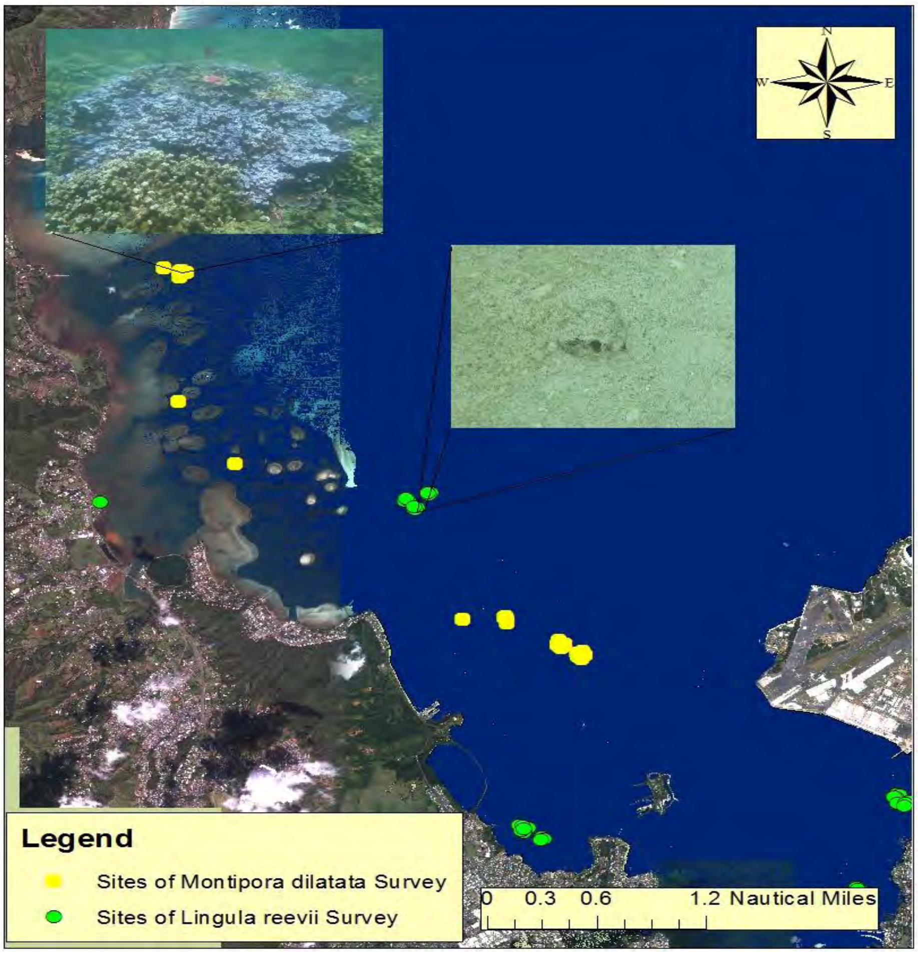
GIS and Spatial Distribution of *Lingula reevii* and *Montipora dilatata* in Kaneohe Bay, Hawaii



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Abstract

Marine organisms have been threatened by anthropogenic impacts for centuries, sometimes leading to their extinction. It is important to understand the diverse interactions between organisms and their habitats in order to make predictions about where the world's ecosystems are headed. Under the National Oceanic and Atmospheric Administration (NOAA) and the National Marine Fisheries Service (NMFS), threatened species in Kaneohe Bay have been labeled as "Species of Concern" (SOC) and research into their ecology has been emphasized in order to battle their extinction. In this research two such species were investigated; an inarticulated brachiopod, *Lingula reevii,* and the Hawaiian reef coral, *Montipora dilatata*. Employing a broad spatial approach, maps were created using GIS programming and satellite imagery which illustrated the abundance and distribution of each species. When associated with abiotic factors qualitative inferences were made regarding the habitat distribution of both species. Predictive habitat maps were then made and compared with current and previous data in order to analyze their accuracy. Survey sites chosen using the aforementioned predictive maps showed presence of said species and suggested a habitat preferences of the south bay. Although this method of predictive modeling showed promise it was concluded that further studies are needed to provide for a more quantitative analysis of this type of mapping.

Introduction

Conservation of the Earth's marine ecosystems, from coral reefs to polar seas, is an obligation that transcends political boundaries. Many of the ocean's marine ecosystems are under increasing stress due to irreversible anthropogenic disturbance (Bremen *et al*., 2010, Bremen *et al.,* 2002, Knowlton *et al*., 2008, Graham *et al.,* 2006). This problem is enhanced by the fact that scientists know relatively little about the ocean and the extent of its depths, spatial arrangements and organisms (Breman *et al.,* 2010).

Geographic information system (GIS) technology is a tool that can be used to study ocean dynamics and allow specialists to visualize new relationships between bathymetry and ecology (Breman, 2010, Knowlton, 2008). Although GIS technology is a relatively new branch of science, its theory has been used for centuries by mariners to understand the oceans and safely navigate the seas (Breman, 2002). Modern technology in conjunction with GIS currently provides scientists with the opportunity to visually analyze spatial data of the ocean. The ability to perform such complex analyses will aid local and federal organizations in the care and maintenance of ocean resources and holds promise in the aid of future conservation efforts.

Marine GIS has been used in various countries and institutions around the world (Breman, 2010). In the Hawaiian Islands, USA and Vancouver Island, British Colombia, GIS is being used to study habitat preference, utilization and spatial organization of baleen whales in coastal areas (Breman, 2010). Additionally, other research, including studies by Pittman *et al*. (2011) have shown that GIS can be extremely useful in gaining information on the spatial distribution and habitat use of a variety of marine species from fish to corals. By understanding the factors which help drive distribution and spatial arrangements of marine species, researchers may better understand important relationships and impacts that shape these ocean ecosystems (Wright, 2007 and Graham, 2006).

Predicting species distributions in the marine environment is challenging and becomes even more involved in tropical ecosystems. Many reef environments, such as the Hawaiian archipelago exist as spatial mosaics with high levels of interconnectedness and spatial complexity, making them especially difficult to study (Pittman, 2011). However, these environments are some of the most biologically important ecosystems on earth (Conell, 1978) and thus are invaluable for studying trends in spatial management and species distribution. Studies have shown that the spatial complexity of marine habitats largely shapes the population dynamics and distribution of organisms (Pittman, 2011). By using GIS to investigate how organisms are distributed within reef habitats in Hawaii, management and protection applications can be applied to endangered species, invasive species and species of concern (SOC).

Two species of concern (*Montipora dilatata* and *Lingula reevii*) that may benefit from GIS assisted research are found in Kaneohe Bay, Hawaii and have both shown significant population decline in recent years: The Hawaiian reef coral, *M. dilatata*, is one of the rarest corals in the world and Kaneohe Bay, Hawaii has been identified as one of the only known habitats where it is found (Barlow et al. 2010b). The inarticulated brachiopod, *L. reevii*, is a filter-feeding organism which has only been recorded in three habitats worldwide (Barlow, 2010a). Previous surveys in Kaneohe Bay have recorded a 99% population abundance decline of *L. reevii*, possibly due to losses in habitat owing to changes in water quality (Barlow *et al.* 2010a, Worcester 1969).

Both of these species are listed as SOC under the NOAA and National Marine Fisheries Service (NMFS) for being potentially at risk of further decline and extinction if conservation efforts are not implemented (Barlow et al., 2010a,b). It is imperative that these two SOC remain studied to better understand their distribution and other impacts effecting their survival. The two main purposes of this study are therefore 1) use GIS techniques to develop a spatial distribution model (benthic habitat map) of *L. revvii* and *M. dilatata* abundances in Kaneohe Bay 2) to add to existing baseline data of these SOC in Kaneohe Bay, and utilize data from previous Biology 403 field classes of 2009-2010 in order to aid in the creation of future predictive maps of these SOC.

The broader impact of this research rests in the realm of marine conservation and management. Primarily, by using GIS to produce spatial models of species abundance we can assess the status of these SOC, supporting their preservation and of others alike. It is important that we further explore the application of GIS to advance our knowledge of the marine environment, utilizing this technology to make more informed decisions about the ocean and the finite resources which reside under the surface.

Materials and Methods

Snorkel surveys were conducted in Kaneohe Bay, Hawaii from July 25th to August 6th, 2011 to assess the distribution of the inarticulated brachiopod, *Lingula reevii* and the coral *Montipora dilatata* (Figure 1). For both species data was compiled and entered into the ArcMap program and subsequent maps were created. Maps detailed the distribution of both *L. reevii* and *M. dilatata* within Kaneohe Bay and also mapped out the parameters such as perimeter and height for each colony of *M. dilatata* surveyed. Species distribution data from previous years (2009-2010) was also used in ArcMap to determine survey sites in order to gauge the predictive ability of such methods.

