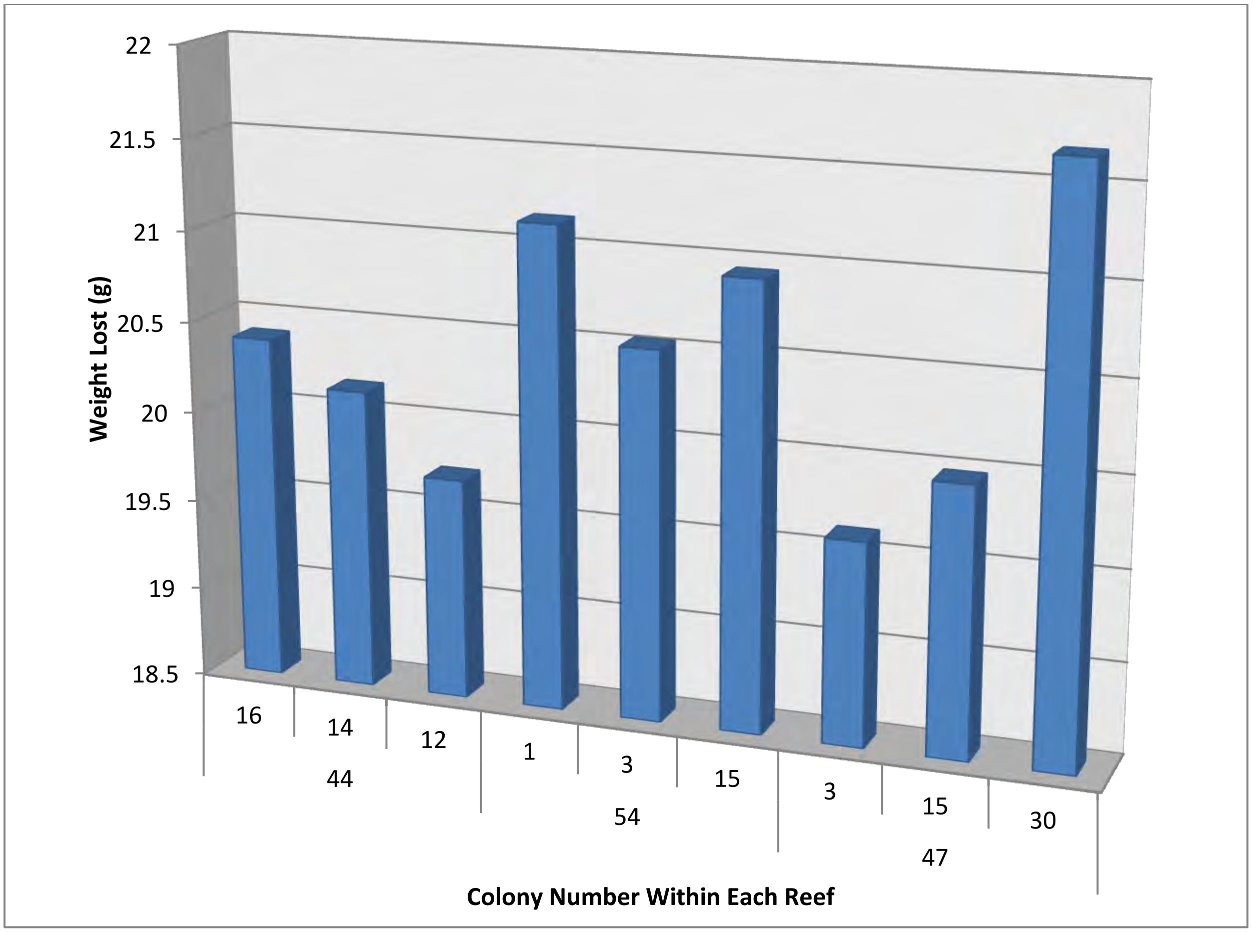

Figure 9: The average flow rate for each colony found by calculating the difference between the beginnig plaster ball weight and the ending plaster ball weight in grams (corrected with control plaster ball weight loss).

