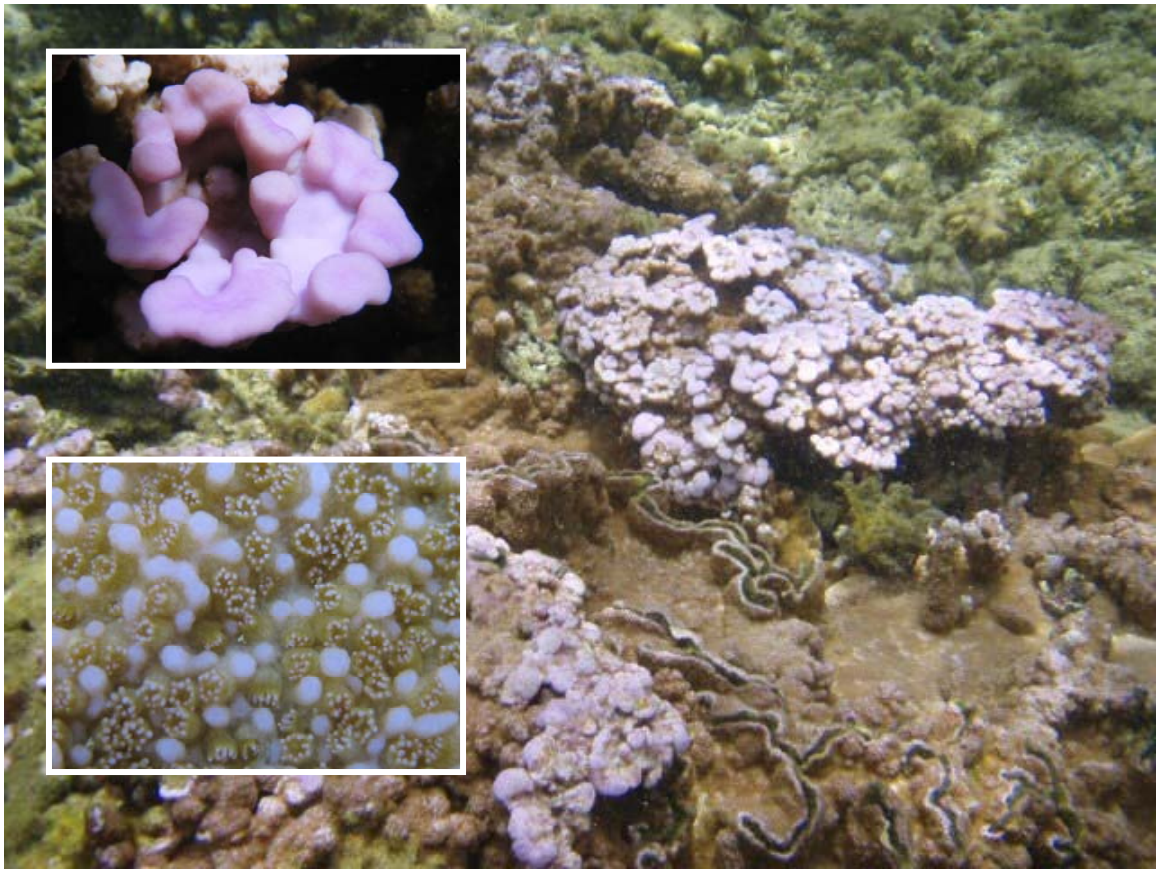
Distribution and abundance of *Montipora dilatata* in Kaneohe Bay, Oahu, Hawaii 2009



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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 suffered a dramatic decline in the previous decades due to freshwater kills, invasive algae, and habitat degradation (NOAA 2007). In the summer of 2009, visual surveys were conducted in Kaneohe Bay, Oahu, Hawaii, in areas of historical *M. dilatata* presence, and in areas where the habitat was suspected to be suitable. Surveys were conducted at 16 sites, with 38 *M. dilatata* colonies found clumped in isolated distributions at 4 of the sites. Invasive algae presence was quantitatively analyzed around each colony, and was found to be abundant near Colony #6 on Patch Reef 44, but at no other sites. An effort was made to conserve the colony and to assess the long-term effectiveness of algae removal. ArcGIS was used to analyze the distribution of *M. dilatata* and its habitat characteristics in Kaneohe Bay and to construct a spatially-predictive habitat map. Based on the numerous threats this species faces, including alien algae presence and the Allee Effect, further monitoring of recorded colonies along with expanded conservation efforts are needed.

Introduction:

The Hawaiian reef coral *Montipora dilatata,* a National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS) Species of Concern (SOC), has declined dramatically over the past few decades (NOAA 2007). In order to improve understanding of possible factors that may lead to a decrease in *M. dilatata,* there is a need to assess and monitor population size and distribution as well as the environmental parameters within these areas. Colonies from 2007 and 2008 field reports, as well as other locations, were surveyed in search of *M. dilatata*. Quantitative and qualitative data collected at survey locations were integrated to inform a GIS-based approach for spatially-predictive modeling of *M. dilatata* preferred habitat. Habitat characteristics identified as potentially important for the presence of *M. dilatata* were integrated to build a spatially-predictive map of *M. dilatata* distribution in Kaneohe Bay. Ultimately this information may be used to inform predictive mapping of potential *M. dilatata* habitat elsewhere in 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) are effective in protecting this species from further decline in Kaneohe Bay, Oahu, Hawaii.