Study sites chosen for *L. reevii* surveys included Pyramid Reef, Sandbar, and the Pier. Three teams consisting of three snorkelers were given specific GPS points to navigate to designated locations that were determined using a predictive map. At the designated GPS points 21 meter transects were anchored and rotated radially marking 3 new endpoints with corresponding GPS points at approximately 120 degree intervals (figure 2). One meter squared quadrats were placed at intervals of 0-1m, 4-5m, 8-9m, 12-13m, 16-17m, and 20-21m along each transect. Snorkelers then recorded the number of observed *L. reevii* in each quadrat.

Survey sites for *M. dilatata* included reefs 11, 12, 15, 33, 37, 52, and 53. GPS points were taken on the edge of each reef and used to guide snorkelers to a starting point from which they could line up at 5 meter intervals spanning its perimeter. Following a compass heading, snorkelers swam parallel to one another until they reached the far end of the reef opposite their starting point (figure 3). Three teams of three snorkelers then moved back and forth down the reef thoroughly surveying its entirety. Upon presumed identification of *M. dilatata* a photo and GPS coordinates were taken marking the colony. Parameters such as water depth, colony height, perimeter, and width were measured using transect tape in centimeters. Each colony was tagged with plastic markers labeled with a number and placed in close proximity to colony. Photographs of both the tag and the colony were taken so that further analysis outside of the field could be conducted. Photos were reviewed and it was agreed upon whether or not the colony was identified as *Montipora dilatata* or *Montipora cf. dilatata*. Following confirmation of positive identification, data was inputted and analyzed using ArcMap.

Results

Forty total colonies suspected to be *Montipora dilatata* were found on four of the seven reefs surveyed (Figures 4-6). *Montipora cf. dilatata* colonies were those classified as similar to, but not clearly identifiable as, *M. dilatata* due to various morphological differences (Figure 7). The 40 colonies found were marked with GPS and colony id tags and all colonies were determined to be *M. cf. dilatata*. Reef 12 contained the highest abundance of observed *M. cf. dilatata* colonies while reefs 33, 37 and 53 contained no colonies (Table 1). Colonies of *M. cf. dilatata* were mapped by location (Figure 8) and dimensions including height, width, and perimeter (Figures 9, 10) on reefs 11, 12, 15 and 52. These demonstrate that not only is *M. cf. dilatata* present in predicted habitat locations, but also exhibits higher abundance in Southern Kaneohe Bay (Figure 11). Table 1 also illustrates trends of decreasing perimeter and increasing height in colonies found towards the southern end of the bay indicating an increasing trend in colonies with branching morphology in this direction.

Average abundance of *Lingula reevii* found within survey transects in Kaneohe Bay ranged from 0.407 individuals/site at the Pier to 0.711 individuals/site at Pyramid Reef (Figure 12). Abundance of *L. reevii* ranged from 1-4 individuals/transect and was highest at Pyramid Reef and lowest at the Pier (Table 2). Density per square meter, average density per site, and highest abundance found per transect were all found to be higher at Pyramid sites than any others (Table 2). The Pier, showed higher variability in the total abundance per transect triplet as well as density per square meter compared to Sandbar locations. Potential habitat for *L. reevii* was chosen from a predictive map created using data collected from prior years (Figure 13). These survey sites were mapped along with transect ends and abundance in order to provide a visual representation of data gathered (Figures 12, 14). This predictive map in addition to Figure 12 shows the predictive ability of these maps. The distribution of observed *L. reevii* habitat location was mapped in Kaneohe Bay as well as wastewater treatment plants within close or effective proximity to *L. reevii* habitat locations (Figure 14).

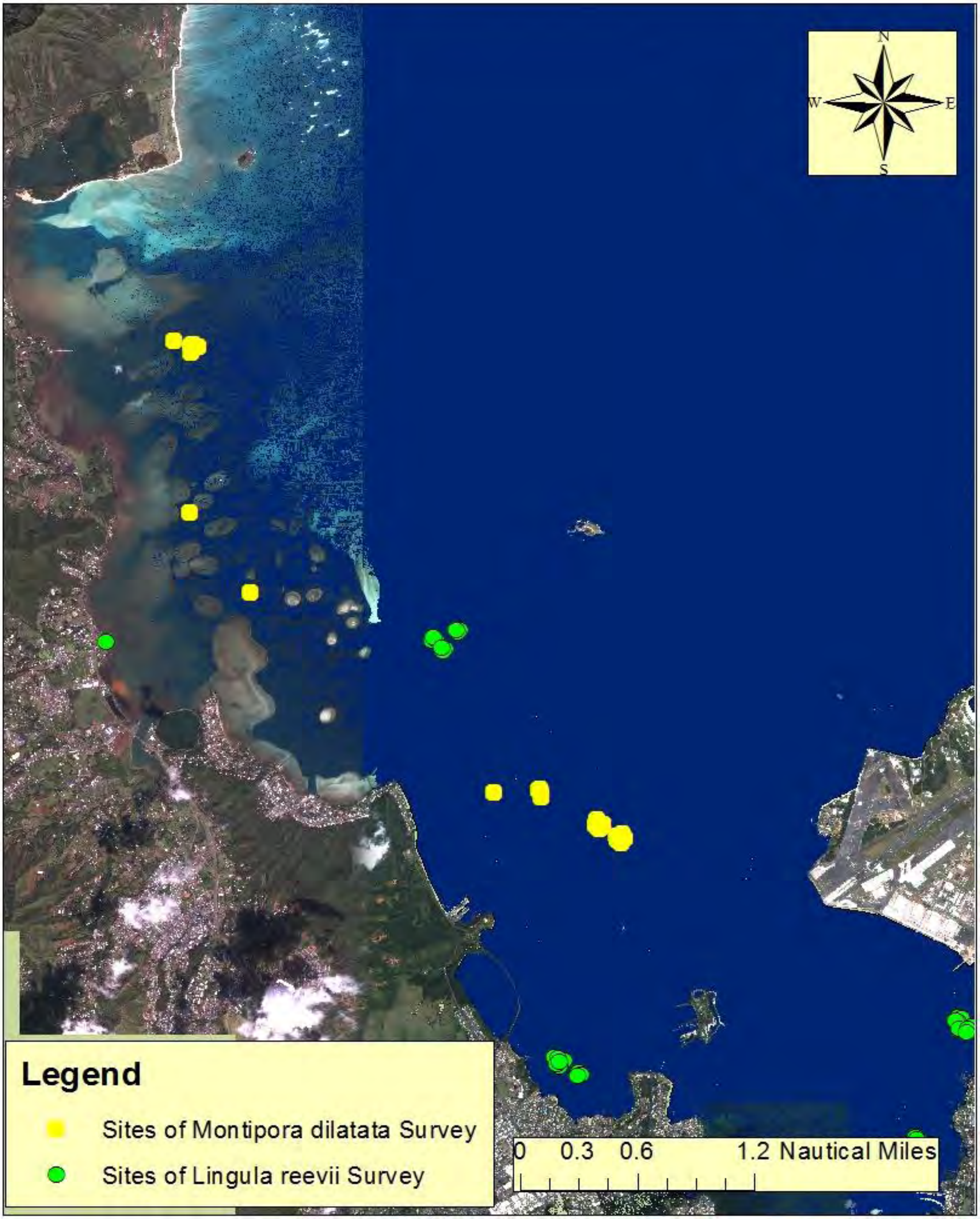

Figure 1. Surveyed area in Kaneohe Bay for *Lingula reevii* and *Montipora dilatata.*

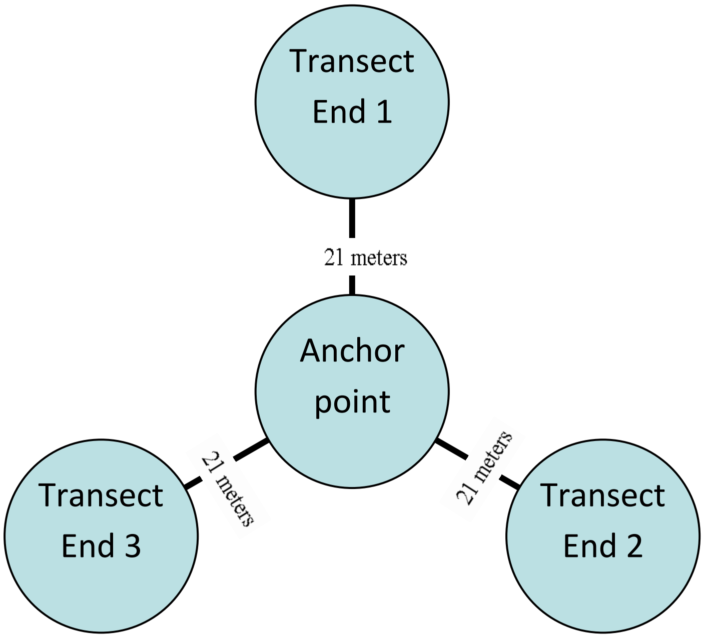

Figure 2. Method of survey for *Lingula reevii* at each designated GPS point.