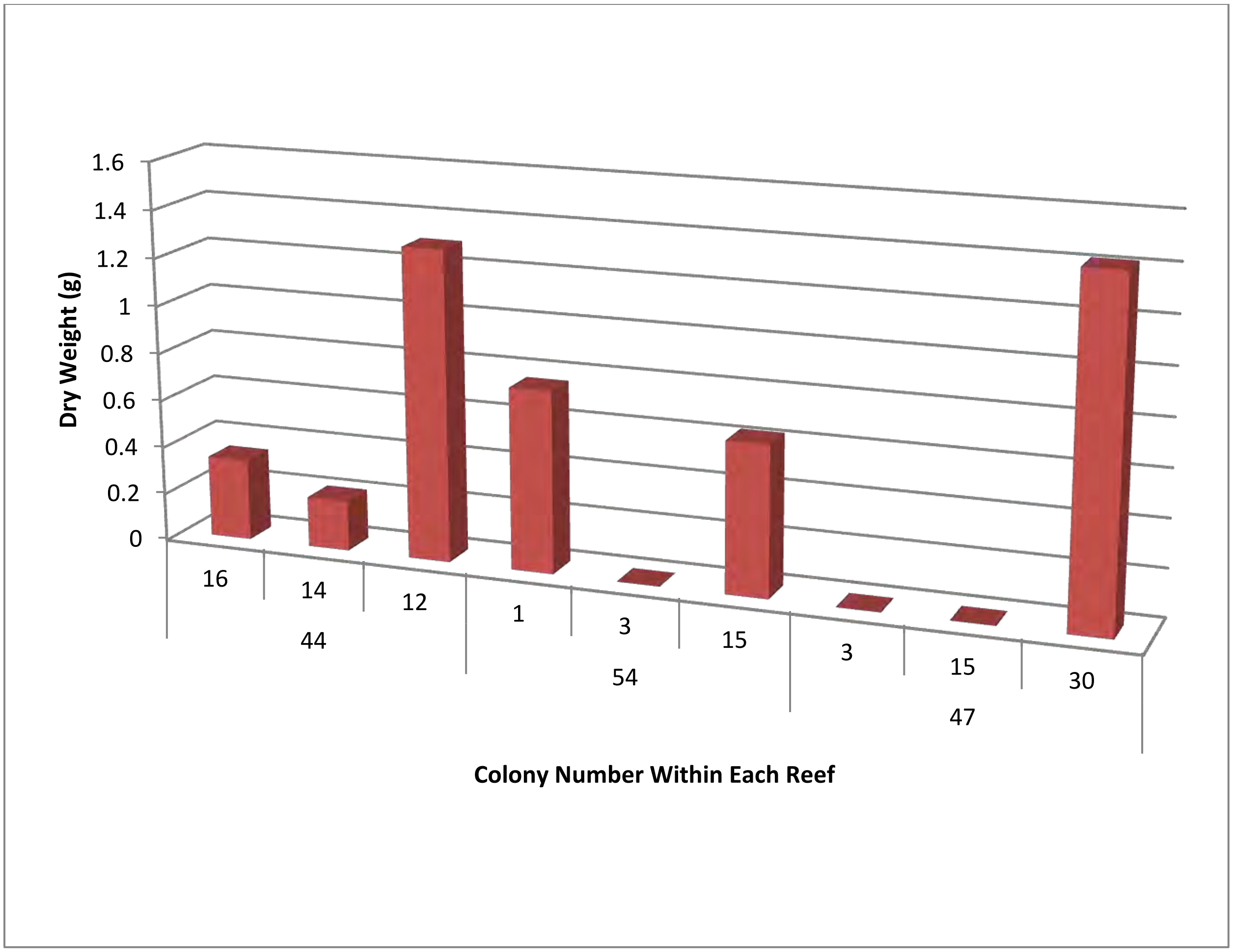

Figure 10: The dry weights (g) of the sediment that was caught at each colony of *M. dilatata* within each reef. The dry weights were measured 24 hours after the sediment was filtered using distilled water.

Discussion:

Montipora dilatata, a NOAA NMFS Species of Concern, could one day be listed as an endangered species without proper conservation techniques. Once abundant in Kane'ohe Bay, O'ahu, Hawai'i (NOAA, 2007), it is now one of the rarest corals in the Pacific (Veron, 2000). The nine colonies that were surveyed within this study were positively identified as *Montipora dilatata* by the 2010 Biology 403 class solely based on morphology due to the fact that collections of coral were prohibited. Of these nine colonies surveyed in North Kane'ohe Bay, the morphologies were similar within the different patch reefs. For example, Reef 44 had the greatest average percentage of branching *M. dilatata* colonies, Reef 47 had the greatest average percentage of plating colonies and, on average, Reef 54 had the most encrusting colonies. Corals tend to be phenotypically plastic, meaning that the environment induces changes in its morphology; moreover, the shape and morphology of corals is affected by light level along with wave stress (Chappell, 1980).