In 2000, surveys of *M. dilatata* identified only three colonies in Kaneohe Bay, Oahu, Hawaii, where it was formerly more abundant (J.E. Maragos, pers. comm.). As part of a 2007 University of Hawaii-Manoa (UHM) field course, students as well as coral experts positively identified three *M. dilatata* colonies in Kaneohe Bay, but were not always successful in clearly identifying it from other species within the same genus (Hunter *et al*. 2008). The colonies found in 2007 were not the same colonies originally identified in 2000, which have not been relocated. In 2008, students in the UHM field course found 20 *M. dilatata* colonies on 5 different reefs in Kaneohe Bay (Hunter *et al*. 2009). They found that Colony #6 on Patch Reef 44 was the only colony that showed any immediate threat from overgrowth by *Eucheuma* spp., although *Eucheuma* spp. was found in the vicinity of a colony on Reef 20 as well.

Habitat degradation as a result of sedimentation, bleaching, pollution, freshwater kills, alien/invasive algae species, and a limited distribution may be contributing factors to the apparent decline of this species in Kaneohe Bay (NOAA 2007). Conservation efforts can be improved by better understanding the degree and nature of the threats on *M. dilatata*. In order to characterize the threat on the colonies, correct identification is necessary, which, due to the morphological plasticity of *M. dilatata*, can be difficult. Not only is it problematic to characterize various *Montipora* species *in situ*, it has yet to be clarified by current molecular data, although efforts are currently underway in the laboratory of R. Toonen at Hawaii Institute of Marine Biology.

The goals of this study were to: 1) conduct surveys throughout Kaneohe Bay to determine the current distribution and abundance of *M. dilatata*; 2) quantify the current occurrence of alien/invasive algae in *M. dilatata* habitat and compare these results to prior surveys to see if recent removal of invasive alien algae has aided recovery efforts; 3) remove alien/invasive algae in proximity to *M. dilatata*; and 4) construct a spatially predictive model that may be used to identify other potential habitats for *M. dilatata*.

Methods and Materials:

Surveys of *Montipora dilatata* were conducted in Kaneohe Bay, Oahu during the months of July and August, 2009. Survey sites were chosen using satellite imagery to determine suitable patch reef habitats. Historical data were also used to determine sites with known *Montipora dilatata* colonies. Sixteen sites were surveyed in total; each was surveyed by 3-6 students snorkeling over the reef in straight lines 5 to 10 meters apart. *M. dilatata* colonies were photographed, measured, depth was noted, and positions were marked using Garmin Geko 201 Global Positioning Satellite (GPS) units. Four 1 x 10 meter transects were laid north, south, east, and west of each colony to quantify invasive algae growing nearby. Invasive algae were removed from the vicinity of one impacted colony (Colony #6 on Patch Reef 44) and a paired t-test was used to determine if there was a significant difference between the removal of the algae from the treated area.

Montipora is a morphologically plastic genus. As such, it is often difficult to classify a colony as *M. dilatata* in the field. Only colonies with flattened, branch-like upward growth were recorded. Colony locations were integrated into GIS-based maps for analysis with environmental parameters

Results:

From surveys of patch reefs in Kaneohe Bay, 38 colonies believed to be *M. dilatata* were documented in the northern area of the Bay.