Figure 3. Survey method of *Montipora dilatata* at each reef.

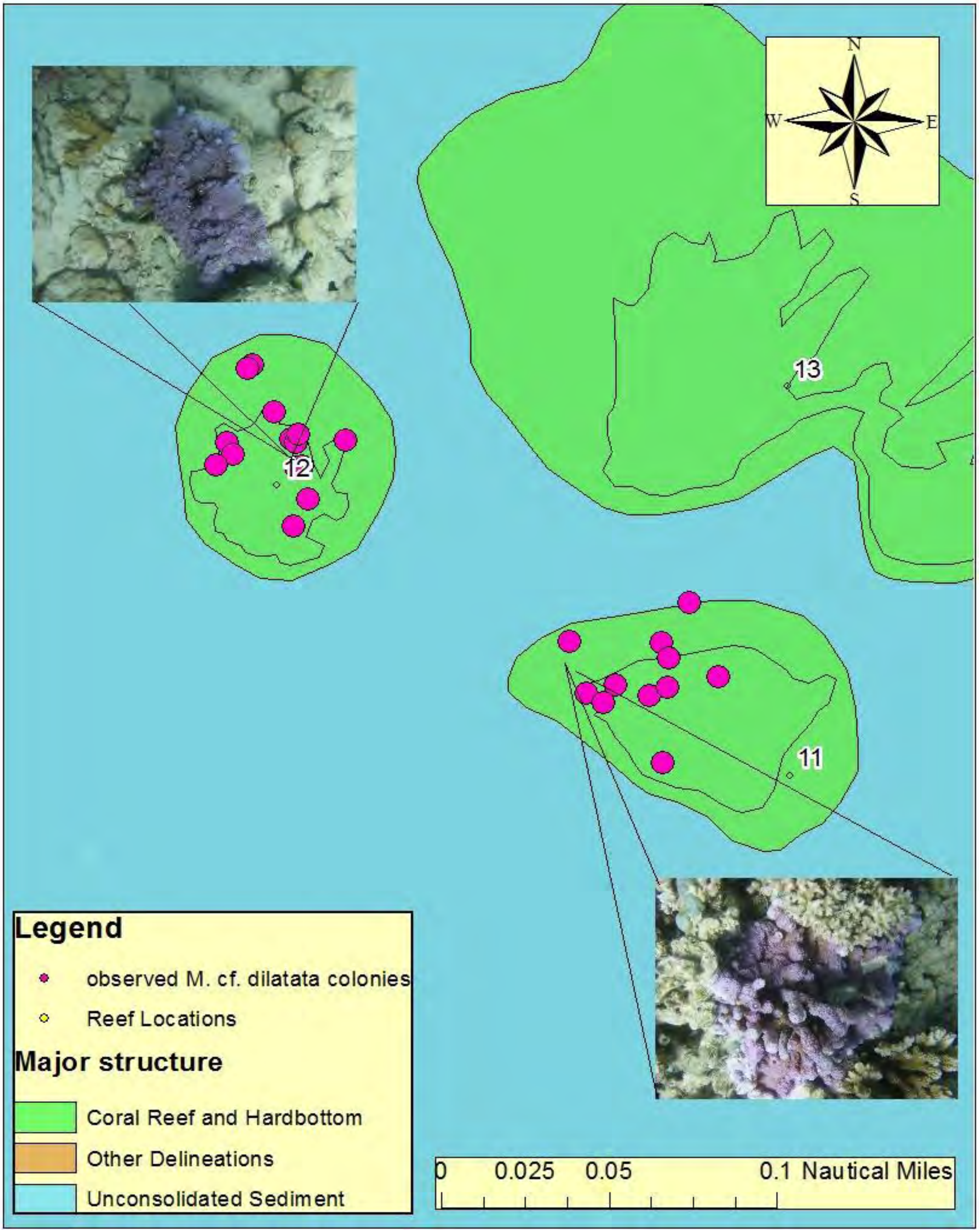

Figure 4. Patch reefs 11 and 12 with GPS points where *Montipora cf. dilatata* colonies are located.

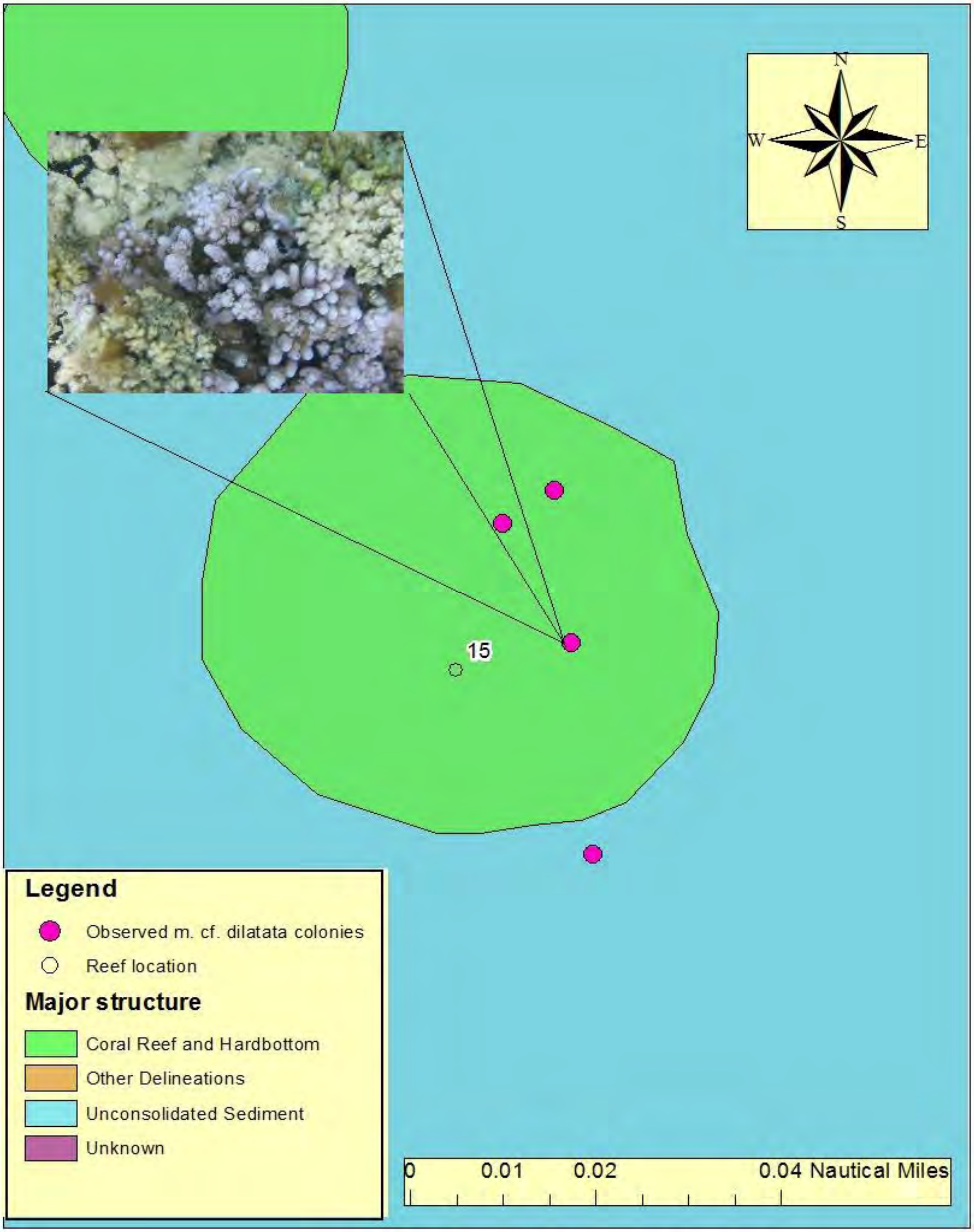

Figure 5. Patch reef 15 with GPS points where *Montipora cf. dilatata* colonies are located.

