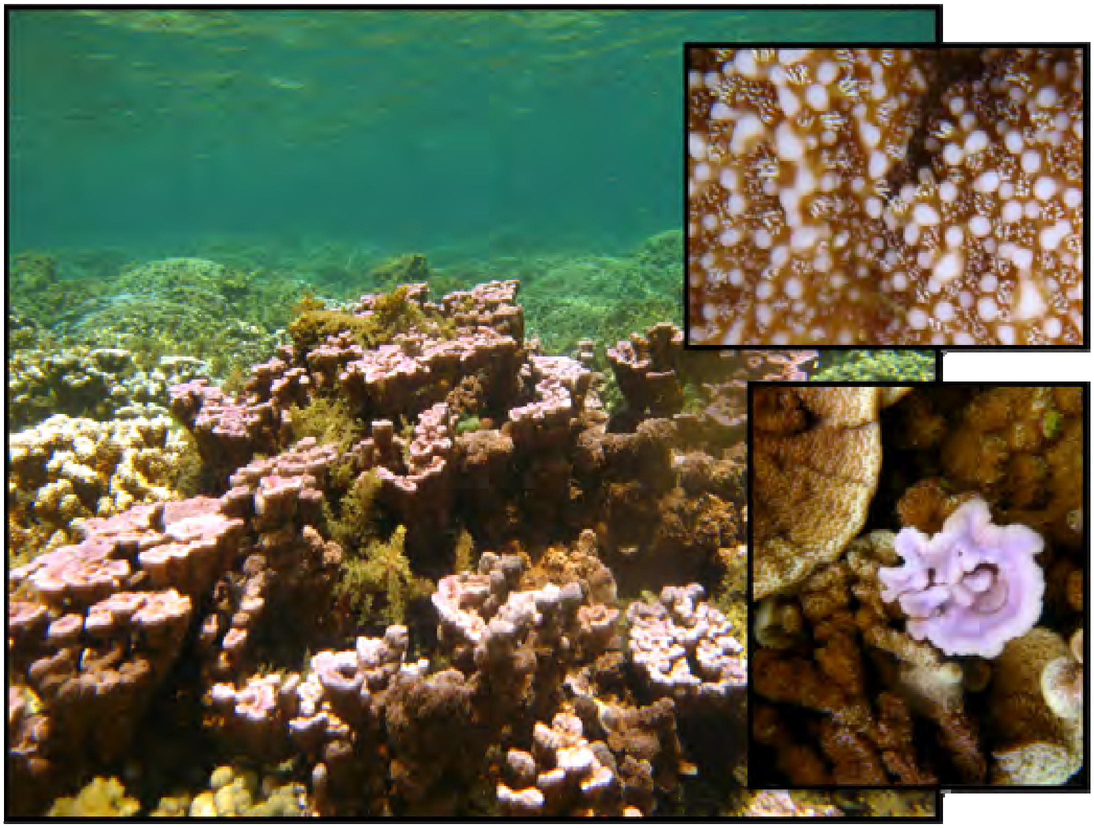
Distribution and abundance of *Montipora dilatata* and introduction of *Tripneustes gratilla* for mitigation of invasive algae (*Kappaphycus* spp.) in Kane'ohe Bay, Oahu, Hawai'i, 2010



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Abstract

The Hawaiian reef coral, *Montipora dilatata,* described as one of the rarest coral species in the Pacific (Veron 2000; Maragos *et al*. 2004; Fenner 2005), has apparently become even more rare in Kane'ohe Bay in recent decades perhaps due to freshwater kills, invasive algae, overfishing of herbivores, and habitat degradation (NOAA 2007). In the summer of 2010, Predictive maps were used to evaluate the distribution of *M. dilatata* and its habitat characteristics in Kane'ohe Bay. Visual surveys were conducted at 26 sites in Kane'ohe Bay, O'ahu, Hawai'i, in areas where *M. dilatata* has been reported to occur in the past and in areas where the habitat was predicted to be most suitable. A total of 43 *M. dilatata* colonies and 28 *M. cf. dilatata* colonies were found on 5 patch reefs in north Kane'ohe Bay, continuing the uptick in locating this species since 2007. Invasive algae presence was quantitatively analyzed around five *M. dilatata* colonies and was found to be most abundant near Colony #6 on Patch Reef 44. An effort was made to reduce algal competition with Colony #6 and to assess the long-term effectiveness of algal removal by a bio-control agent, the sea urchin *Tripneustes gratilla*. Based on the numerous threats this species faces, further monitoring of recorded colonies along with expanded conservation efforts are needed. Out-planting of additional sea urchins, particularly smaller individuals that might be better able to move into areas between colony plates and branches, will facilitate bio-control and improve coral survival.

Introduction:

The abundance of the Hawaiian reef coral *Montipora dilatata*, a National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) Species of Concern (SOC), is thought to have declined over the past few decades (NOAA 2007). In 2000, surveys for *M. dilatata* identified only three colonies in Kane'ohe Bay, O'ahu, Hawai'i, where it was formerly more abundant (J.E. Maragos, pers. comm.). As part of a 2007 University of Hawai'i-Manoa (UHM) field course (BIOL 403), students as well as coral experts identified three *M. dilatata* colonies in Kane'ohe Bay despite the difficulties in distinguishing it from other species within the same genus (Hunter *et al*. 2008). The three colonies found in 2007 were not the same three colonies originally identified in 2000. Students in the UHM field course found 20 *M. dilatata* colonies on 5 different reefs in Kane'ohe Bay in 2008, and 38 colonies on 4 reefs in 2009 (Hunter *et al*. 2009). Students found that Colony #6 on Patch Reef 44 is currently the only colony in any immediate threat of overgrowth by the invasive alga, *Kappaphycus* spp.

Habitat degradation as a result of sedimentation, bleaching, pollution, freshwater kills, overfishing and harvesting of herbivores, alien/invasive algae, and limited distribution may be contributing factors to the apparent decline of this species in Kane'ohe Bay (NOAA 2007). Conservation efforts can be improved based on better understanding of the degree and nature of threats *to M. dilatata*. Alien/invasive algal cover assessment is necessary to understand management efforts that may be needed to protect the habitat in which *M. dilatata* occurs.

Herbivores play an important role in coral reef ecosystems by limiting competition between algae and corals (e.g. Hughes *et al.* 1987). The herbivore *T. gratilla* has been a successful bio-control agent on Patch Reef 16 in Kane'ohe Bay where 1,300 urchins were introduced by the State of Hawaii Department of Land and Natural Resources (DLNR) Division of Aquatic Resources (DAR) Aquatic Invasive Species Team to half of the reef following large scale removal of *Kappaphycus* spp. and *Gracilaria salicornia* in 2009 (B. Hauk, pers. comm. 2010).

Like many other corals, the morphological plasticity of *M. dilatata* can make positive identification difficult in the field. Variation in morphology can be due to a number of factors including genetic variation, light and current regimes, and the substrate on which it is growing (Forsman *et al.*, 2009). Organisms residing within the tissue and skeletal matrix may also play a role in morphological variance (Studer, 1901). Not only is it problematic to characterize various *Montipora* species *in situ*, species distinctions have yet to be clarified by current molecular data. Mitochondrial DNA regions from *M. dilatata, M. turgescens, M. flabellata*, *M. patula,* and *M. verrilli* were found to be 100% identical, supporting the possibility that these species are closely related or potentially interbreeding (Forsman *et al.* 2009).

In order to better understand factors contributing to the decline of *M. dilatata,* there is a need to assess population size and distribution and the potential environmental parameters that affect them. Specific habitat characteristics of *M. dilatata* were integrated to build a spatially predictive map of distribution in Kane'ohe Bay by the 2009 UHM field course. This information could be used to predict possible habitats within the Hawaiian Islands. Data collected will aid the NMFS Pacific Islands Regional Office (PIRO) in determining whether *in situ* conservation measures (e.g., continued removal of alien/invasive algae from SOC habitats or introduction of bio-control agents) are effective in protecting this species from further decline.

The goals of this study were to: 1) conduct surveys throughout Kane'ohe Bay to determine the current distribution and abundance of *M. dilatata*; 2) quantify the current occurrence of alien/invasive algae in the *M. dilatata* habitat on Patch Reef 44; 3) remove alien/invasive algae in proximity to a threatened *M. dilatata* colony (Patch Reef 44, Colony #6); and 4) set up an area to release the bio-control agent, *T. gratilla*, for the control of alien/invasive algae that will be further monitored on Patch Reef 44, in the vicinity of Colony #6.

Methods and Materials:

Recognition of *M. dilatata* depended most heavily on color and morphology. Encrusting *Montipora* colonies with encrusting, plating/branching morphologies, that were light purple to light chocolate brown in color, became candidates for further investigation. If colonies exhibited branches that ended in flat and/or slightly concave tops, the colony in question was definitively recorded as the SOC. If not, colonies were assigned as *M*. cf *dilatata*.