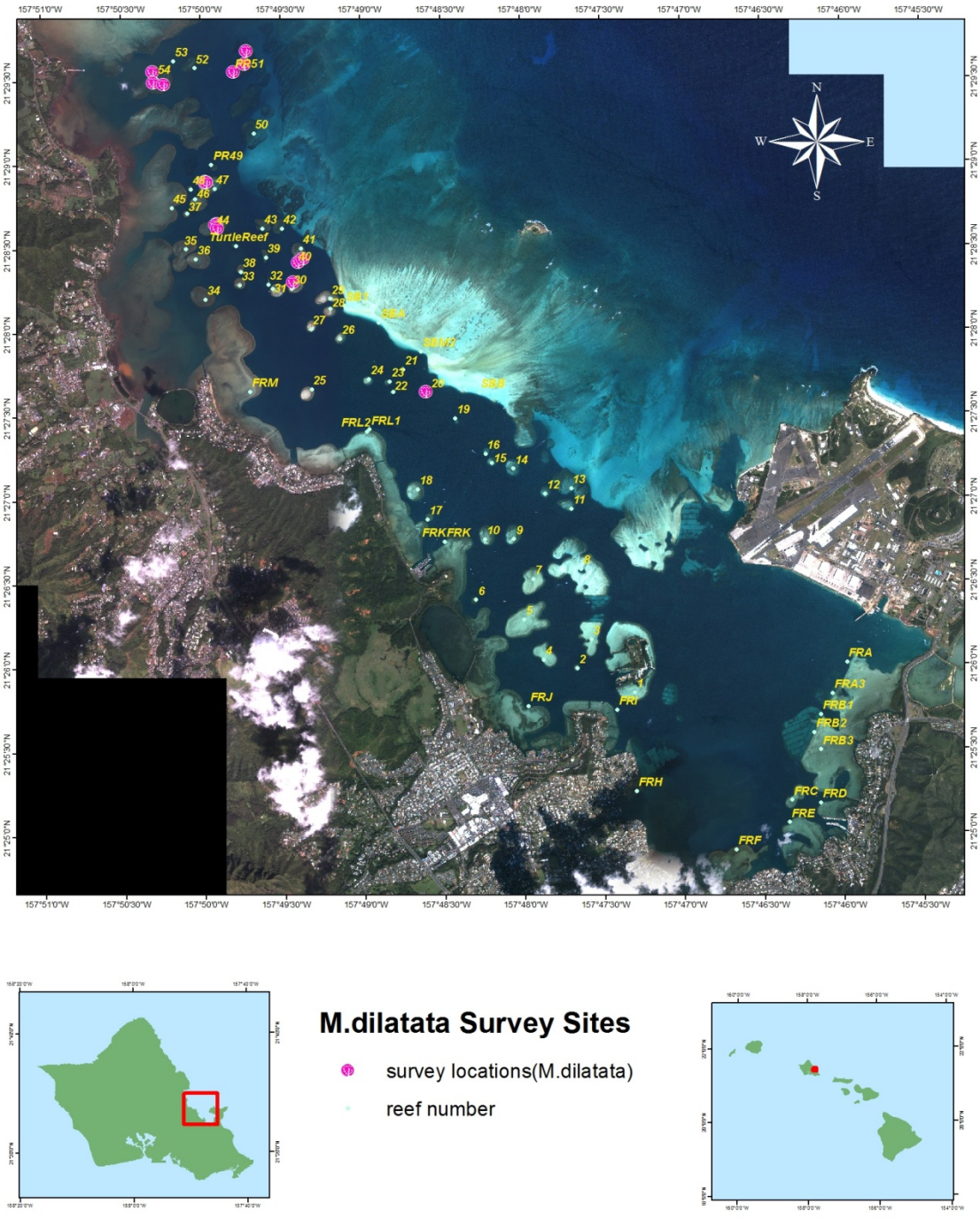

Fig 1: Survey locations of *M. dilatata* in Kaneohe Bay.

M. dilatata surveys conducted throughout Kaneohe Bay patch reefs resulted in the positive identification of 30 *M. dilatata* colonies and 8 "putative colonies" through comparison of colony morphology characteristics (Tables 1-4).

Table 1: GPS location, size, depth, and surrounding alien algae cover for *M. dilatata* Colonies on Patch Reef 44.

Site	Colony	Latitude	Longitude	Approximate colony area (cm squared)	Identification (yes/putative)	depth below surface (m)	% *Kappaphycus/Eucheuma* spp. Cover
44	1	21.47751	-157.83183	2993	y	1	0.000
44	2	21.47751	-157.83183	255	y	1	0.000
44	3	21.47751	-157.83183	8	y	1	0.000
44	4	21.47740	-157.83192	9100	y	1	0.250
44	5	21.47705	-157.83172	3200	y	1	1.875
44	6	21.47705	-157.83172	10000	y	1	33.750

Approximate colony area was derived from length and the width measurements.

Table 2: GPS location, size, depth, and surrounding alien algae cover for *M. dilatata* Colonies of Patch Reef 51.

Site	Colony	Latitude	Longitude	Approximate colony area	Identification (yes/putative)	depth below surface (m)	% *Kappaphycus/Eucheuma* spp. cover
51	1	21.49255	-157.82996	925	Y	3	0.000
51	2	21.49335	-157.82878	7280	Y	3	0.000
51	3	21.49335	-157.82878	224	Y	3	0.000

Table 3: GPS location, size, depth, and surrounding alien algae cover for *M. dilatata* colonies on Patch Reef 47.

Site	Colony	Latitude	Longitude	Approximate colony area	Identification (yes/putative)	depth below surface (m)	% *Kappaphycus/Eucheuma spp.* cover
47	1	21.48169	-157.83299	220	Y	1	0.000
47	2	21.48169	-157.83299	104	Y	1	0.000
47	3	21.48169	-157.83299	200	Y	1	0.000
47	4	21.48169	-157.83299	500	Y	1	0.000
47	5	21.48169	-157.83299	225	P	1	0.000
47	6	21.48160	-157.83300	180	P	1	0.000
47	7	21.48160	-157.83300	50	Y	1	0.000
47	8	21.48160	-157.83300	875	Y	1	0.000
47	9	21.48160	-157.83300	135	Y	1	0.000
47	10	21.48160	-157.83300	10	Y	1	0.000
47	11	21.48160	-157.83300	56	Y	1	0.000
47	12	21.48160	-157.83300	12635	Y	1	0.000
47	13	21.48160	-157.83300	25	P	1	0.000
47	14	21.48160	-157.83300	25	P	1	0.000
47	15	21.48160	-157.83300	25	P	1	0.000
47	16	21.48160	-157.83300	25	P	1	0.000
47	17	21.48160	-157.83300	750	Y	1	0.000
47	18	21.48160	-157.83300	150	P	1	0.000
47	19	21.48165	-157.83288	4900	Y	1	0.000
47	20	21.48165	-157.83288	7650	Y	1	0.000
47	21	21.48163	-157.83287	900	P	1	0.000

Table 4: GPS location, size, depth, and surrounding alien algae cover for *M. dilatata* colonies on Patch Reef 54.

Site	Colony	Latitude	Longitude	Approximate colony area	Identification (yes/putative)	depth below surface (m)	% *Kappaphycus/Eucheuma* spp. cover
54	1	21.49156	-157.83656	3842	Y	1	0.000
54	2	21.49156	-157.83656	304	Y	1	0.000
54	3	21.49156	-157.83656	4400	Y	1	0.000
54	4	21.49156	-157.83656	324	Y	1	0.000
54	5	21.49156	-157.83656	50	Y	1	0.000
54	6	21.49156	-157.83656	3864	Y	1	0.000
54	7	21.49156	-157.83656	810	Y	1	0.000
54	8	21.49137	-157.83724	300	Y	1.5	0.000

The spatial distribution of *M. dilatata* colonies appeared to be limited to the northern region of Kaneohe Bay (PR 44, 47, 51, and 54). The numerical abundance of colonies was highest in the northwest region of Patch Reef 47 (Fig 2).