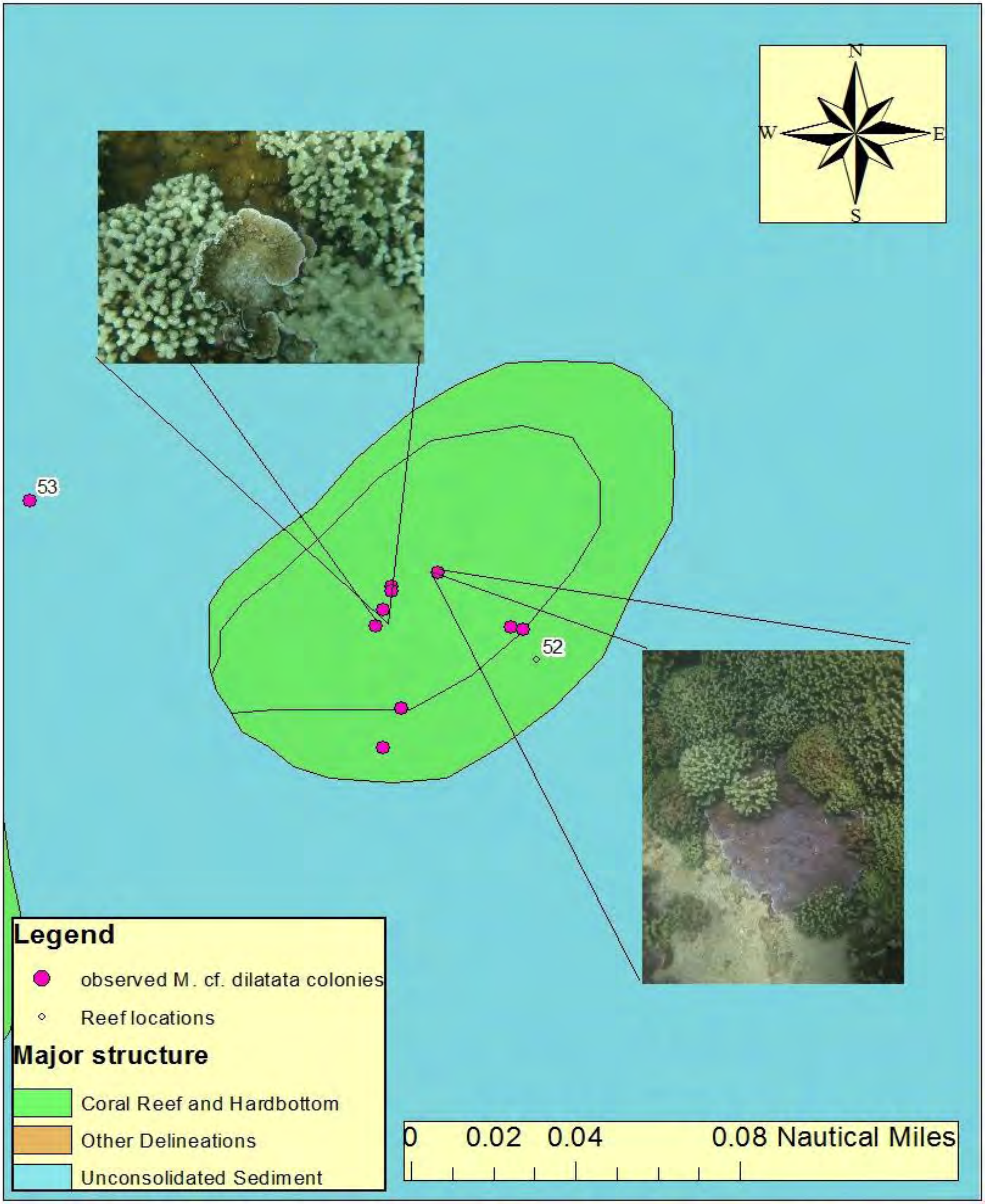

Figure 6. Patch reef 52 with GPS points where *Montipora cf. dilatata* colonies are located.