Twenty-six reefs in Kane'ohe Bay were systematically surveyed for new and previously recorded colonies of *M. dilatata*. These sites were: Patch Reefs 1, 3, 8, 9, 10, 16, 17, 18, 25, 29, 38, 42, 43, 44, 46, 47, 48, 49, 51, 52, and 54; Fringing Reefs A, A3, B2, and B3 (Figure 1). Each of these reefs has been searched in previous years (2007-2009), but not exhaustively due to their size. Snorkelers spread out over one end of a reef and swam across it keeping visual contact with their neighbors. When potential colonies were discovered, their size, depth, and GPS location were recorded. Photos and qualitative observations were also taken of each potential colony. Once a colony was discovered, its location was marked with a zip tie or piece of flagging tape tied to an adjacent rock or dead coral, to avoid duplicate recording.

After *M. dilatata* colonies were identified and mapped using ArcGIS, population size for the North Kane'ohe Bay was estimated using the ratio of the number of colonies found in the area surveyed compared to the total area of that determined as suitable habitat for *M. dilatata*. A NOAA habitat map of Kane'ohe Bay was used to identify patch reefs and high (>10%) coral cover areas. Areas in the South Bay, within the Sand Bar, or at unsuitable depths for snorkel surveys (>3m) were disregarded. Areas defined by the NOAA maps as rubble within patch reefs were added to the potential habitat of *M. dilatata*.

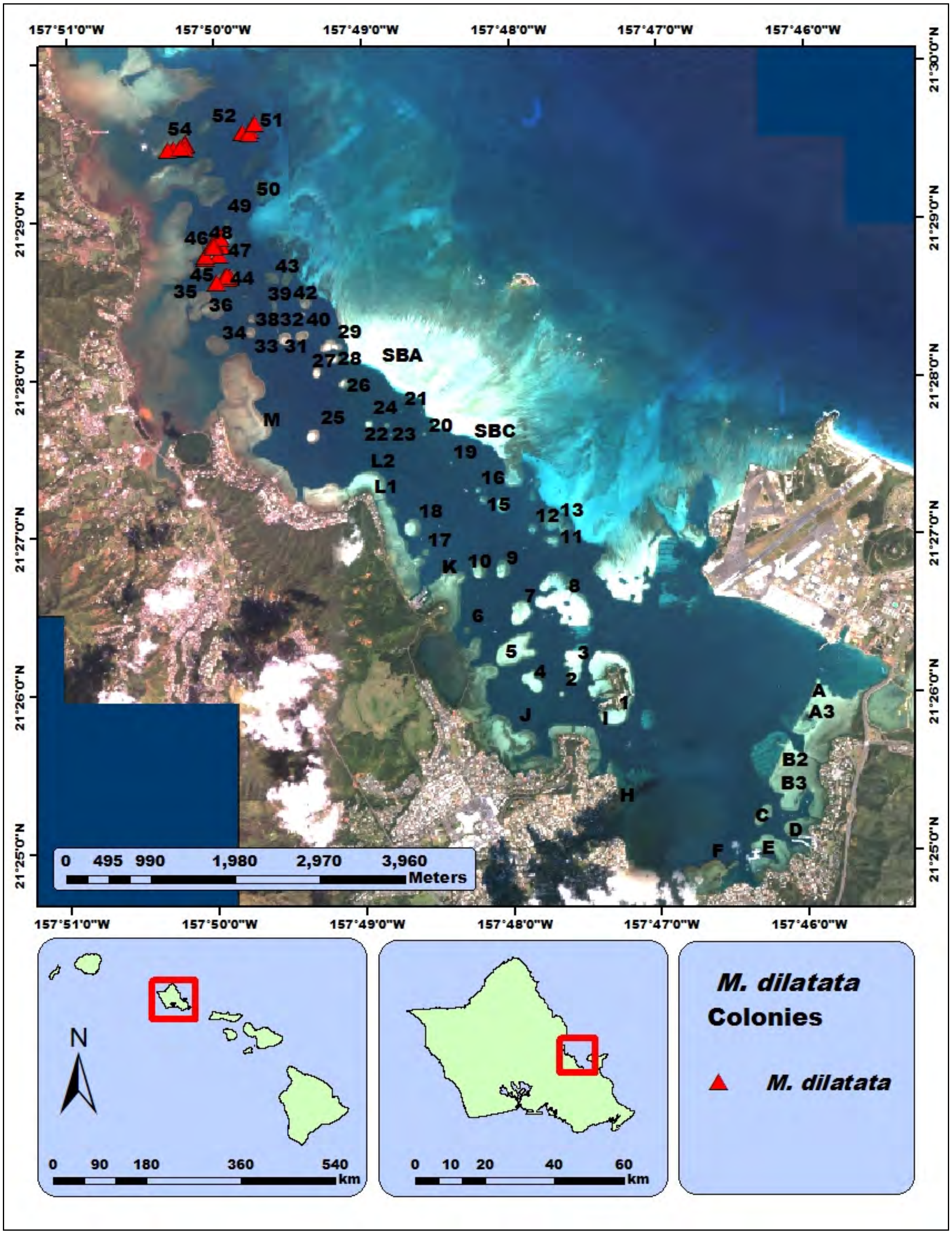

Figure 1: Locations of survey sites and 71 *M. dilatata* colonies found on 5 patch reefs in the north end of Kane'ohe Bay in July 2010.

A baseline estimate of algal cover was conducted on Patch Reef 44 on July 12th and 13th 2010. Five line reels were used to divide the reef into six survey regions, along NE-SW axes. Randomly determined GPS points were identified along the northeast side of the reef using Google Earth™ to site the placement of the transects (Table 1):

Table 1: Latitude and longitude start points for algal survey transects on Reef 44.

Reel #	Latitude	Longitude
1	21.478081	-157.831328
2	21.478042	-157.831905
3	21.477731	-157.832464
4	21.477600	-157.833000
5	21.477281	-157.833428

From each of these GPS points, a line reel was run across the reef at a heading of 155º. Three 50 m transects were run perpendicular to each line at approximately equal distances from each other and the edges of the reef, for a total of 18 survey transects oriented along 65º or 245º (Figure 2). A quarter square meter quadrat was used to estimate algal cover at 1 m intervals; on odd numbers the quadrat was placed on the left side of the transect and on even numbers the quadrat was placed on the right side. Percent cover of the following algal categories was estimated: *Kappaphycus spp,* crustose coralline algae, turf, and other macro algae. Percent cover values were divided into the following classes: 0-30%, 30-60%, 60-90% and 90-100%. Line reel two was inadvertently oriented at 180º, resulting in displacement of the three transects run from this point of reference. This discrepancy went unnoticed until after the survey was completed but was not believed to have affected the survey results since the line reels simply served as points of reference on the reef.

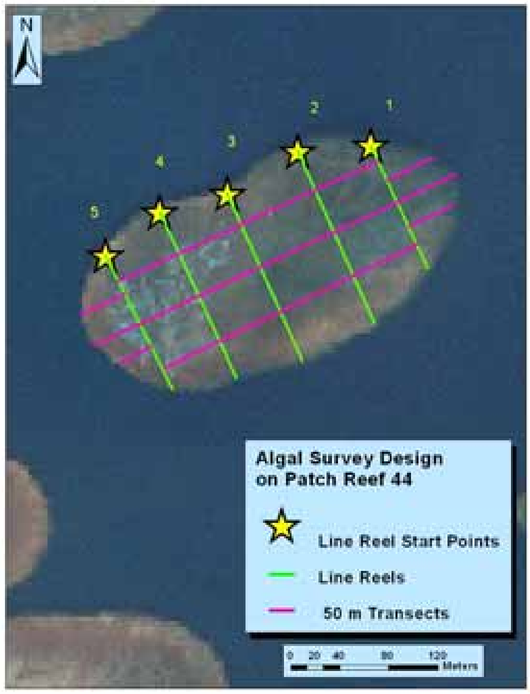

Figure 2: Intended experimental design for baseline algal surveys of Reef 44. Transect start points (stars) were GPS points listed in Table 1.

In order to quantify the amount of *Kappaphycus* spp. potentially or directly competing with *M. dilatata,* surveys were conducted from 0-10 m at cardinal directions from impacted Colonies 6, 14, 15, and 18 on Patch Reef 44, and Colony #15 on Patch Reef 47 (Table 2). Percent cover of *Kappaphycus* spp. (and *Gracilaria salicornia* around Colony #15, Patch Reef 47) was recorded using quarter square meter quadrats that were placed at 1 m intervals along the transects. Quadrats were placed on the right side of the transect on even meter marks and the left side on odd meter marks.

Invasive Algae Control

In an attempt to reduce competition between *Kappaphycus* spp. and *M. dilatata, Kappaphycus* spp. was manually removed from the vicinity of Colony #6. Transects were laid out over the colony such that they extended 10 m in north, south, east, and west directions. *Kappaphycus* was then removed from the east side of the colony to a distance of 10 m. A total of

17 bags of algae (approximately 27 kg each) were removed by 6 snorkelers over a period of 1.5 hours. The impacted colony was re-surveyed after the *Kappaphycus* spp. removal using the same procedure described above and monitored for six months.

On July 14th, 2010, DLNR-DAR Aquatic Invasive Species team members delivered 315 urchins to the site. Urchins were collected from an artificial reef at 20 m depth off Waianae, O'ahu, held in quarantine for 2 days at Anuenue Fisheries Research Center, and then transported in 14 crates containing approximately 22-23 individuals each. Transects were again laid out over Colony #6 such that they extended 10 m north, south, east, and west creating 4 quadrants. Urchins were haphazardly placed, with two crates into the northwest section, three crates in the southwest section, four crates in the northeast section, and five crates in the southeast section.