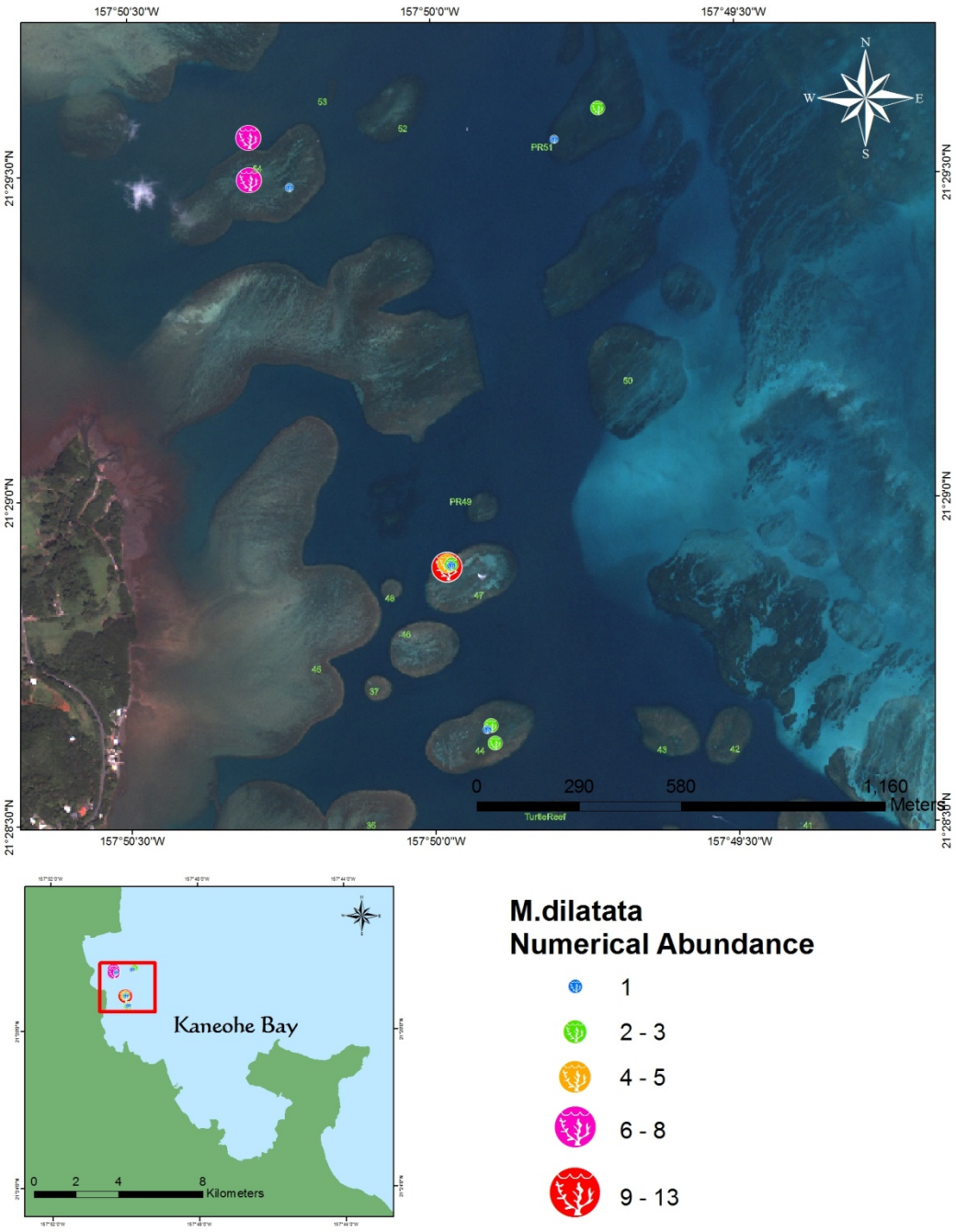

Fig 2: Numerical abundance of *M. dilatata* colonies in North Kaneohe Bay.

The total area covered by *M. dilatata* colonies per reef was also found to be highest in the northwestern region of Patch Reef 47. In contrast to the relatively large numerical abundance of individual colonies seen on Patch Reef 57, the total area covered by *M. dilatata* in the same location was low (Fig 3).