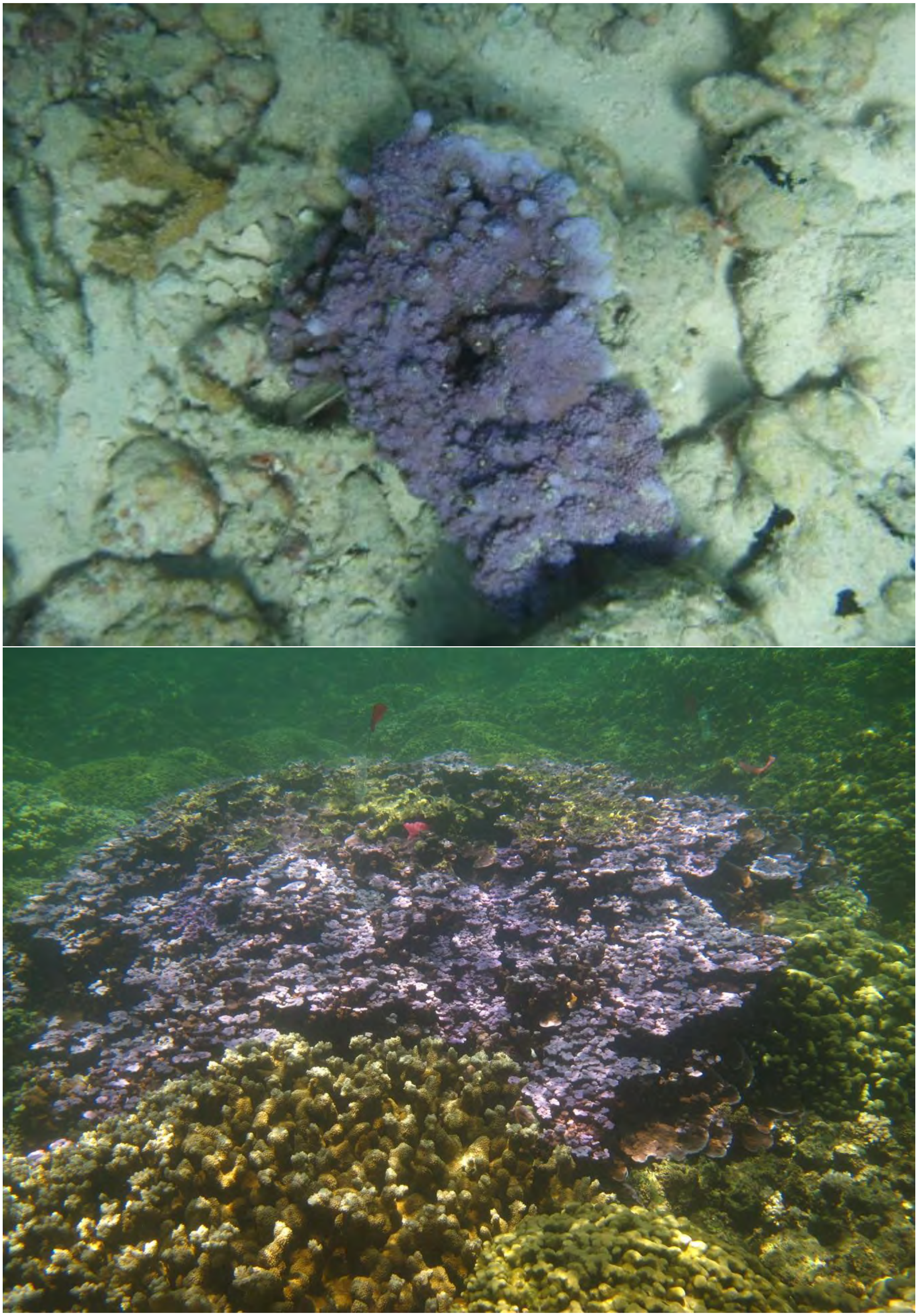

Figure 7. Top: *Montipora dilatata*. Bottom: *Montipora cf. dilatata.*

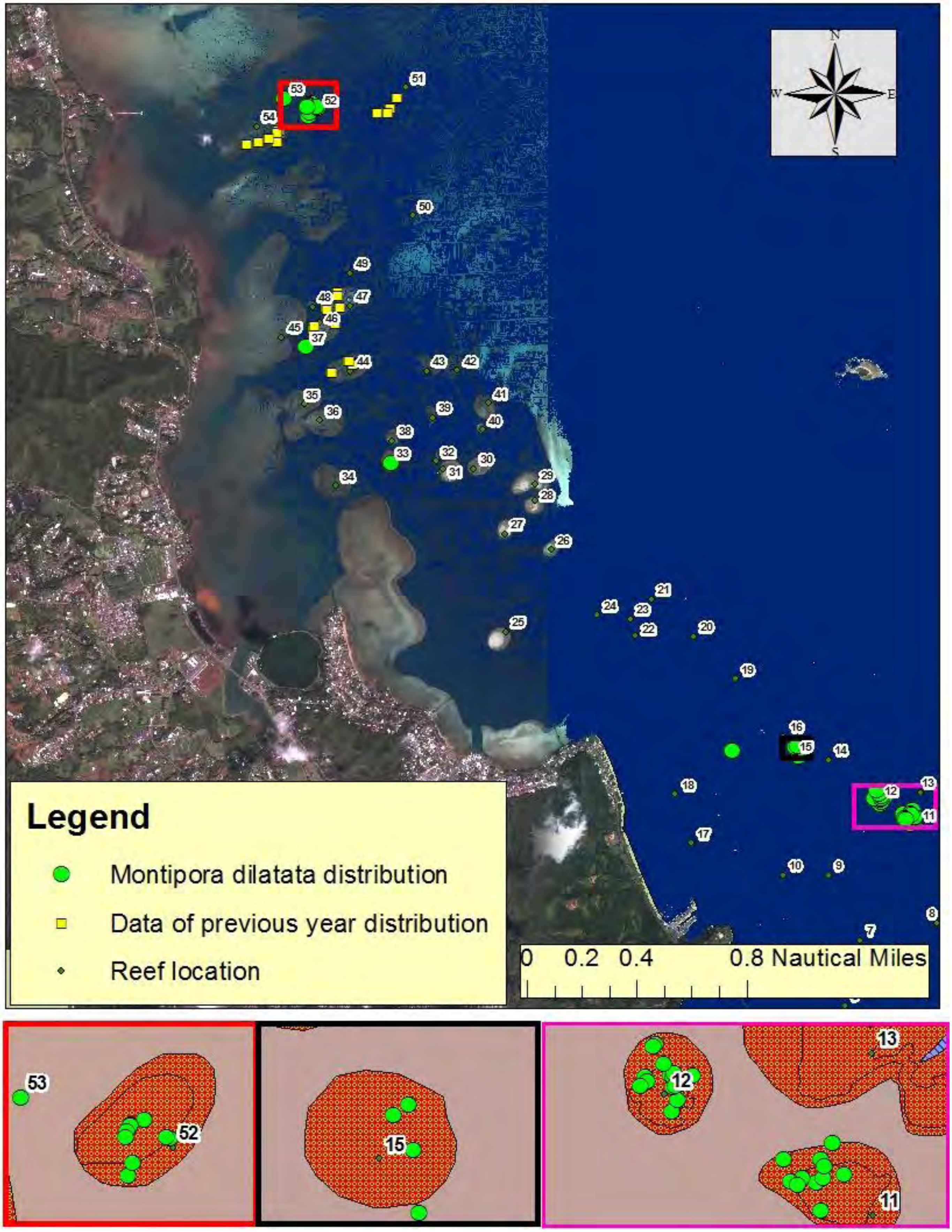

Figure 8. Distribution of *Montipora cf. dilatata* colonies at surveyed sites.

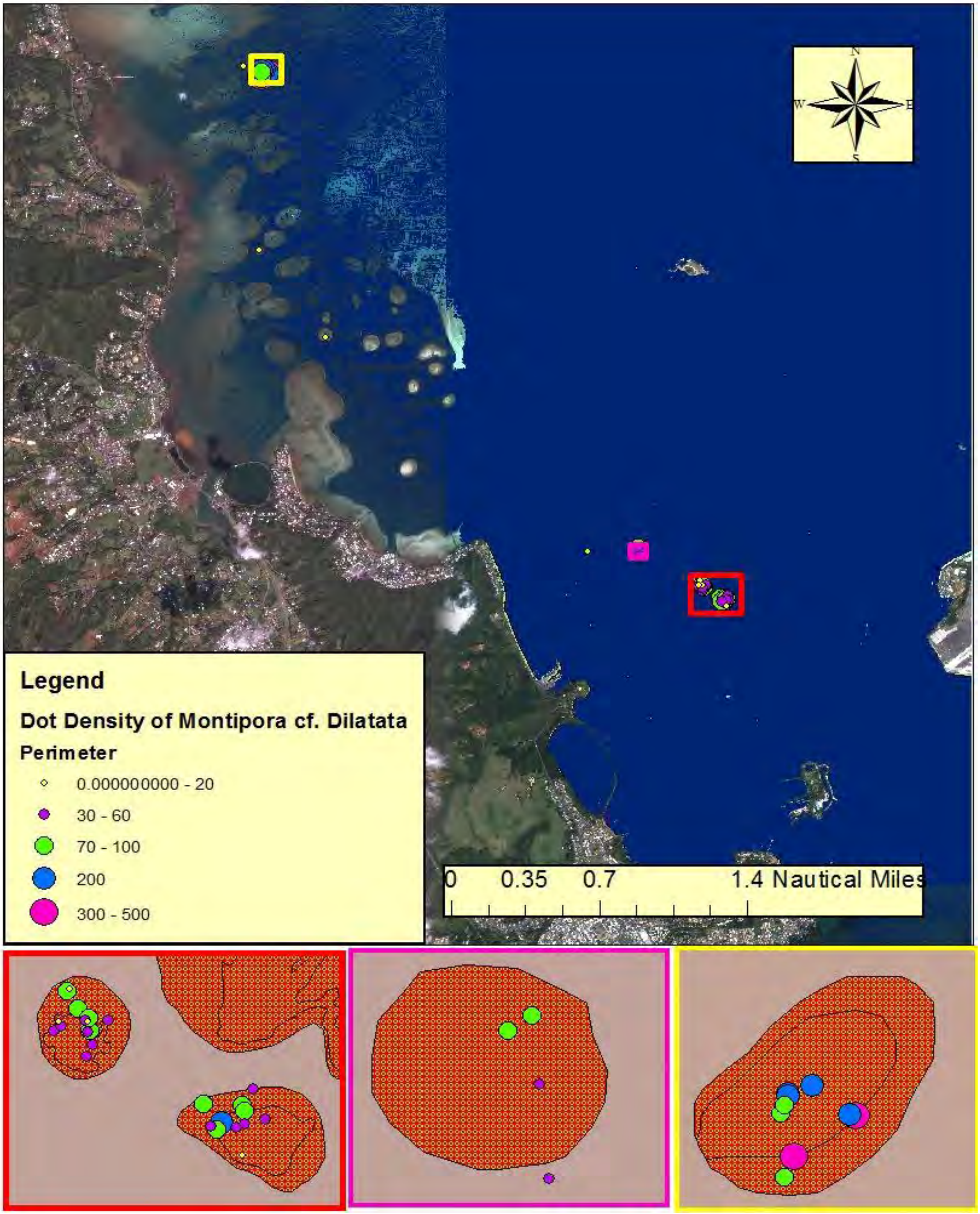

Figure 9. Dot density map for colony perimeters of surveyed *Montipora cf. dilatata* in centimeters.