After deployment, urchin monitoring continued in order to assess efficacy in controlling abundance of *Kappaphycus* spp. Urchin surveys were accomplished by placing transects over the impacted *M. dilatata* colony such that they extended 10 m north, south, east, and west. Additional transects were run 10 m east and west from the end points of the north-south transect to provide visual landmarks for the surveys. Ten snorkelers then lined up east to west along the southern-most transect and swam north, recording the number of urchins along each 2 x 20 m belt transect, while visually recording whether they were on *Kappaphycus* spp., crustose coralline algae, turf algae, coral, or other substrate. Surveys during the BIOL 403 course were conducted on July 15th, July 17th, July 21st, July 28th, and August 4th, 2010; monthly follow-up surveys were conducted on September 11th, October 16th, November 13th, December 14th, 2010, and January 15th, 2011 (Table 3).

Results:

In total, 26 sites were surveyed for the presence of *Montipora dilatata* in Kane'ohe Bay. Of those sites, 71 colonies were found and marked with GPS on 5 reefs in the North Bay (Figures 1, 3). Of the 71 colonies of *M. dilatata* found, 43 were definitively labeled as *M. dilatata* while 28 were recorded as *M. cf. dilatata* (taxonomically "compare to"; Figure 4). *M. cf. dilatata* colonies were colonies classified as similar to but not clearly identifiable as *M. dilatata* due to varied morphological differences. *M. cf. dilatata* colonies were present on four of the five reefs where *M. dilatata* was also found. There were no colonies of *M. cf. dilatata* present on Reef 44. Colonies of *M. dilatata* were mapped by size on Reefs 44, 46, 47, 51, and 54 in the north end of Kane'ohe Bay (Figure 5). Reef 47 contained a higher abundance of colonies of smaller sized colonies than other reefs surveyed (Fig. 5 & Table 4).

A predictive habitat map was generated using NOAA's depth and benthic habitat cover data for the area (Figure 6). The south end of Kane'ohe Bay was excluded, as no *M. dilatata* have been found in this area in the past two years. Average cover of *Kappaphycus* spp. per m^2 near colonies of *M. dilatata* was surveyed on Reef 44 and 47 (Figure 7). Higher percentages of *Kappaphycus* spp. were present on Reef 44 (Table 3). There was no *Kappaphycus* spp. in the vicinity of colonies of *M. dilatata* on Reef 47 (Figure 7) but *Kappaphycus* spp. cover on and around Colony #6 on Reef 44 neared 25% (Figure 8).

A survey of benthic cover of 5 algal categories on Reef 44 found that *Kappaphycus* spp. was present on 11 of 18 transects (Figure 9) and they were more frequent in the south and center of the reefs.

A total of 315 urchins were deployed on Reef 44 in the immediate vicinity of Colony #6 (Figure 10). The number of *T. gratilla* and the substratum types on which they were found at each census in July-August span shows a slight decline in *Kappaphycus* abundance (Table 3, in process of updating from Aug 10 to March, 2011). Surveys before and after removal of ~460 kg of *Kappaphycus* and again after four weeks of urchin grazing (Figure 11, still in progress) show that manual removal followed by introduction of an urchin grazer was effective in controlling alien algal competition with the coral colony. Average alien algal cover before hand removal (28%), after hand removal (17%), and one week after urchin introduction (15%), showed a trend in the "right" direction.

After six months, just 10% (32) of the initial sea urchins remained within the 20 x 20 m target area on Reef 44 (Table 3). Urchins appear to have moved or survived better on crustose coralline algae (Table 3). Attrition of urchins appeared to be due both to movement out of the study site as well as mortality. A small number of urchins (1-6) were found outside of the target area after considerable searching on any particular survey date, and returned to the center point. Dead tests found in the area (total of 86), represented approximately 27% of the original number.

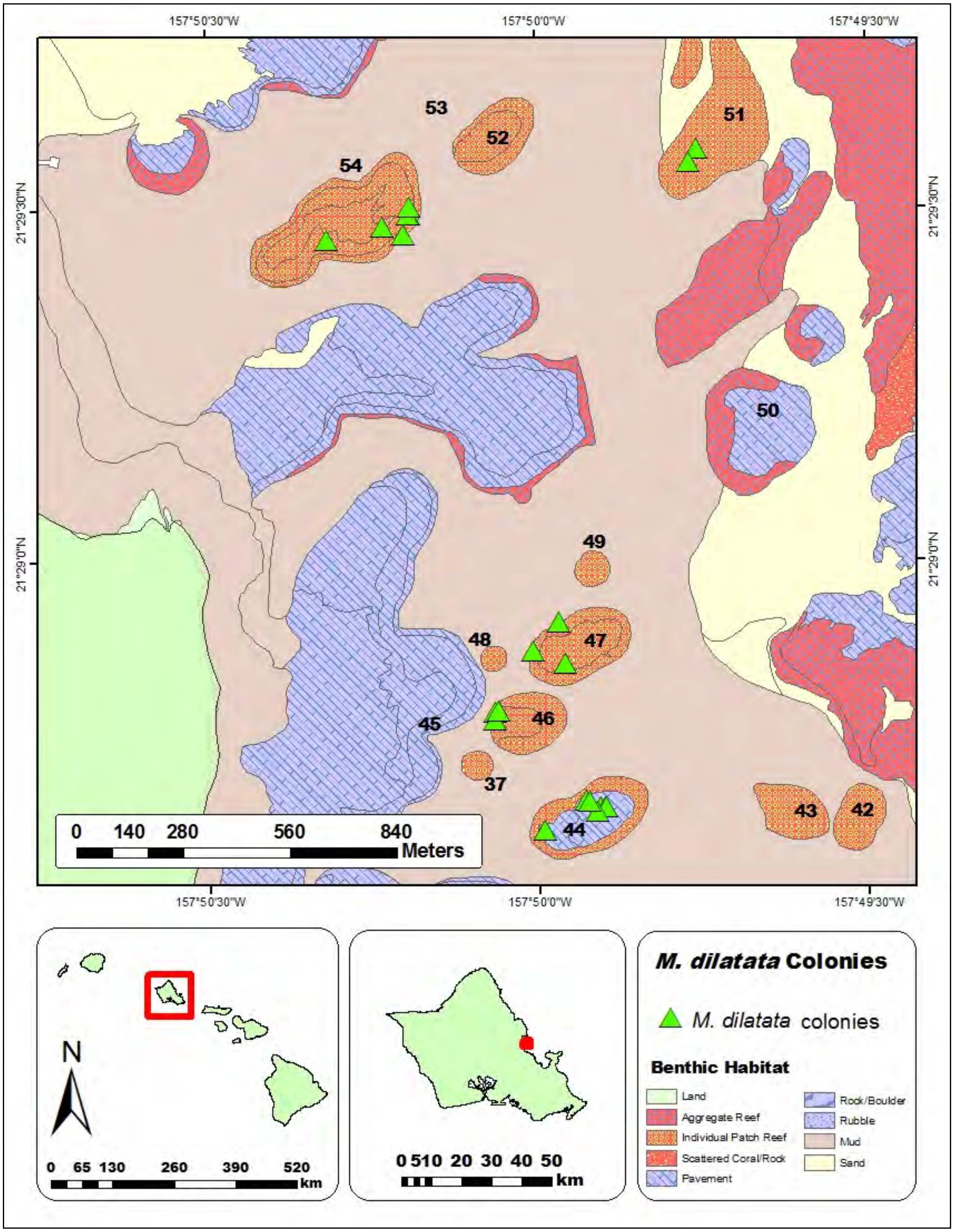

Figure 3: NOAA benthic map exhibiting the habitat surrounding five patch reefs in Kane'ohe Bay where *M. dilatata* was found in July 2010.