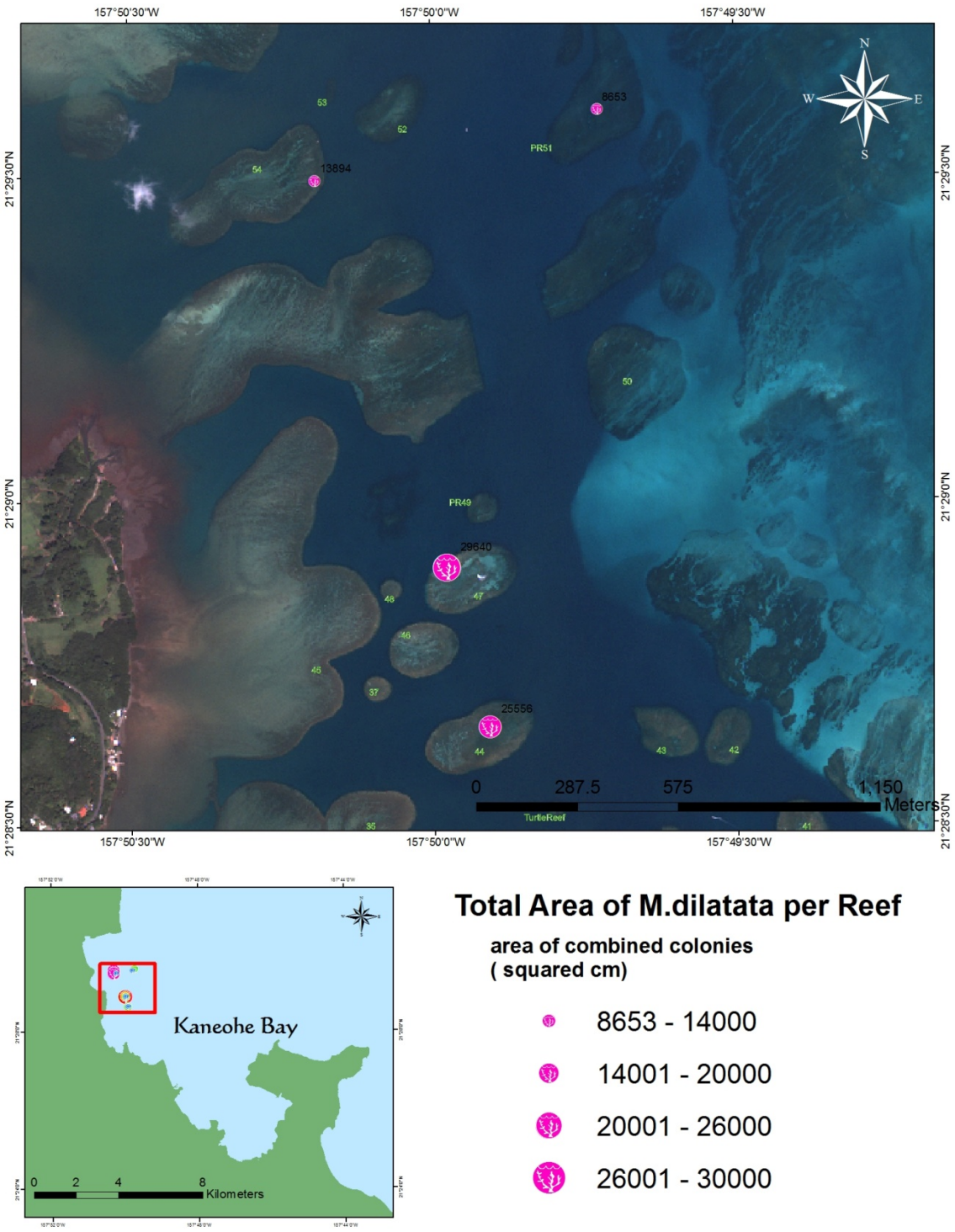

Fig 3: Total area of *M. dilatata* colonies per reef.

In comparison to the bathymetry of Kaneohe Bay, *M. dilatata* colonies were found in regions that were shallow and uniform in depth, relative to the range of depths throughout the entire bay (Fig 4).