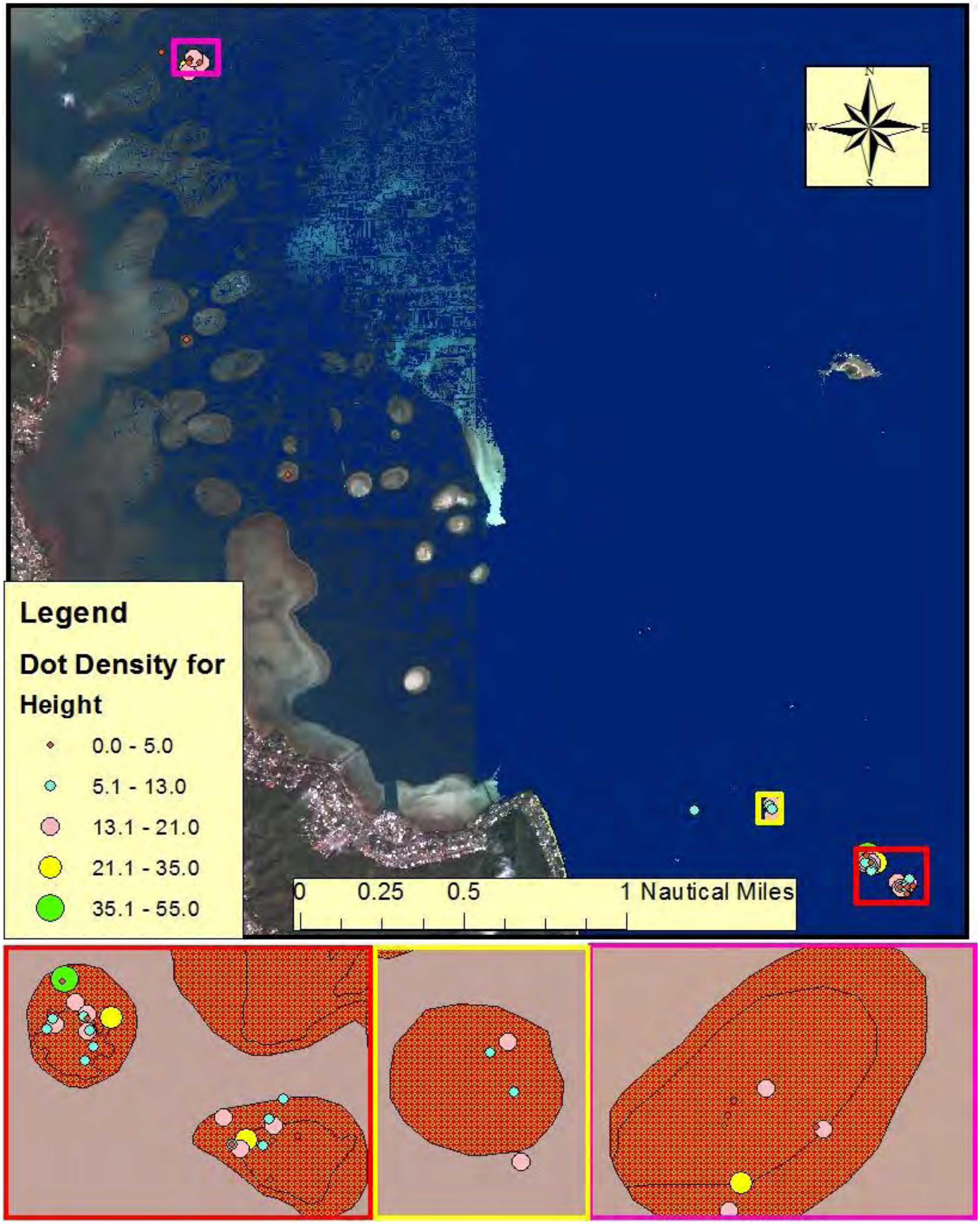

Figure 10. Dot density map for colony height of surveyed *Montipora cf. dilatata* colonies.

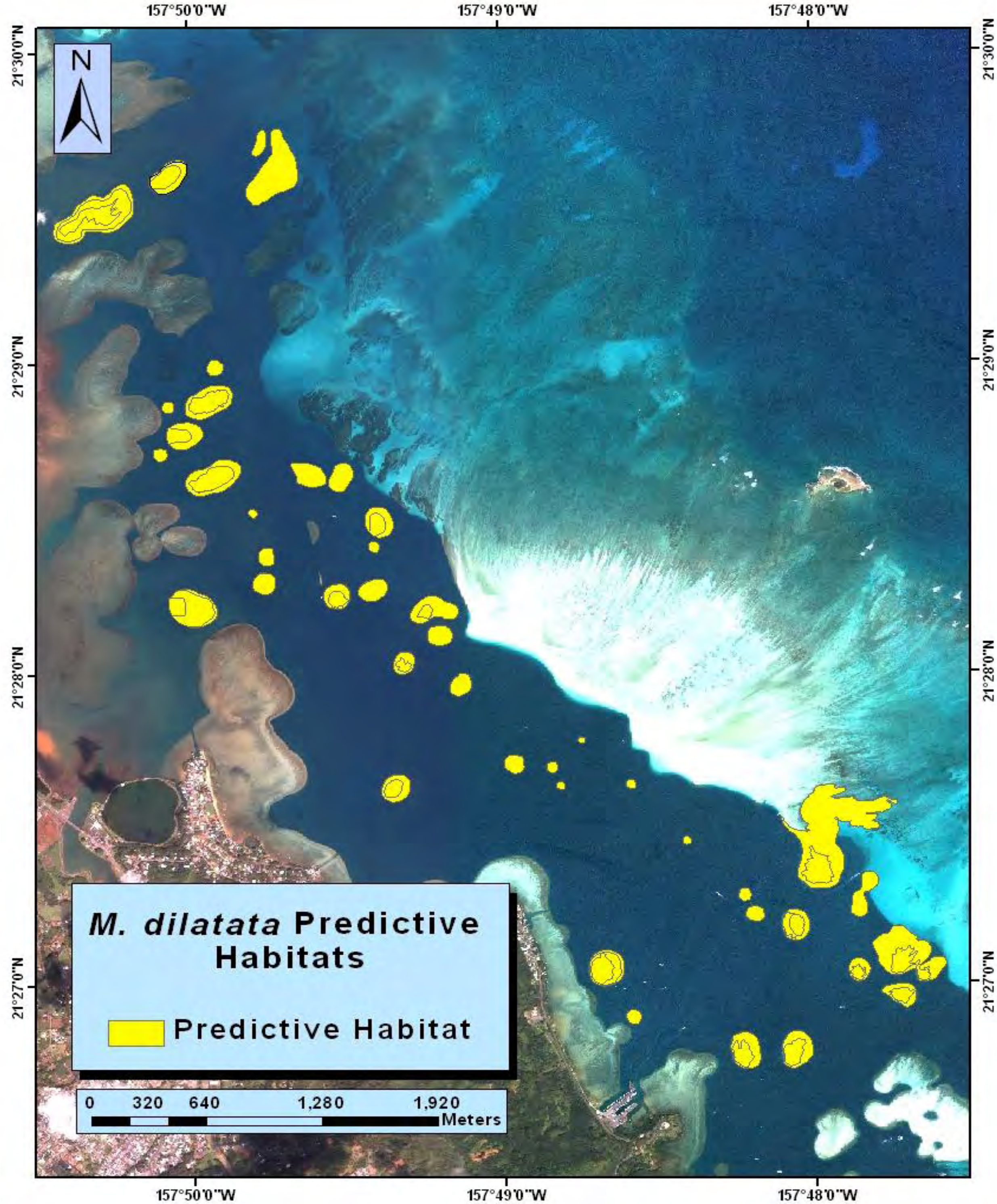

Figure 11. Predictive habitat map for prospective *Montipora dilatata* colonies (Barlow et al 2010a).