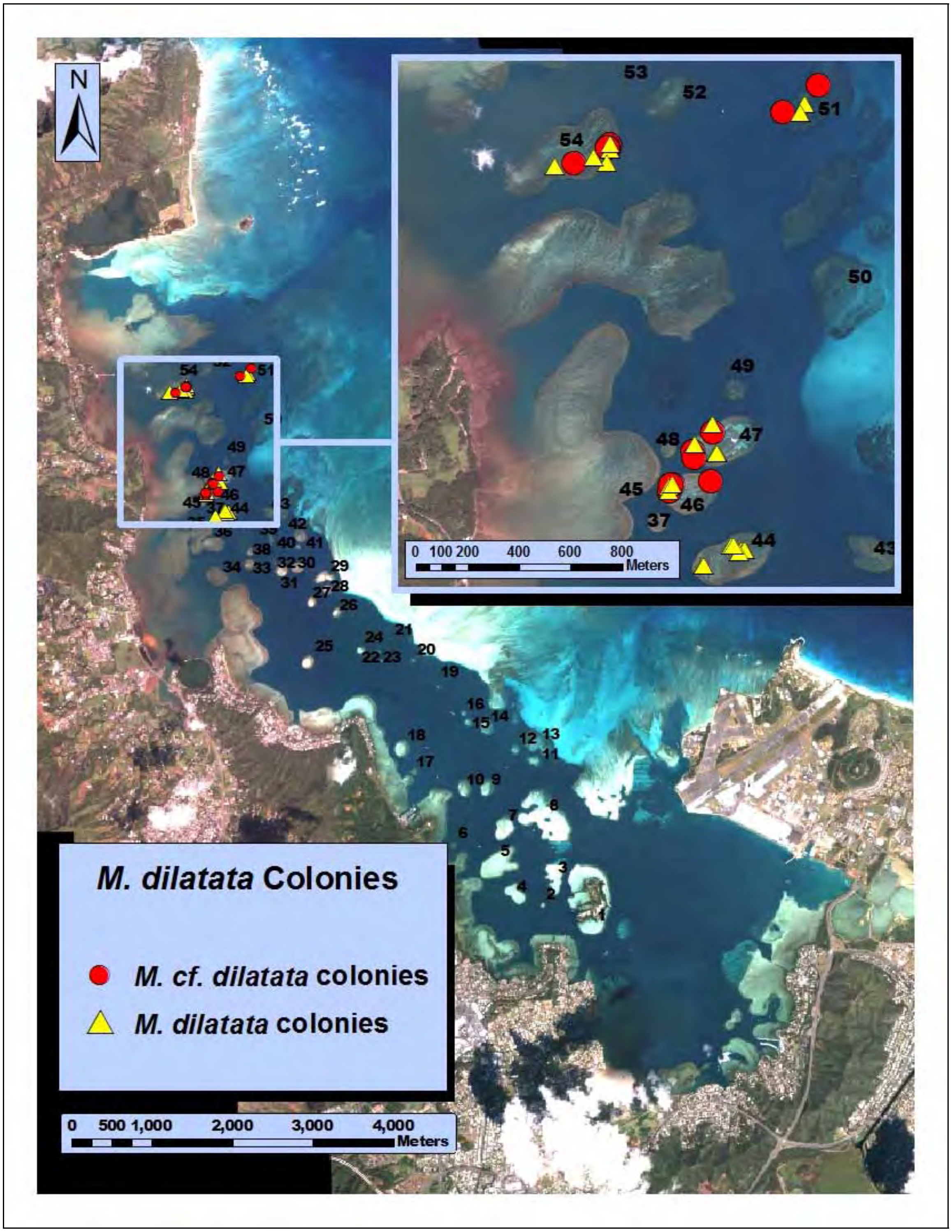

Figure 4: Locations of *M. dilatata* colonies vs. *M. cf. dilatata* colonies in July 2010.

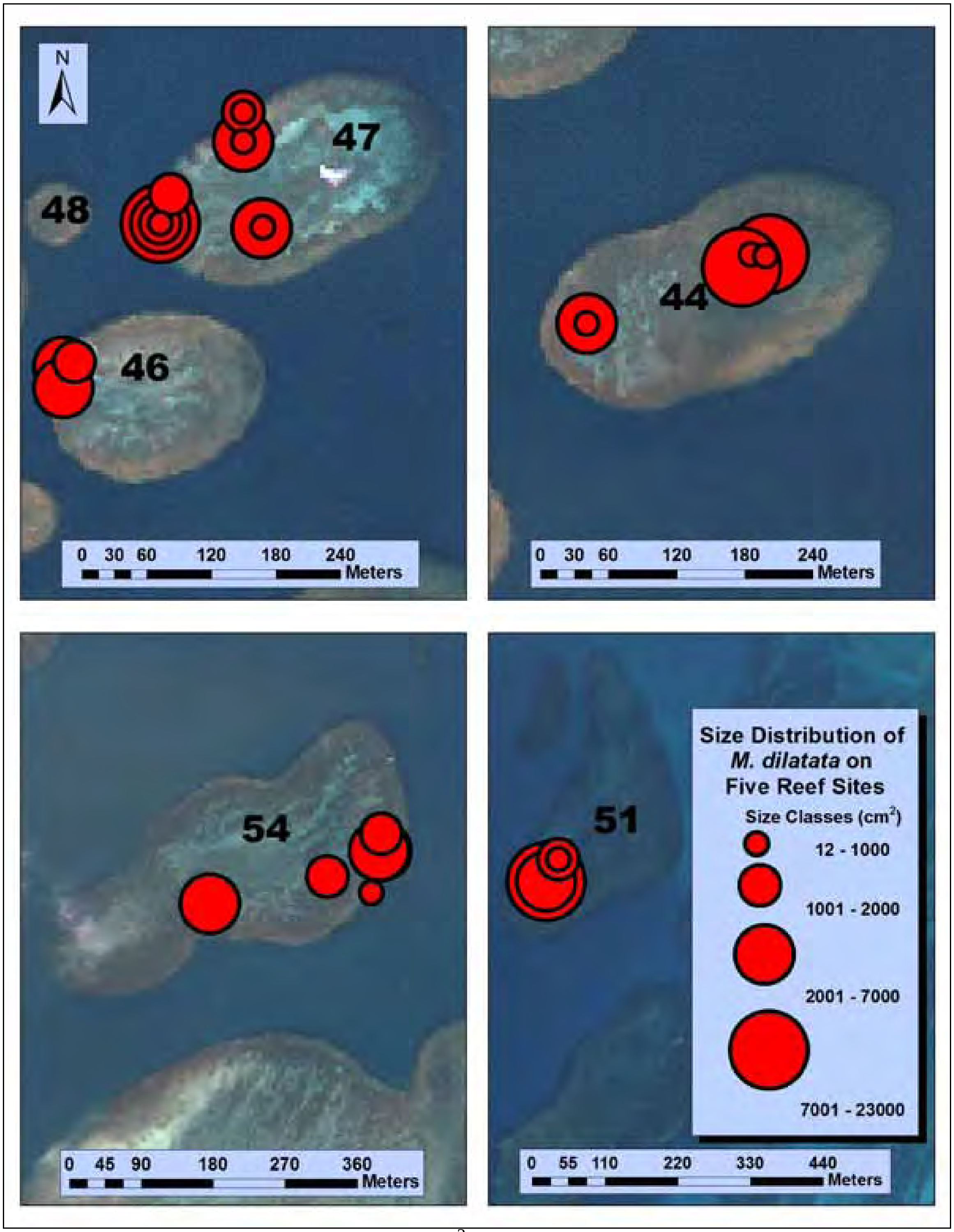

Figure 5: Size distribution of *M. dilatata* in cm^2 on Reefs 44, 46, 47, 51 and 54 in July 2010.

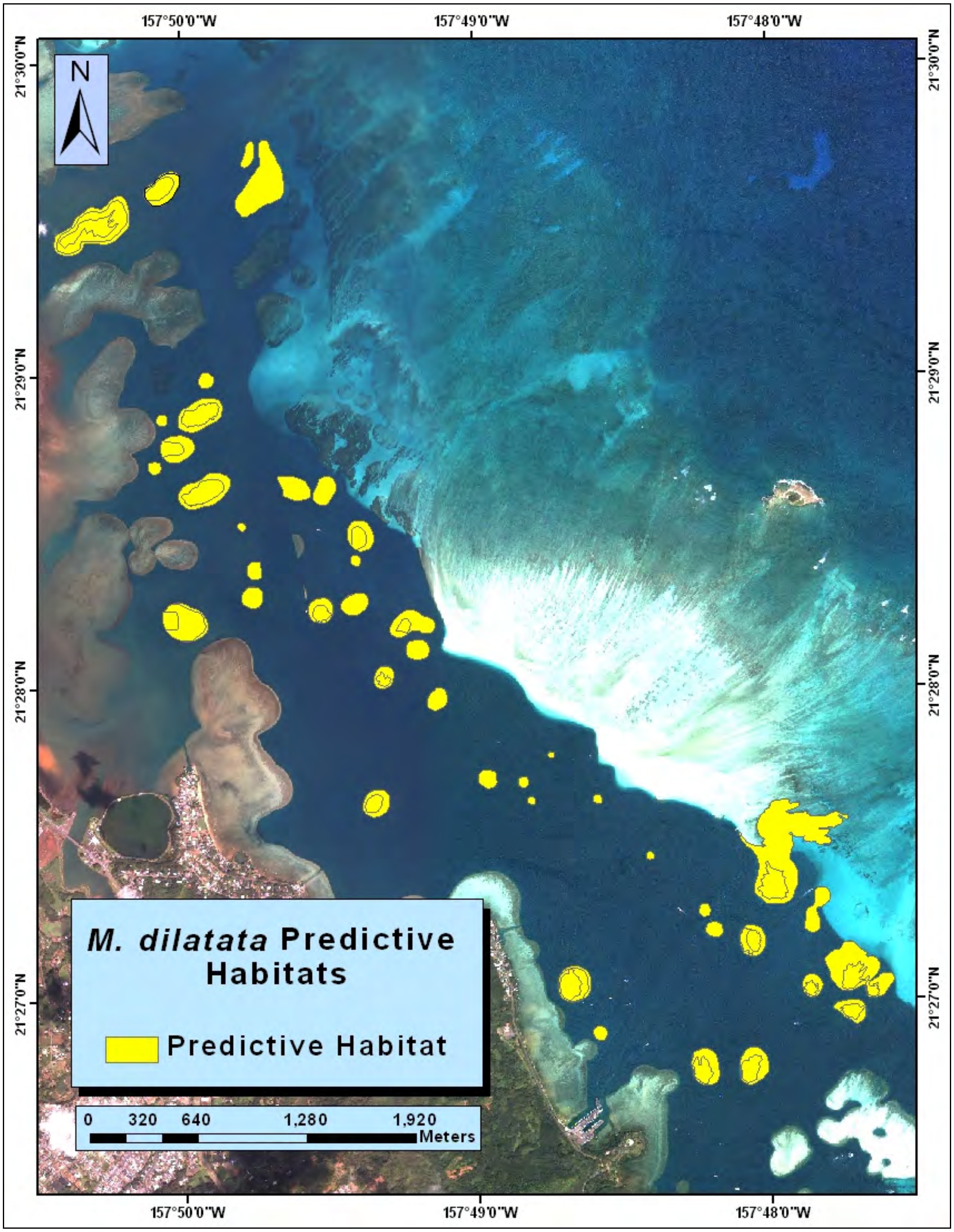

Figure 6: Predictive habitat of *M. dilatata* colonies based on depth and coral cover in Kane'ohe Bay, July 2010.