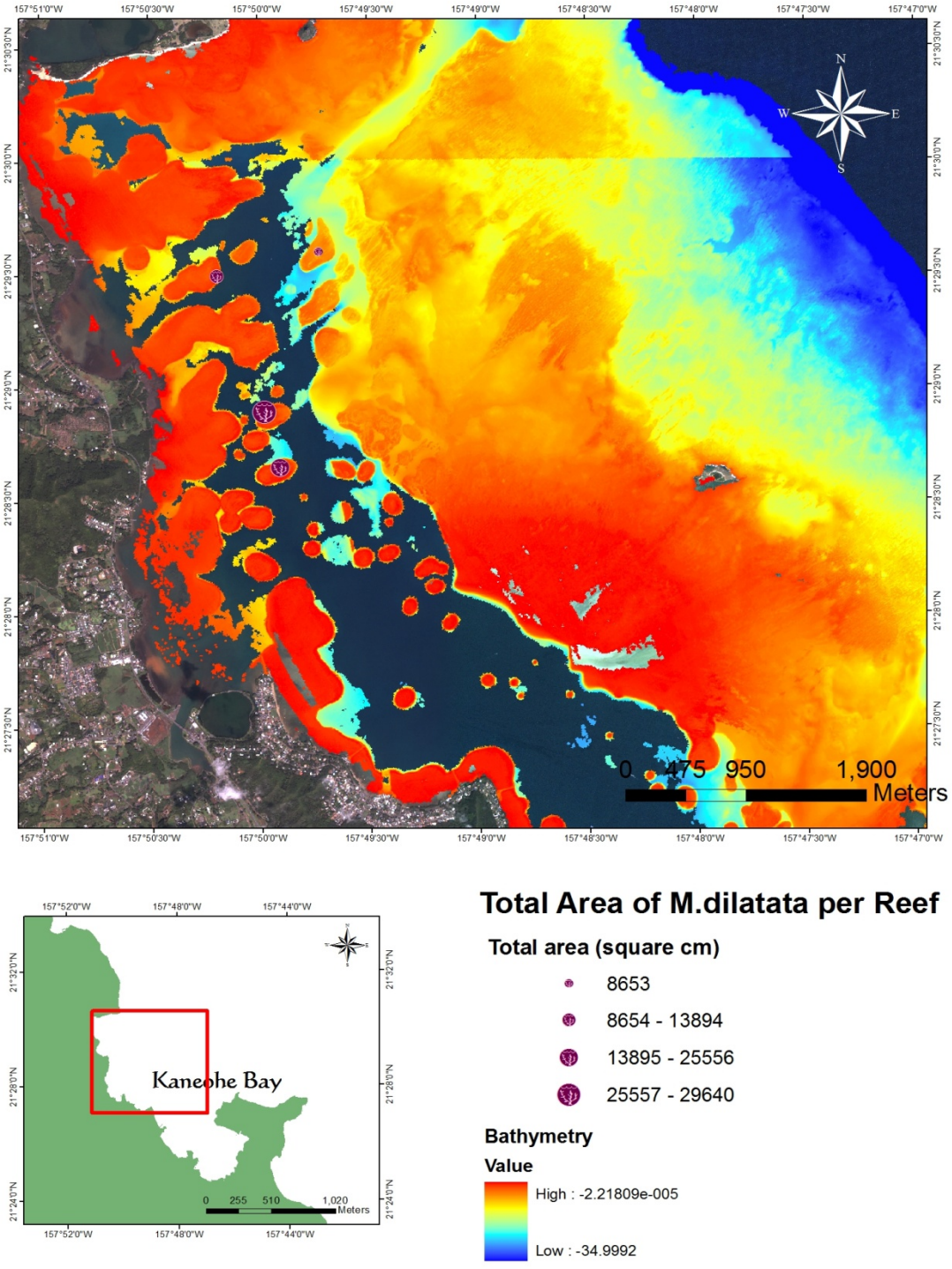

Fig 4: Total area of *M. dilatata* per reef throughout Kaneohe Bay. Red areas indicate shallow depths; blue areas indicate deeper regions.

Based on qualitative observations in the field, a predictive habitat map was built, illuminating regions that are possibly suitable for *M. dilatata* colonies in Kaneohe Bay. All colonies found were consistent with the northern predictive maps. However, none were found in predictive habitats in southern regions of Kaneohe Bay (Fig 5).

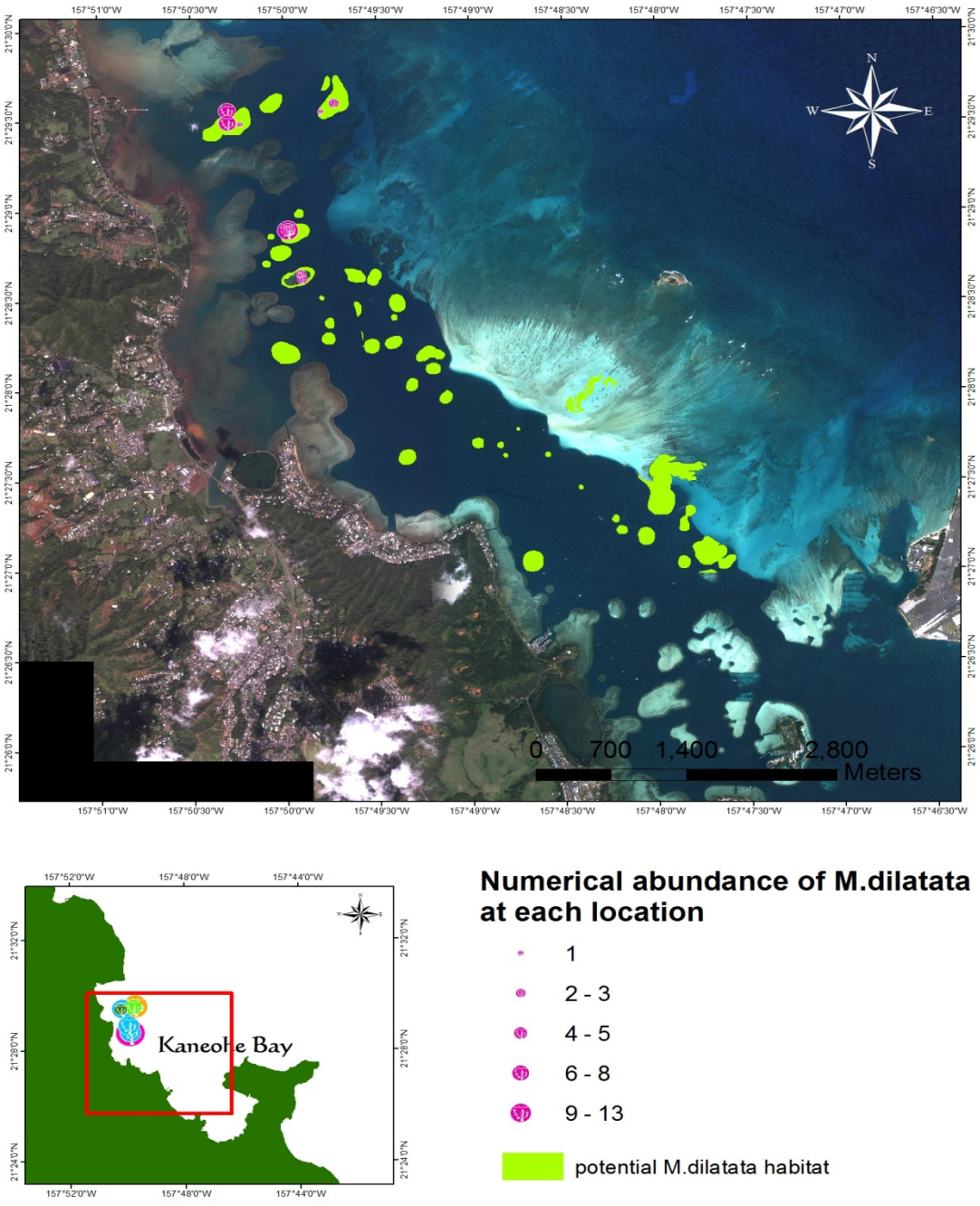

Fig 5: Predictive habitat for *M. dilatata* in Kaneohe Bay.

Predictive habitat was based on features including coral cover, rather than sand or sediments, and patch reefs rather than fringing reefs along the coast.