A significant relationship between sedimentation rate and morphology was expected, however, no relationship was found. Reef 44 had the lowest sedimentation rate and colonies of *M. dilatata* displayed the greatest percentage of branching morphologies. Reef 47 depicted an intermediate sedimentation rate and colonies contained mostly plating with a combination of branching and encrusting morphologies. This may be further evidence that some corals may fuse in response to increased sedimentation, meaning that different morphologies may converge on one colony in order to adapt to the sediment conditions (Brown et al. 1986). Reef 54 portrayed the greatest sedimentation rate, and the colonies of *M. dilatata* also comprised of the most encrusting morphological features. However, most of the sediment traps for this reef were found on their side which could have skewed the data. It is possible that the water flow was so strong that the traps got knocked over by the currents, or that certain sediments were not thick enough to hold the sediments traps vertically in the water. In order to prevent this, stronger, longer metals poles are required so that the sediment traps have a sturdier base and can remain vertical in order to obtain an accurate reading of sedimentation. It would also be helpful to place these traps where a smaller amount of sediment could be biased by human error.

Sedimentation can be a huge controlling factor in the overall development of coral reefs (Hubbard 1986, Macintyre 1988) because it may also affect colony morphology (Foster, 1979, 1980). In reefs with heavy sedimentation, one can expect a greater abundance of branching forms of coral (Rogers, 1990). However, with minimal sedimentation traps and only a couple weeks to gather data, any direct correlation was unable to be determined within this study. Hopefully future research incorporates a larger sample size as well as a longer duration of sediment collection, which may produce a successful correlation between morphology and sedimentation.

A strong relationship between water flow and morphology was expected; however, there was no relationship found. Based on observation, it can be determined that flow is a slightly variable parameter. Reef 54 appeared to portray the most water flow because it is located in the northern part of Kane'ohe Bay where the winds are fairly strong. Due to the strong winds and currents, it was hypothesized that *M. dilatata* colonies in higher water flow would primarily be composed of encrusting morphs. Conversely, Reef 44 appeared to have the calmest waters with the least amount of water flow because it is sheltered from the open ocean by a barrier reef. The calmer waters of this reef aided in the conclusion that these *M. dilatata* colonies would exhibit branching morphologies. The results of this study showed that Reef 54 had the highest water flow, and they also indicated that both Reef 44 and 47 had similar water flow; however, Reef 47 did not demonstrate as much branching as Reef 44 did. Instead, Reef 47 displayed colonies with more plating than any other morphology. There was a possibility that some of the plaster balls drifted away in the current, so in order to fix this problem, the plaster balls should not be placed directly on top of the reef. Instead, they should be enclosed in a mesh cage tied to a sturdy flag.

Water depth is a highly variable parameter because of different tides. Using the standardized calculations, Reef 54, on average, presented the deepest growing colonies, Reef 47 had the second deepest colonies, and Reef 44 had the shallowest growing colonies. A significant relationship was ascertained between water depth and percent branching, illustrating that colonies may only branch if they grow closer to the water's surface. Branching colonies may allow for concentrated light to diffuse evenly across the organism's surface. On the other hand, plating colonies have a larger surface area which may allow them to catch more light at deeper depths. In shallow waters, the light may be too intense for plating colonies to thrive without bleaching.

Reef 44 had on average the largest colonies of *M. dilatata*. It can be hypothesized that these colonies are older than the ones on the other surveyed sites. Furthermore, colonies on reef 44 had mostly branching colonies, which may grow at a faster rate than encrusting or plating forms (Jackson, 1991). Reef 47 had the smallest average area of the surveyed reefs, which exhibited more plating forms. Reef 54 had an intermediate average area. Nonetheless, no significant relationship was found between area and morphological patterns.

This study concluded that Reef 44 depicted an intermediate sedimentation rate, the lowest water flow, and had the shallowest water habitat with the most branching and most extensive colonies. It would appear that Reef 44 illustrates the optimal environment described by NOAA for *M. dilatata* to flourish due to these factors. Of the three sites that were surveyed, it is also the most sheltered. Reef 47 illustrated the lowest average sedimentation rate, an intermediate water flow, an intermediate water depth environment with the most plating and smallest colonies. Since Reef 47 contains smallest colonies, it can be hypothesized that these colonies are newly formed. The plating morphologies may thrive at this reef due to the low sedimentation rate; however, further research is needed to verify this conclusion.

Lastly, Reef 54 demonstrated the highest average sedimentation rate, the highest flow rate, and had the deepest water habitat with the most encrusting and mid-sized colonies. The stronger currents that were found at this reef could be a contributing factor in the high sedimentation rate because the water aids in the suspension of the sediment particles. Usually, smaller coral colonies are situated in high sediment environments because they are more efficient at rejecting sediment (Rogers, 1990); however, the colonies that were found at Reef 54 were of intermediate size (in comparison with Reefs 44 and 47).

Further research that should be conducted would be to 1) repeat this study with a larger sample size for a longer duration, 2) continue monitoring the positively identified colonies, 3) sample positively identified colonies for genetic work, and 4) to place aquarium-raised colonies in various environments to show any effects the environment may have on *M. dilatata* morphology. These future research experiments would aid coral specialists in being able to properly identify the morphologically plastic colonies of *Montipora dilatata*.

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