Figure 7: Average cover/m^2 of 10 m of *Kappaphycus* spp. within a 400 m area around *M. dilatata* colonies on Reef 44 and 47 surveyed July 2010.

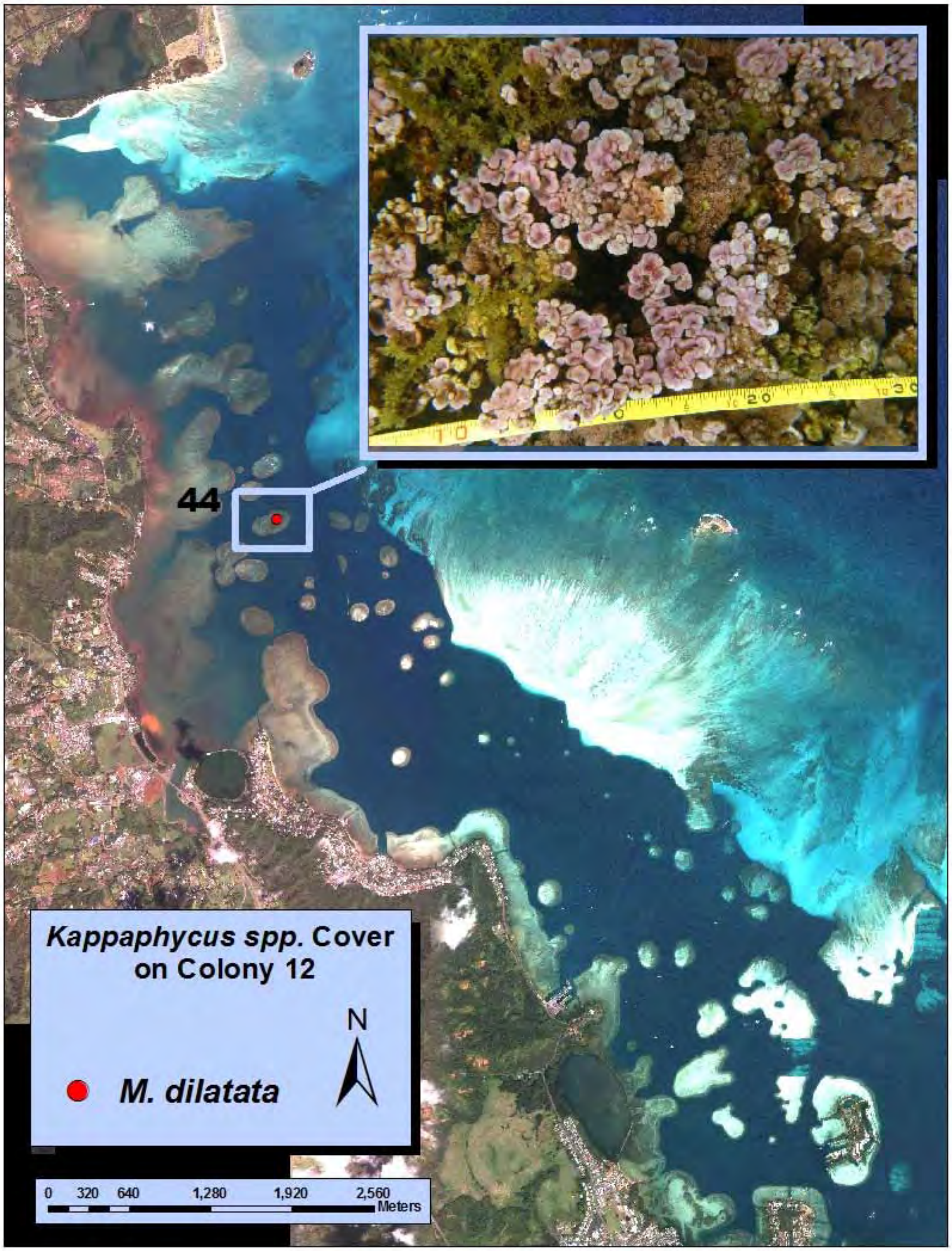

Figure 8: *Kappaphycus* spp. cover around Colony #6 of *M. dilatata*, Reef 44 in July 2010.

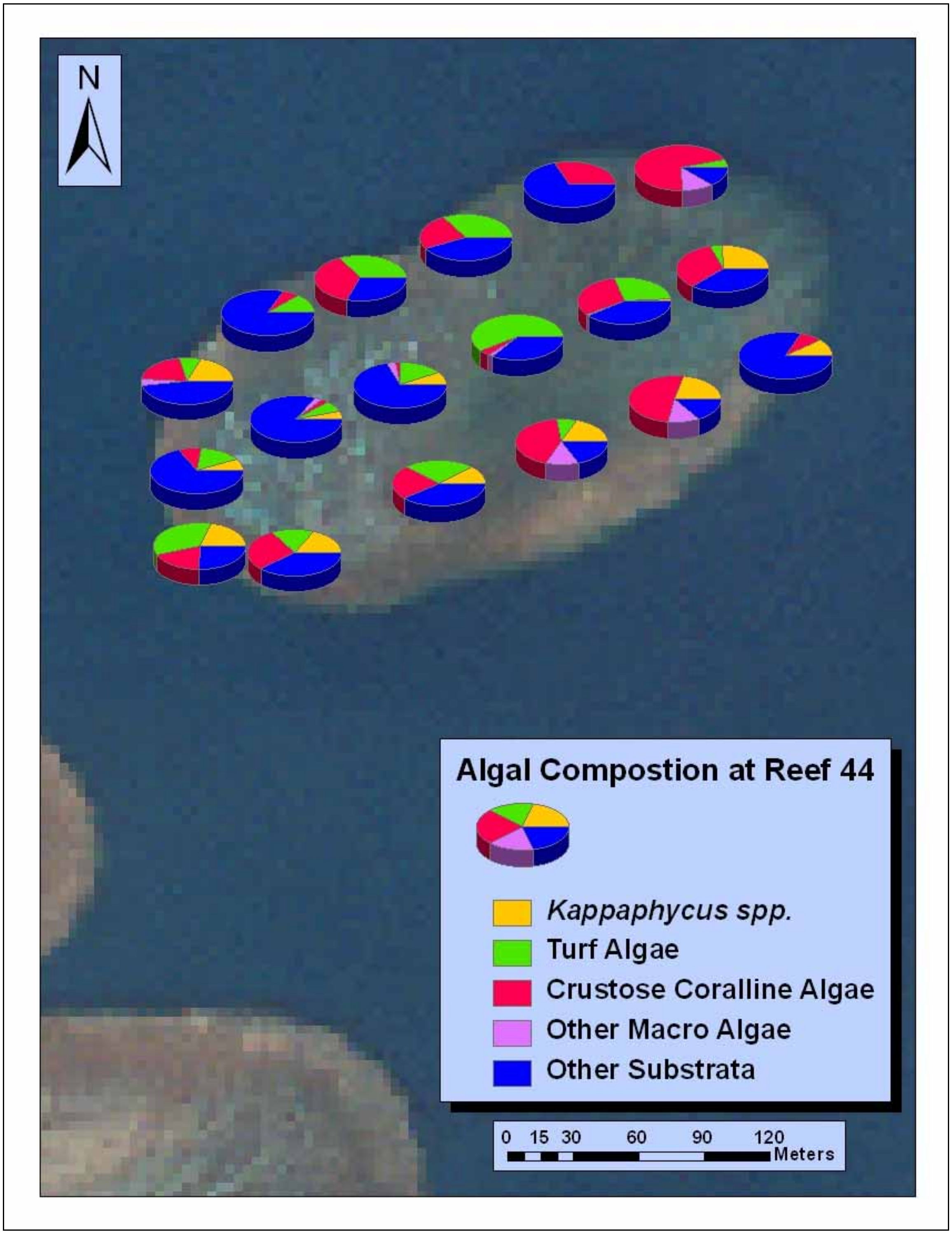

Figure 9: Algal composition on Reef 44 surveyed July 2010.