Algae cover around each *M. dilatata* colony (Tables 1-4) showed an absence of *Kappaphycus* spp. or *Eucheuma* spp. for all but three colonies. These colonies were located on Patch Reef 44. Colony #6 on Patch Reef 44 was recorded to have the most surrounding algae cover (Fig 6).

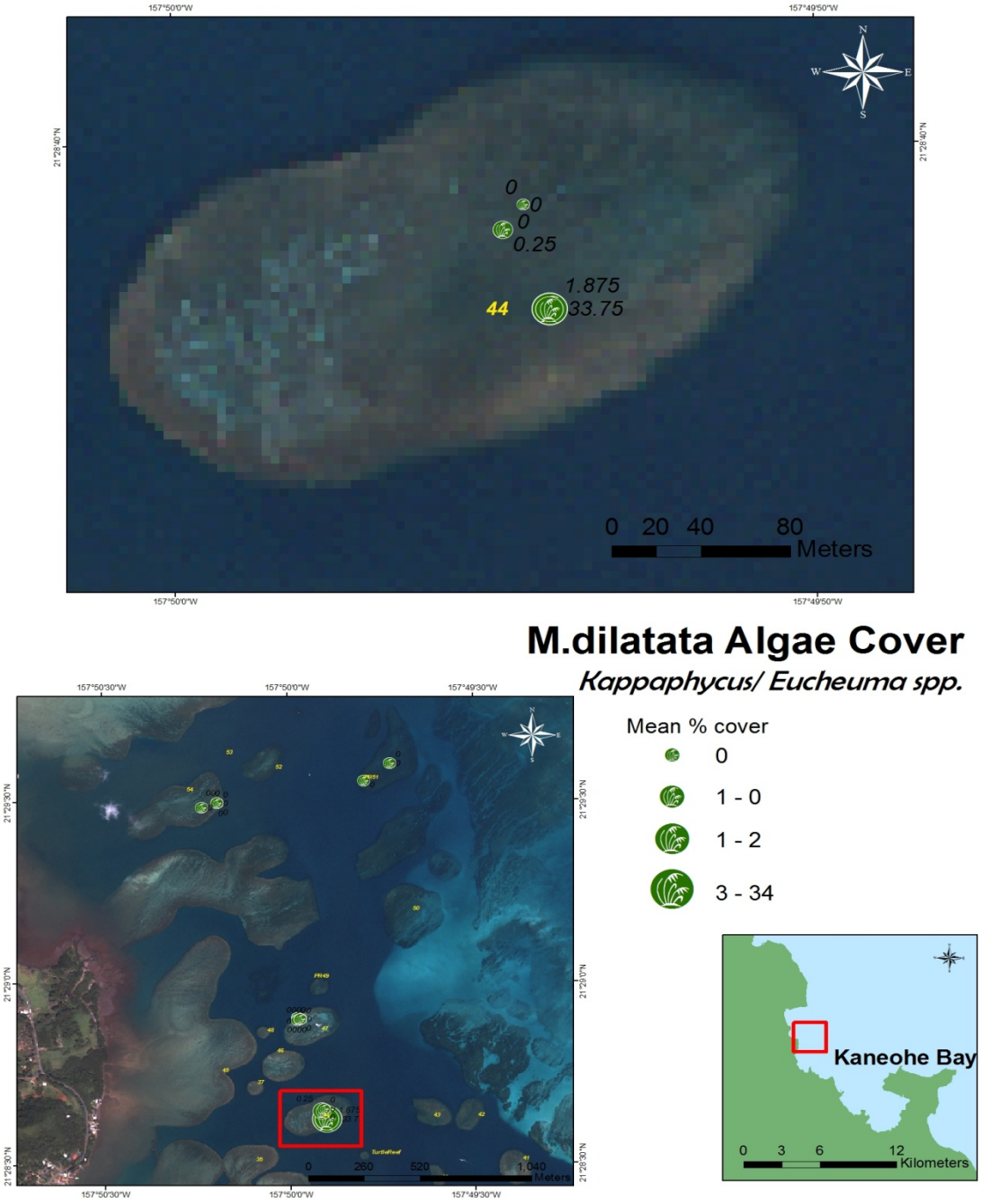

Fig 6: Alien Algae cover of *M. dilatata*.

Mean algae cover was assessed in four transects (along N, S, E, and W axes) from the center of each colony. The percent cover of *Kappaphycus/Eucheuma* spp. was recorded for every square meter along the transects. Mean algae cover around Colony #6 on Patch Reef 44 before removal was 33.75%. This decreased to 29.75% after removal. Approximately 800 pounds of *Kappaphycus/Eucheuma* spp. were collected during the removal efforts (Tables 5-6).

Results of pre- and post-removal surveys along four 1x10 (m) transects bearing in the cardinal directions from the center of *M. dilatata* Colony #6, Patch Reef 44 are shown in Tables 5 and 6. The GPS coordinates for this colony are: 21.47705 N, 157.83172 W.

Table 5: Pre-removal abundance of *Kappaphycus/Eucheuma* spp. on transects surrounding *M. dilatata* Colony #6, Patch Reef 44.

	%*Kappaphycus/Eucheuma* spp. cover			
Square meter	North	South	East	West
1	70	80	35	10
2	40	50	30	5
3	40	60	40	40
4	30	30	50	45
5	30	30	30	30
6	20	25	70	50
7	5	10	60	50
8	5	5	50	35
9	0	50	10	40
10	0	10	45	35
Mean	24	35	42	34
s.d.	22.58	24.49	17.03	14.63
Overall mean	33.75			
s.d.	20.5			

Table 6: Post-removal abundance of *Kappaphycus/Eucheuma* spp. on transects surrounding *M. dilatata* Colony #6, Patch Reef 44.