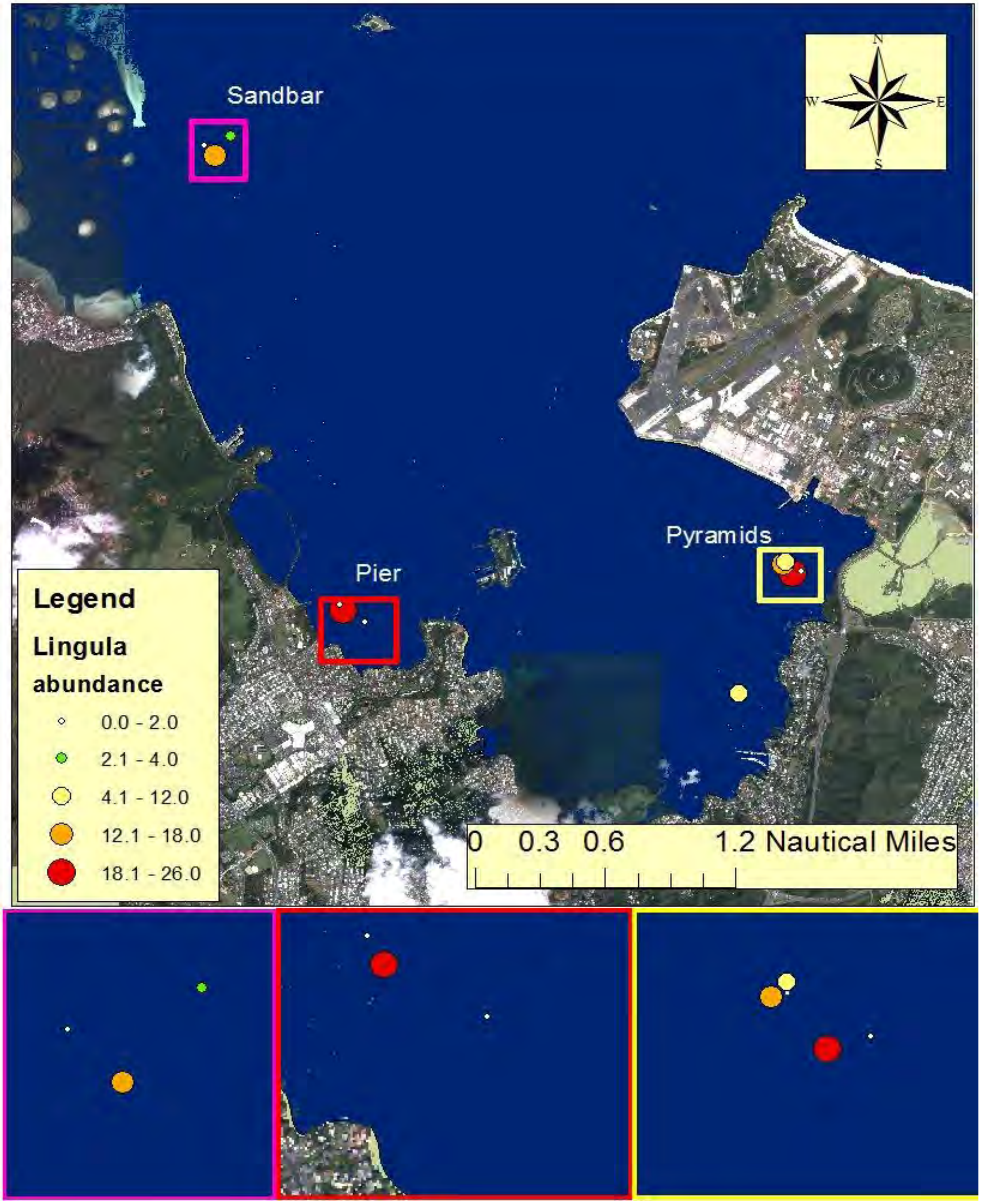

Figure 12. Dot density plot of *Lingula reevii* abundance at three different sites; Pyramid reef, Sandbar, and the Pier.

Figure 13. Potential habitat of *Lingula reevii* based on parameters such as water depth, sediment type, and previous years (2010) data. The predetermined survey locations were determined using GIS techniques. Survey sites for Pyramid Reef were determined using previous years (2010) data of areas of high *L. reevii* abundance.

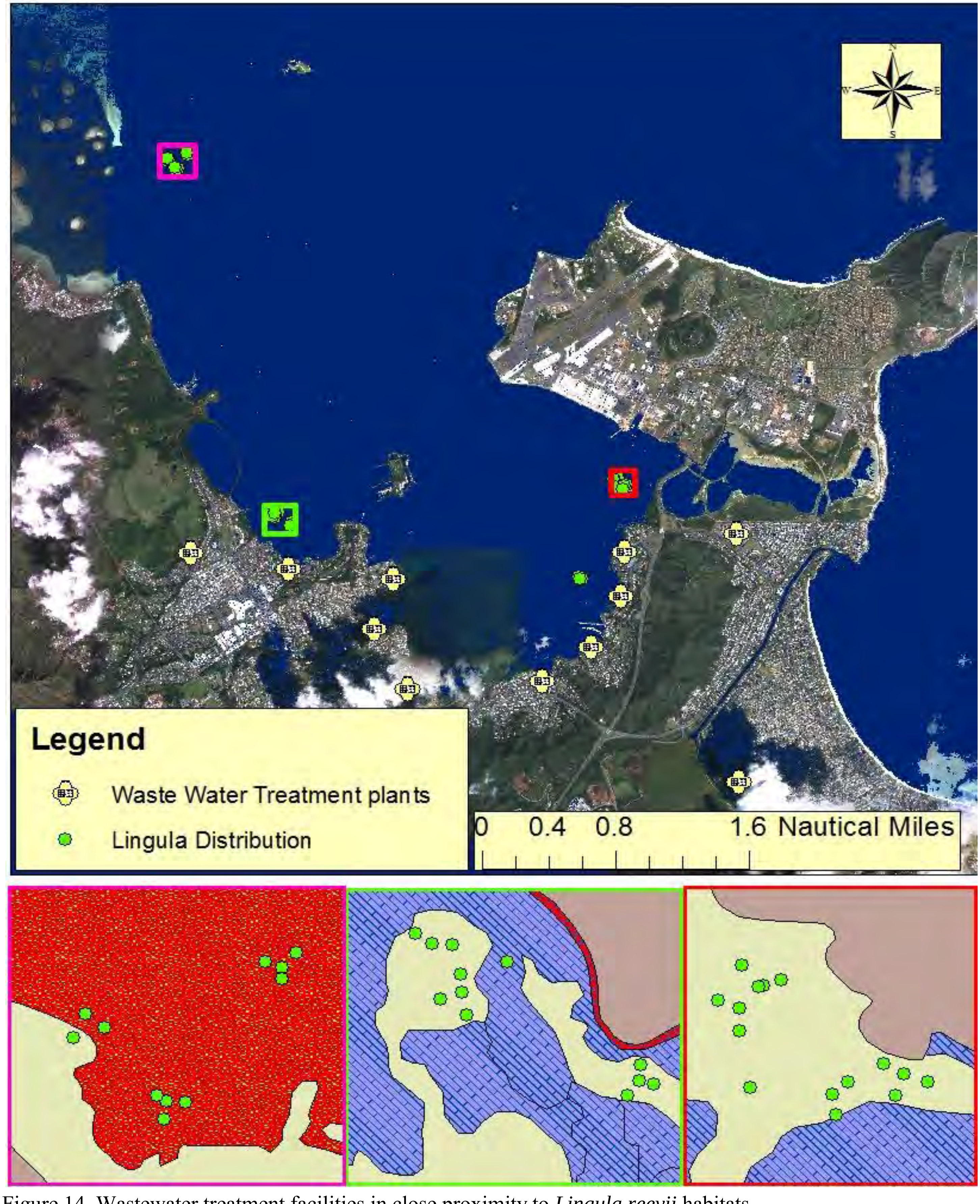

Figure 14. Wastewater treatment facilities in close proximity to *Lingula reevii* habitats.

Table 1: *Montipora cf. dilatata* abundance data collected for seven patch reefs in Kaneohe Bay. Colors code for the seven different reefs surveyed.

Reef	Colony	Lat	Long	Perimeter	Width	Height	Water_depth
53	0	21.4937	-157.8362	0	0	0	0
52	21	21.49263	-157.83467	68	30	21	117
52	13	21.4928	-157.83459	381	90	35	179
52	14	21.49338	-157.83443	140	42	15	250
52	18	21.49332	-157.83463	151	45	2	238
52	19	21.4933	-157.83463	119	114	2	255
52	20	21.49322	-157.83467	68	20	0	266
52	2	21.49313	-157.83406	476	154	19	256
52	70	21.49314	-157.83411	198	67	0	274
52	11	21.49315	-157.8347	75	25	0	255
37	0	21.47855	-157.8349	0	0	0	0
33	0	21.47139	-157.82941	0	0	0	0
12	119	21.45074	-157.79736	40	12	24	200
12	120	21.45113	-157.79785	17	12	55	200
12	146	21.45073	-157.79799	11	6	9	209
12	147	21.45067	-157.79796	36	18.5	16	200
12	148	21.4503	-157.79764	60	25	10	206
12	149	21.45044	-157.79756	52	21	13	79
12	151	21.4506	-157.79762	30	15	18	85
12	152	21.45075	-157.79765	52	19	10	189
12	153	21.45073	-157.79762	12	12	2	193
12	118	21.45062	-157.79805	46	20	11	190
12	119	21.45061	-157.79759	70	27	11	180
12	120	21.45077	-157.79761	68	36	17	176
12	121	21.45089	-157.79774	90	34	20	190
12	123	21.45111	-157.79788	71	31	0	154
15	219	21.4536	-157.8073	19	3	7	97
15	240	21.45321	-157.80298	35	12	15	160
15	243	21.4536	-157.80302	45	17	8	109
15	229	21.45382	-157.80315	107	30	10	95
15	238	21.45388	-157.80305	93	35	15	95
15	239	21.44943	-157.79608	30	15	3	100
11	221	21.4497	-157.79617	93	25	16	150
11	213	21.449416	-157.79575	51	16	7	100
11	227	21.44946	-157.79565	35	10	5	96
11	236	21.44989	-157.79553	48	17	10	110
11	237	21.44907	-157.79568	21	7	2	126
11	210	21.44947	-157.79593	123	36	25	132
11	232	21.44951	-157.79538	37	12	2	102
11	214	21.44969	-157.79568	75	20	12	150
11	226	21.44961	-157.79564	62	20	18	150
11	234	21.44943	-157.79608	58	16	10	110
11	215	21.44938	-157.79599	70	25	14	100

Table 2. *Lingula reevii* abundance of surveyed sites in Kaneohe bay. Sites highlighted in yellow were surveyed on the 3rd day, red were the 2nd day, and blue were the 1st day: water conditions varied each day.