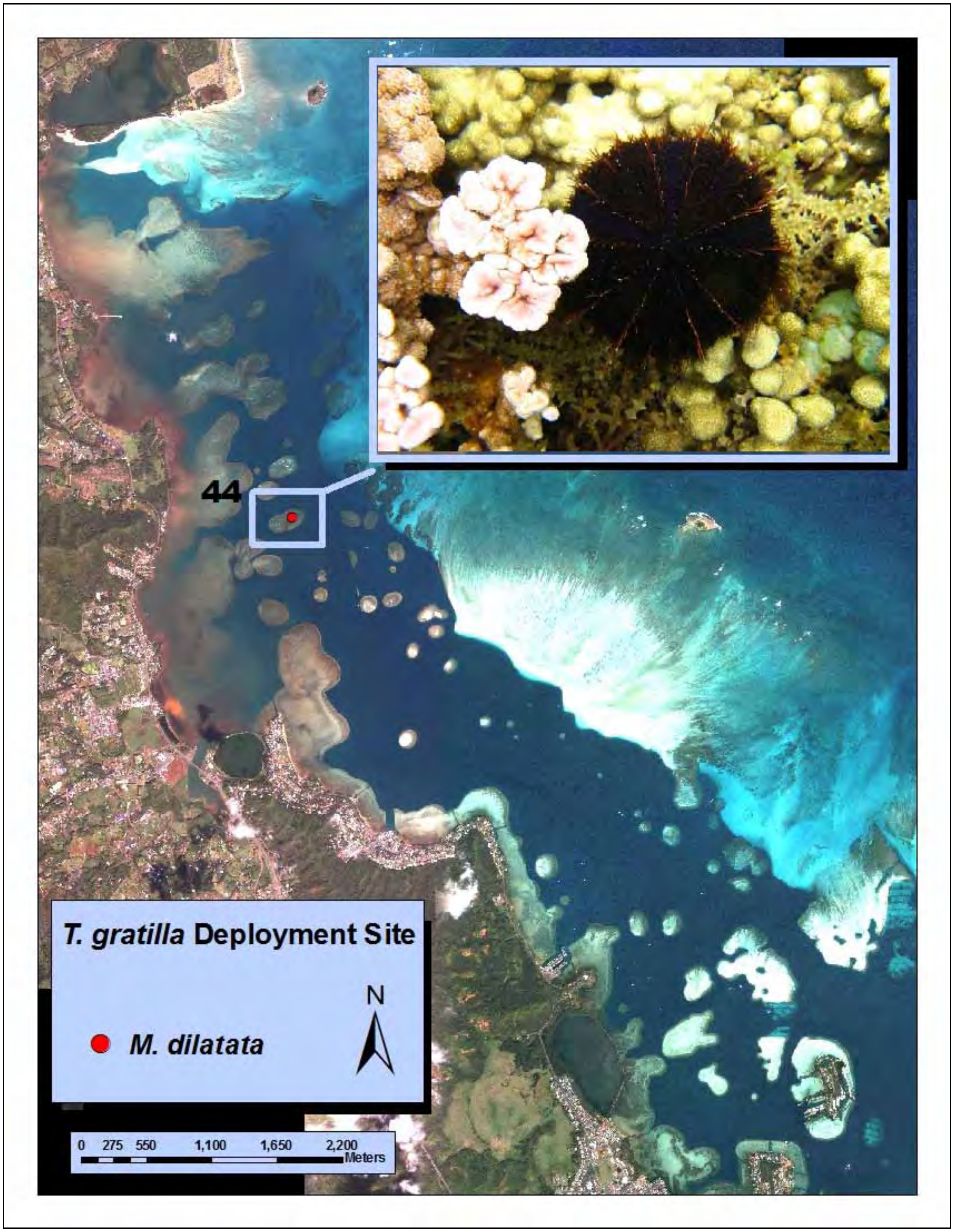

Figure 10: *Tripneustes gratilla* placement on Colony #6 of *M. dilatata*, Reef 44, July 2010.

Table 2: Average percent cover of *Kappaphycus* spp. on five colonies of *M. dilatata* on Reef 44 and 47.

Date	Site	Colony	Latitude	Longitude	Average % Coverage	Area/m2
7/13/2010	44	12	21.47751	-157.8317	24.3	400
7/13/2010	44	14	21.47768	-157.8322	0	400
7/13/2010	44	15	21.4775	-157.8317	0	400
7/13/2010	44	18	21.47764	-157.8321	4.4	400
7/23/2010	47	15	21.48095	-157.8336	0	400

Table 3: Percent of *Tripneustes gratilla* found on dominant substratum types at each census. Initial number of urchins deployed on 7/14/2010 was 315.

Date	Coral	CCA	Kappaphycus	Turf	Other macro algae	Urchins found outside of transect	Total urchins found	Dead
7/15/10	12.9	33.6	39.6	10.1	0	4	217	1
7/17/10	10.8	32.5	40.6	14.1	0.5	1	212	2
7/21/10	17	30	35.5	13	0	5	200	5
7/28/10	9.8	31.6	45.9	8.6	0.6	3	174	10
8/4/10	18.6	30.7	32.9	17.1	0	1	140	4
9/11/10	8.8	26.5	52	11.8	0	1	102	11
10/16/10	15.3	25	40.3	18.1	0.7	1	144	11
11/13/10	15.1	31.5	34.2	17.8	1.4	6	79	5
12/14/10	4.2	45.8	25	25	0	3	27	16
01/15/11	7.1	50	35.7	7.1	0	4	32	21
02/12/11								

Table 4: Colony number, GPS location, size, and depth for *M. dilatata*. Colonies of surveyed Patch Reefs are displayed. The status of the colonies is described as Y: *M. dilatata*, and P: *M. cf. dilatata*.

Reef	Colony Number	Latitude	Longitude	Size (cm^2)	Depth (m)	Status
44	12	21.47751	-157.831678	15000	0.5	Y
44	13	21.47751	-157.831828	900	1	Y
44	14	21.47768	-157.832172	90000	0.75	Y
44	15	21.4775	-157.831706	300	1	Y
44	16	21.47751	-157.831678	37800	0.5	Y
44	17	21.47741	-157.831908	15000	0.75	Y
44	18	21.47764	-157.832092	1200	1	Y
44	19	21.47697	-157.83323	4050	0.75	Y
44	20	21.47697	-157.83323	450	0.75	Y
46	1	21.47957	-157.83448	300	1.4	P
46	2	21.47957	-157.83448	2400	1.4	P
46	3	21.47979	-157.83438	2000	2	P
46	4	21.47981	-157.83445	48	1.5	P
46	5	21.47993	-157.83296	100	1.5	P
47	1	21.48091	-157.83285	48	1.5	Y
47	2	21.4809	157.83269	4225	1.6	Y
47	3	21.48119	-157.83351	1225	1.4	Y
47	4	21.47975	-157.83448	3825	1.4	Y
47	5	21.47957	-157.83448	2400	1.4	Y
47	6	21.47979	- -157.83438	2000	1.7	Y
47	7	21.48188	-157.83285	625	1.5	Y
47	8	21.48188	-157.83385	900	1.4	Y
47	9	21.48188	-157.83285	1500	1.5	Y
47	10	21.48188	-157.83285	18	1.5	Y
47	11	21.48163	-157.83285	12	1.5	P
47	12	21.48163	-157.83285	2800	1.5	P
47	13	21.48163	-157.83285	600	1.5	Y
47	14	21.48163	-157.83285	36	1.5	Y
47	15	21.48163	-157.83285	144	1.5	Y
47	16	21.48163	- 157.83285	21	1.5	Y
47	17	21.48163	-157.83285	55	1.5	Y
47	18	21.48163	-157.83285	88	1.5	Y
47	19	21.48163	-157.83285	900	1.5	P
47	20	21.48163	-157.83285	400	1.4	P
47	21	21.48095	-157.83360	22500	1.5	P

47	22	21.48095	-157.83360	1500	1.4	P
47	23	21.48095	-157.83360	195	1.4	Y
47	24	21.48095	-157.83360	64	1.4	P
47	25	21.48095	-157.83360	140	1.5	Y
47	26	21.48095	-157.83360	3600	1.6	Y
47	27	21.48095	-157.83360	3600	1.5	P
47	28	21.48095	-157.83360	160	1.5	Y
47	29	21.48095	-157.83360	375	1.5	Y
47	30	21.48095	-157.83360	182	1.5	Y
47	31	21.48095	-157.83360	49	1.4	Y
47	32	21.48095	-157.83360	56	1.2	Y
47	33	21.48095	-157.83360	120	1.4	Y
47	34	21.48095	-157.83360	150	1.3	Y
47	35	21.48075	-157.83355	180	2	P
51	1	21.49278	-157.83017	250	2.5	P
51	2	21.49278	-157.83017	1500	2.5	P
51	3	21.49278	-157.83017	75	2.5	Y
51	4	21.49278	-157.83017	7200	2.5	P
51	5	21.49278	-157.83017	2400	2.5	Y
51	6	21.49278	-157.83017	1200	2.5	P
51	7	21.49278	-157.83017	3200	2.5	P
51	3	21.49278	-157.83017	75	2.5	Y
51	5	21.49278	-157.83017	2400	2.5	Y
54	1	21.49153	-157.83658	5000	1	Y
54	2	21.46153	-157.83661	4250	1	Y
54	3	21.49165	-157.83661	600	1	P
54	4	21.49173	-157.83658	1200	1.5	Y
54	5	21.49173	-157.83663	7200	1.5	P
54	6	21.49159	-157.83667	4500	1	P
54	7	21.49159	-157.83671	100	1.4	P
54	8	21.49159	-157.83672	150	1.4	P
54	9	21.49159	-157.83673	25	1.4	P
54	10	21.49159	-157.83673	225	1.4	P
54	11	21.49106	-157.83674	9	1.4	P
54	12	21.49106	-157.83671	15	1.4	Y
54	13	21.49106	-157.83795	3025	1.2	P
54	14	21.83866	-157.83866	4125	1.3	Y
54	15	21.49125	-157.83724	1050	1.2	Y