	%*Kappaphycus/Eucheuma* spp. cover			
Square meter	North	South	East	West
1	10	20	35	35
2	15	15	10	30
3	5	40	40	50
4	5	30	40	60
5	0	40	60	50
6	0	45	35	35
7	10	30	55	35
8	30	50	60	10
9	10	25	70	10
10	0	45	25	20
Mean	8.5	34	43	33.5
s.d.	9.14	11.74	18.29	16.84
Overall mean	29.75			
s.d.	19.05			

A paired t-test showed no significant difference (P = 0.354) in percent cover before and after the treatment. The data proved to be normal for both the pre and post treatment.

Discussion:

Montipora dilatata has only been observed in the Northwestern Hawaiian Islands (J. E. Maragos, pers. comm.) and in Kaneohe Bay, Oahu, Hawaii where it has been reported as becoming increasingly rare (Maragos 1977; NOAA 2007). In 2004, NOAA declared *M. dilatata* a Species of Concern. In light of continual habitat degradation, invasive algae overgrowth, and pollution (NOAA 2007), recent surveys have been conducted to quantify the distribution and abundance as well as the degree and nature of

the threats to this species. A difficulty in surveying *M. dilatata* is that it is similar in appearance to several other *Montipora* species. This was ameliorated by the use of a reliable search image that has been reinforced by taxonomic experts.

From the qualitative observations of environmental conditions in which *M. dilatata* colonies were found, a predictive habitat map for Kaneohe Bay was developed. *M. dilatata* was seen in areas of high coral cover and atop patch reefs, as opposed to sandy regions or fringing reefs. The predictive map contained all of the patch reefs where *M. dilatata* was found but also many other patch reefs in the Bay (Figure 5). This discontinuity may be a result of a lack of *M. dilatata* surveys conducted on patch reefs in the southern region or may be a result of unknown environmental parameters discouraging *M. dilatata* colonization on the reefs in which it was not found. Future *M. dilatata* surveys may use these areas of potential habitat as a guide.

Of the 30 colonies positively identified, “Colony #6” from PR 44 was the most threatened by *Eucheuma* spp. overgrowth, similar to the results of surveys conducted in 2008 but to a greater degree. In 2008, there was approximately 20% algal cover in the 10 meter transects north, south, east, and west before removal (Hunter *et al*. 2009). Five 60 pound bags were removed reducing algal cover to 12% in 2008. In 2009, a total of 13 bags, each weighing approximately 60 pounds for a total of 780 pounds, of *Eucheuma* spp. were removed from the immediate vicinity of the colony. Although a larger amount of algae was removed in 2009, a significant difference was not made in the reduction of algae cover. This is most likely due to an inadequate amount of time being devoted to algae removal; it would likely take several thousand pounds of removal to make a significant impact on the algae cover. *Eucheuma* spp. remains an imminent threat to *M.*

dilatata on PR 44 and is likely to pose a threat to other colonies in the future. Unfortunately, the abundances of many introduced species of macroalgae are highest at sites with shallow depth and moderate water motion, the very place in which *M. dilatata* is found (Rodgers *et al*. 1999). Manual removal may help in the short term, but it is likely that a more comprehensive approach must be utilized.

Many of the colonies found were in close proximity of one another, possibly indicating fragmentation of the original colony (Jokiel *et al.* 1983; Heyward and Stoddart 1985; Cox 1992). All of the 14 positively identified colonies found on PR 47 were found on the northern side of the reef within three meters of each other. Three of the six colonies on PR 44 and seven of the eight colonies found on PR 54 were also clustered. More testing (i.e., via tissue grafting) needs to be performed in order to determine whether these colonies are genetically distinct from one another. Unfortunately, samples of *M. turgescens, M. flabellata,* and *M. dilatata* cannot be differentiated with the current molecular data (R. Havercourt, pers. com.). All of the other colonies found were either isolated or in a group of two. These include: 3 on PR 44, 3 on PR 51, and 1 on PR 54. If tissue grafts show that all of these clumped colonies are genetically identical then it is likely that the diversity of *M. dilatata* is very low. This approach will hopefully be applied soon to be able to better understand the population structure of *M. dilatata*.

As this species has been petitioned to be listed as an endangered species under the Endangered Species Act, it is important to note that it is locally rare in Kaneohe Bay, and not found outside of the Bay in the Main Hawaiian Islands. Threats to *Montipora dilatata* may be attributed to factors on a local scale rather than the threat of global climate change. While the colony found on PR 20 in 2008 may have been lost due to boat

grounding, alien algae overgrowth, particularly by *Kappaphycus/Eucheuma* spp., may be considered the most prevalent cause of loss of *M. dilatata* from Kaneohe Bay. In 2008, 2 of the 20 colonies found had *Kappaphycus/Eucheuma* spp. growing nearby and in 2009, 4 of the 30 colonies found had *Kappaphycus* spp. growing nearby. The "Super Sucker" is a collaboration of the State of Hawaii and the community to work to find a solution to this problem. Another feasible solution to the algae invasion may be in the form of biological control. Augmenting native species abundance (*e.g.*, the sea urchin, *Tripneustes gratilla*) can potentially prevent algal overgrowth from returning, but further research is needed to understand the ecological impact of this option (Conklin and Smith 2005). *M. dilatata* is possibly one of the most rare endemic species of coral in Hawaii, possibly even in the Unites States (J.E. Maragos, pers. comm.), and needs to be continually monitored and actively protected to ensure its survival in the wild.

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