		Anchor GPS									
location	Group	Latitude	Longitude	Latitude	Longitude	transect	average # per quadrat	Total abundance per triplet	Density_per_sqmeter	Average Density per Site	Highest abundance found per transect
pier				21.43024	-157.802	e1	0				
pier				21.42995	-157.80106	e2	0.166666667				
pier	1	21.43014	-157.80182	21.43013	-157.80162	e3	0	1	0.055555556		1
pier				21.4289	-157.7997	e1	0				
pier				21.4287	-157.79956	e2	0				
pier	2	21.42874	-157.79971	21.42859	-157.79984	e3	0	0	0		0
pier				21.42941	-157.80148	e1	0.83333				
pier				21.42958	-157.80174	e2	1.666666666				
pier	3	21.42964	-157.80153	21.42983	-157.80154	e3	1	21	1.166665555	0.407407037	3
sandbar				21.46802	-157.01029	e1	0.166666667				
sandbar				21.46773	-157.81046	e2	0.333333333				
sandbar	1	21.46786	-157.81046	21.46793	-157.81064	e3	0.166666667	4	0.222222222		1
sandbar				21.46707	-157.81288	e1	0.166666667				
sandbar				21.46719	-157.81252	e2	0.166666667				
sandbar	2	21.46719	-157.84271	21.46735	-157.81274	e3	0	2	0.111111111		1
sandbar				21.46633	-157.81158	e1	1.166666667				
sandbar				21.46613	-157.81183	e2	0.666666667				
sandbar	3	21.46634	-157.8118	21.46641	-157.81192	e3	1.166666667	18	1	0.444444444	2
pyramid				21.4333	-157.76489	e1	0.166666667				
pyramid				21.43348	-157.76503	e2	0.833333333				
pyramid		21.43331	-157.76484	21.43335	-157.76469	e3	0.666666667	10	0.555555556		2
pyramid				21.43292	-157.76506	e1	0.166666667				
pyramid				21.43311	-157.76506	e2	1				
pyramid	1	21.43311	-157.76506	21.43318	-157.76524	e3	1.333333333	15	0.833333333		2
pyramid				21.43246	-157.76341	e1	0.166666667				
pyramid				21.43235	-157.76369	e2	0				
pyramid	2	21.43253	-157.76361	21.43262	-157.76379	e3	0	1	0.055555556		1
pyramid				21.43242	-157.76497	e1	1				
pyramid				21.43247	-157.76411	e2	1.5				
pyramid		21.43236	-157.76425	21.43218	-157.76422	e3	1.833333333	26	1.444444444		4
pyramid				21.42268	-157.76865	e1	1.5				
pyramid				21.42292	-157.76895	e2	0.333333333				
pyramid	3	21.42273	-157.71884	21.42273	-157.76892	e3	0.166666667	12	0.666666667	0.711111111	3

Discussion

In this research two species were studied; the inarticulated brachiopod, *Lingula reevii,* and the morphologically variable coral *Montipora dilatata*. In conjunction with basic statistics, maps were created illustrating the spatial patterns of abundance and distribution of each species in Kaneohe Bay, Oahu, in comparison with previous Biology 403 data (2010) and abiotic factors.

Data was gathered at the Pier, Sandbar, and Pyramid Reef. *Lingula reevii* at Pyramid Reef showed a decrease in maximum average density from 2.93 individuals/m^2 in 2010 (Barlow 2010a) to 0.711 individuals/m^2 in 2011. This decline, however, has remained consistent with trends of population declines in *L. reevii* prior to 2010 (Barlow, 2010a, Worcester 1969). It has been postulated that this species' natural population was enhanced via the sewage line break in the early 1900's to late 1970's which caused heightened nutrient levels around Kaneohe Bay in the following years (Maragos et al. 1985, Worcester 1969). Figure 13 illustrates the proximity of high density *L. reevii* populations to wastewater treatment facilities. This suggests that those areas more likely to be impacted by sewage outfall may have some correlation to the larger *L. reevii* populations within their vicinity. The validity of considering species such as *L. reevii* as SOC must be scrutinized and population declines of any species under these pretext beg the question, is the current population the natural population?

Maps using environmental parameters such as benthic habitat and abiotic data such as water depth from previous years were made to predict possible habitat for *L. reevii*. These were then used to find new survey sites in order to study populations at various locations around the bay. Although some of these were successful in predicting the presence of the inarticulated brachiopod, it is uncertain whether the method used was always accurate due to a high variation in *L. reevii* abundance between groups. Further analysis of predictive maps for this species needs to be done in conjunction with measurements of abiotic factors with an emphasis on recording sediment depth and water quality. Furthermore, studies could be conducted on monitoring and mapping water currents in the bay and the effect they have on wastewater movement and subsequent impact on *L. reevii*.

Similarly, Barlow et al. (2010a) made a predictive map for possible *M. dilatata* habitats in Kaneohe Bay which were considered in this study. In 2010, 26 reefs were surveyed and 71 colonies were found (Barlow et al, 2010a). It is apparent that the higher percentage of *M. cf. dilatata* colonies found in those reefs surveyed this year suggests that the predictive ability of the map created is relatively accurate. In order to fully understand the predictive power of such methods, however, there must be a continuation of spatial studies around the bay which includes the mapping of a number of abiotic factors that includes temporal current changes, salinity, light, etc. around these colonies. As of yet there is little more than qualitative analysis that can be done to assess this method given the data gathered.

It was found through mapping and analysis of *M. cf. dilatata* distribution that more surveyed reefs in the southern portion of the bay contained habitats where the coral was present. In the northern portion of the bay, *M. cf. dilatata* presence was much less frequent and only observed on one of four reefs surveyed, as opposed to the southern bay where all reefs contained *M. cf. dilatata.* This suggests that parameters shaping *M. dilatata* habitat are more suitable in the southern portion of the bay. Moreover, GIS maps created of *M. diliatata* habitat distribution showed that colonies with larger perimeters were more abundant in the north bay than in the south, despite the fact that less colonies overall were observed in the north bay. Alternatively, colony heights of *M. dilatata* were found to be greater in the south bay. These observations also infer information about differences in habitat conditions between the north and south bay. From personal observation of the two areas, the north bay receives higher wave action than that of the south bay which may be the cause for this trend. Future surveys may benefit from recording substrate types at locations of *M. cf. dilatata* colonies, assisting in the creation of future predictive maps.

As with all research there is a large possibility of error, especially surveying *L. reevii*. During this study, nine different surveyors observed *L. reevii* at various sites, and as a result there is a possibility that the populations were either greatly underestimated due to the uncertainty of identification or that populations were overestimated because random burrows were mistaken for *L. reevii*. In the process of surveying *M. dilatata*, colonies may have been overlooked because areas of reef were missed due to currents pushing snorkelers off course, despite the use of compasses and waterproof GPS devices.

In conclusion, densities of *L. reevii* have once again declined after a brief increase in 2010. This could either be the result of changing environmental factors detrimental to the organism or, perhaps, the population has finally reached an apparent equilibrium 41 years after the aforementioned sewage spill. It is important to note that small sample sizes and variations in methods and researchers could also have played a role in the observed decline. A much higher abundance of survey sites covering larger areas would aid future researchers in estimating populations of *L. reevii.* Simultaneously sampling a large number of previously listed abiotic factors will also contribute data used for more conclusive mapping of habitat of *L. reevii*. Those maps made by previous years, which illustrate possible *M. dilatata* habitat, proved useful in this study. These predictive maps show promise for future studies although more data is needed to quantitatively assess their accuracy. Areas of interest for spatial study include temporal current changes throughout the bay as well as variation in water quality, sediment depth, temperature, and salinity.

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