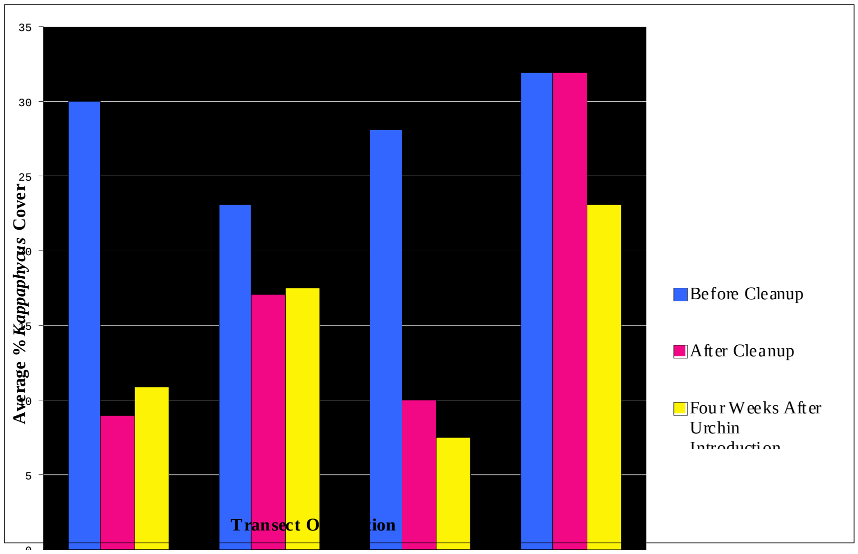

Figure 11: Changes in percent cover of *Kappaphycus* spp. cover on Colony #6, Patch Reef 44. Percent cover is shown before and after removal of ~460 kg of *Kappaphycus* on the E half of the center (N/S) transects and again after four weeks of urchin grazing—monitoring is on-going.

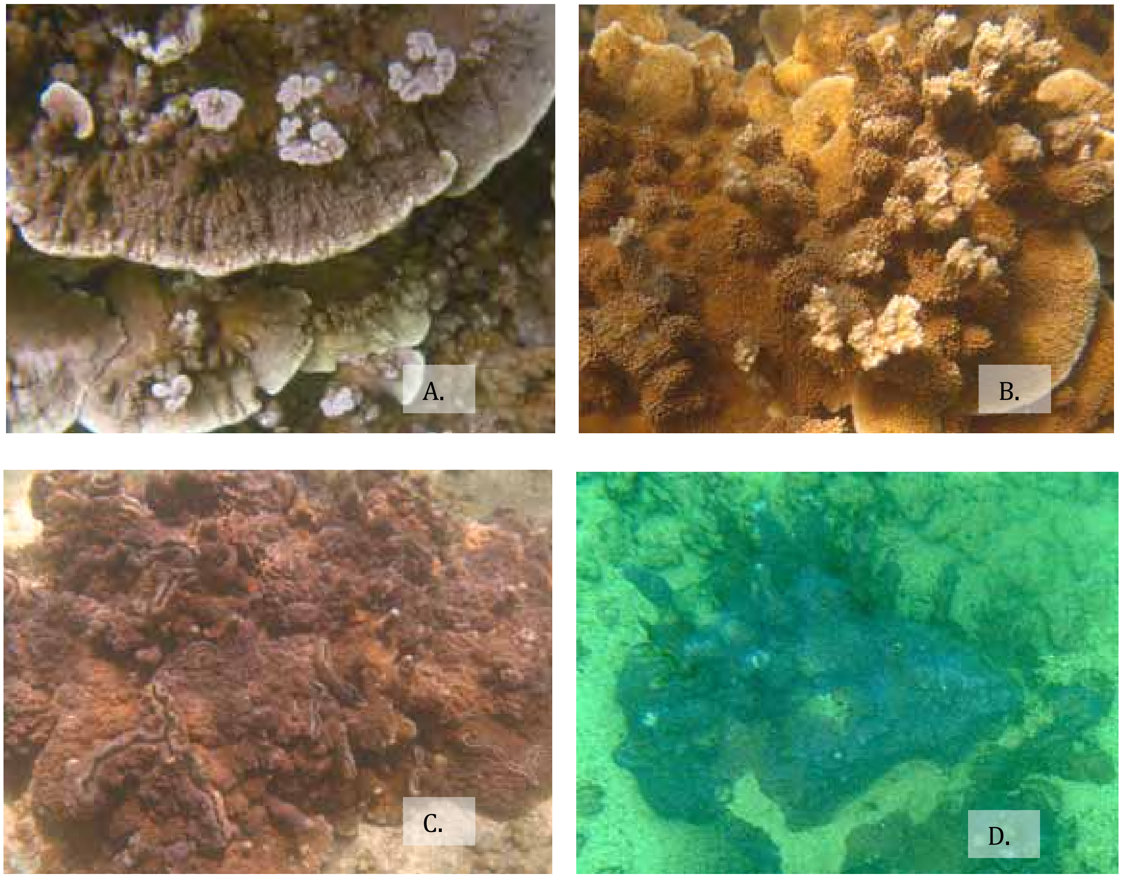

Figure 12: A.) *Montipora dilatata* Colony #14, Reef 44 plated and branched forms. B.) *Montipora capitata* colony, Reef 46 branched and plated forms. C.) *Montipora cf. dilatata* Colony #1, Reef 46 encrusting and submassive forms. D.) *Montipora flabellata* sand bar encrusting and submassive forms.

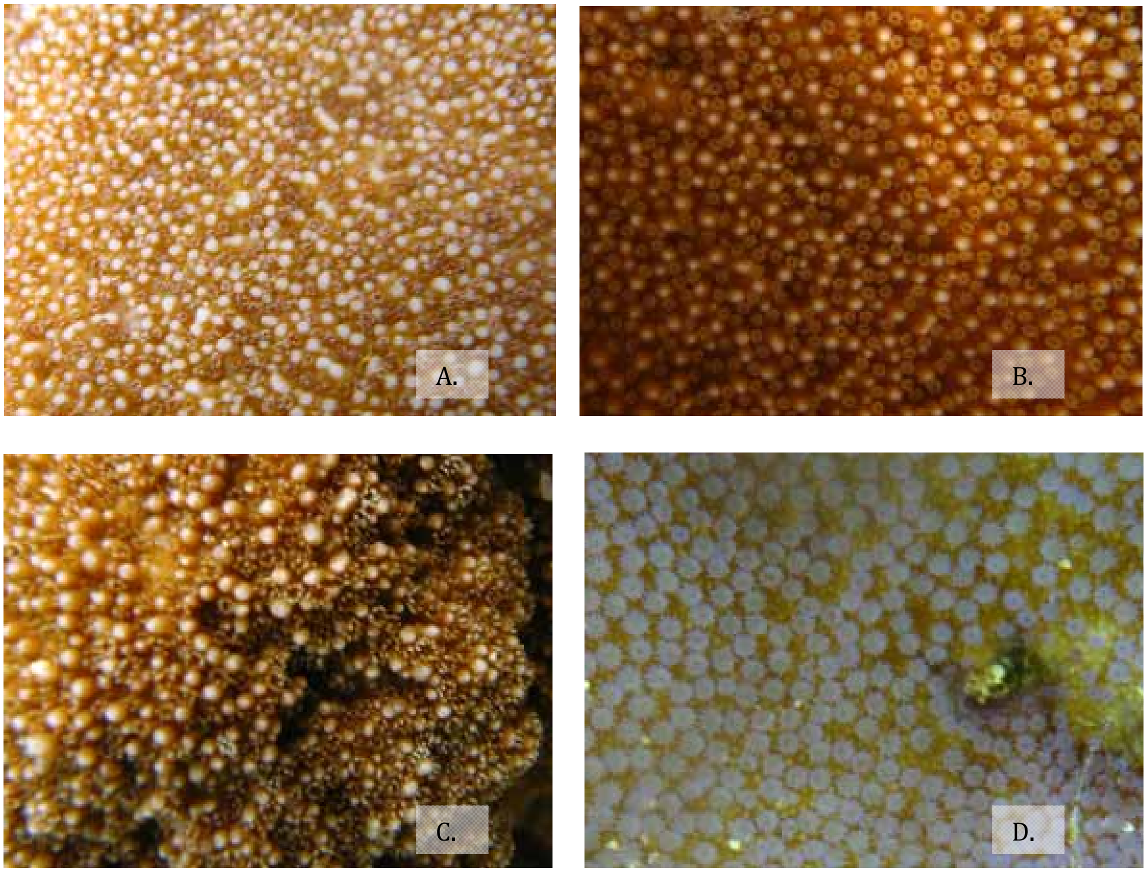

Figure 13: A.) *Montipora dilatata* Colony #14 Reef 44 plated. B.) *Montipora capitata* Reef 46 plated. C.) *Montipora cf. dilatata* Colony #1, Reef 46 encrusting. D.) Other *M. flabellata* sand bar plated.

Discussion:

Within 26 sites surveyed in Kane'ohe Bay in summer 2010, a total of 43 coral colonies were definitively classified as *Montipora dilatata*, as identified collaboratively by Biology 403 students and course instructor, C. Hunter. This classification was based solely on field observations of morphology, as collection of samples was not permitted during this time period by the State of Hawaii. Total colonies found showed an increase from 3 in 2000, to 3 different colonies in 2007, 20 in 2008, 38 in 2009. This increase was likely due to the identification of additional colonies with each survey rather than recruitment of new colonies.

M. cf. dilatata exhibited some of the features of *M. dilatata* but lacked characteristic flat-tops on the branch ends (Figure 12:C). *M. cf. dilatata* may be another *Montipora* species or hybrid that shares morphological traits of other montiporids. A total of 28 colonies were categorized as *M. cf. dilatata,* all of which were localized on the same reefs as *M. dilatata* colonies (PR 44, 46, 47, 51, 54).

Based on the environments in which *M. dilatata* were observed and descriptions in the primary literature, potential habitats for *M. dilatata* within the Bay were predicted based on depth, wave action and coral cover (Fenner 2005, Veron 2000). *M. dilatata* colonies were observed growing on patch reefs of the northern bay in subtidal regions with low wave action. These observations concur with the primary literature which describe *M. dilatata* habitat as lagoons and shallow water (Vaughan 1907, Fenner 2005, Veron 2000). Total predicted potential habitat for *M. dilatata* in Kane'ohe Bay was determined to be 825,415 m^2. Given the estimated 71 colonies of *M. cf. dilatata* on five reefs in north Kane'ohe Bay, if extrapolated to predicted habitat availability throughout the Bay, a projected population size of 180 *M. cf. dilatata* colonies is estimated. Please note that this number is just a first projection as potential habitat differences between north and south areas of the Bay need to be further characterized.

Reasons for colonization restriction could include abiotic and biotic factors, such as water temperature, salinity, competition, and currents; none of these have been tested in this investigation. Many of the *M. dilatata* colonies were very small and found in close proximity to larger well-established colonies. It is unclear if these satellite colonies are independent colonizations or clones produced from fragments of parent colonies, an important consideration in regard to true population estimates (Jokiel *et al.* 1983; Heyward and Stoddart 1985; Cox 1992), suggesting the need for genetic analyses.

The average size and number of colonies was greater than estimated a year ago. In 2009 the *M. dilatata* colonies average size was calculated at 2040 cm^2, while in 2010 the average colony size was 3824 cm^2. When comparing the average size differences for both years, a p-value of 0.02 supports this observation as being significant, implying that *M. dilatata* colonies are improving their hold in the reef communities, perhaps as overall water quality has improved in the north Bay. This factor would suggest successful reintroduction of *M. dilatata* to be feasible.

However, the threat of competition with *Kappaphycus* spp. is a potential obstacle to the reintroduction of *M. dilatata* to Kane'ohe Bay and may decrease the survivorship of resident colonies. *Kappaphycus* spp. is currently overgrowing *M. dilatata* Colony #6 on Reef 44 (Figure 8). *Kappaphycus* spp. biomass decreased after manual removal in the summers of 2007-2009 and the introduction of *T. gratilla* in 2010 (Figure 11). It may be beneficial to first control *Kappaphycus* spp. before the introduction of new *M. dilatata* colonies. The combination of manual removal of algae while increasing grazers to help reduce competition between *Kappaphycus* spp. and *M. dilatata* may be an efficient way to increase the survivorship of introduced colonies (Figure 10). Preliminary investigations are underway to determine the feasibility of such introductions (Figure 11).

It is recognized that identification of *M. dilatata* is difficult due to the plasticity of not only the genus but the individual species as well (Forsman, *et al.* 2009). *M. dilatata* may exhibit both variation of coenosteum structures and colony growth forms, including encrustations, plates, knobs, branches, and submassive forms (Veron 2000; Fenner 2005). The varying coenosteum among *Montipora* species is often a key identifier. Another problem with correctly identifying *M. dilatata* is the varying descriptions that exist in the literature (Vaughan 1907; Veron 2000; Fenner 2005).

The presence of papillae and the flat-tops found on the ends of the branches are defining characteristics of *M. dilatata* (Figure 13:A). In this study, only colonies showing this distinct morphology were classified as definite *M. dilatata*. It is possible that *M. cf. dilatata* colonies could be members of other species such as *M. flabellata*, *M. patula,* or *M. turgescens*.

M. flabellata color can range from blue to purple or brown, all of which have been used to describe *M. dilatata. M. flabellata* has fingerlike projections with a tiny black tip, which was also observed in the field on Reef 46, Colony #1 (Fig. 13C). The two species are described as having different habitats, but both species were documented to be on the same reefs, sometimes adjacent to each other (Veron 2000). *M. flabellata* could be easily distinguished by examining corallite morphology especially at the microscopic scale; however, this method was unable to be utilized in the field (Veron 2000). These differences can also be documented in the field using macrophotography (Figure 14:D).

M. patula colonies can be larger than 2 m in diameter. The morphology of *M. patula* consists of mainly plating and encrusting growth. All of the probable colonies of *M. dilatata* had at least one branch with a flattened top which aids in identification, but can't be used to completely rule out *M. patula* as an option. Color and texture are the greatest varying points between the two species. *M. patula* is orange with purple polyps whereas *M. dilatata* is brown to purple. Due to color differences, it is unlikely colonies were mistaken for *M. patula.*

M. turgescens is the species most likely to be confused with *M. dilatata*. The species are similar in their encrusting structure and their lavender or brown color. *M. turgescens* are thought to be lumpy in appearance with larger corallites and do not form branching structures (similar to what we are calling *M. cf. dilatata* here). Description of colonies also includes possible columnar growth structure; this is one of the few structures not listed as an *M. dilatata* character (Veron 2000). Even with these differences, it is unclear whether the two species can be classified as separate (Fenner 2005).

Abiotic and biotic factors could account for morphological variability in this species or species complex. Polyps of *M. dilatata* grow in a wave like pattern under normal circumstances (Studer 1901). The polyps grew in closer proximity when *M. dilatata* was determined to be overgrowing other corals. Studer (1901) also described the different “chimney” types of branches due to polychaetes and barnacles the coral grows around. It has been shown that closely related coral species found in the same reef can have varying responses to physicochemical factors such as light, sedimentation, dissolved oxygen levels, water movement, and grazing (Yap 2003). While Yap studied the growth and survival of sister taxa, it would be of interest in the future to study the influences of abiotic factors to the growth of *M. dilatata.*

There are 12 reported *Montipora* species in the Hawaiian Islands that have the possibility to produce hybrids (Veron 2000). This observation could explain some of the difficulties in separating colonies into their proper classification and better explain the morphological diversity seen in the genus (Forsman, et al. 2009).

A microscopic analysis of the corallite structures and experiential tissue grafting might help to better distinguish between similar species of *Montipora* in Kane’ohe Bay. However, *M. flabellata*, *M. dilatata*, and *M. turgescens* cannot be differentiated with the present molecular data (Forsman *et al.* 2009). Research needs to be continued to identify distinct molecular markers for these three species.

Garmin Gekos were used to locate colonies and approximate transect positions. These units were, at best, accurate to only 7 m; thus, colonies in close proximity to each other often recorded the same GPS points (Table 2).

In the future more physiochemical parameters (e.g. salinity, nutrient flow, and light levels) should be studied in detail to obtain a clearer understanding of *M. dilatata* habitats. Such information would benefit the accuracy of predictive habitat modeling as well as increase understanding of how alterations to the environment might impact the species. Reproductive cycles of *M. dilatata* and competition with other coral species could be studied to determine optimal reintroduction sites.

In the final analysis, morphological similarities between montiporid species coupled with the absence of sufficiently high resolution molecular markers made it difficult to draw definitive conclusions about the population structures of *M. dilatata*. However, with the use of *in situ* macrophotography and close attention to growth forms, it was possible to map and make population estimates for potential colonies exhibiting similarities in morphologies consistent with descriptions of *M. dilatata* in the primary literature.

If the colonies in question indeed represent the Species of Concern and there is an equal chance of species occurrence in all suitable habitats, then these population estimates can be accepted as representative of Kane'ohe Bay. Furthermore, *in situ* observations of the persistence of *M. dilatata* in the face of algal competition provide cautiously optimistic insight into the feasibility of reintroduction.

Conservation and Future Research Recommendations

Continue surveys for new colonies in areas identified as potential habitat for *M. dilatata*

Continue monitoring of identified colonies

Collect small samples of identified and presumptive colonies for morphological and genetic vouchers

Compare of colonies through tissue grafts and genetic markers (if available) to determine population structure (i.e. number of clones vs. unique genotypes

Continue manual removal of *Kappaphycus* spp from vicinity of Colony #6 on Reef 44

Continue introduction of new *Tripneustes gratilla*, particularly small individuals, to affected area on Reef 44

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