Distribution and abundance of *Lingula reevii* in Kaneohe Bay, Oahu, Hawaii 2009

Cover photo: **Unique siphon openings formed by *Lingula reevii* burrows**

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Abstract:

The inarticulated brachiopod, *Lingula reevii,* is listed as a NOAA National Marine Fisheries Service (NMFS) Species of Concern (SOC) due to its sharp population decline in the last few decades. *L. reevii* has been observed in the wild in Kaneohe Bay, Oahu, Hawaii, as well as Japan and Ambon, Indonesia. In 1969, estimates of the *L. reevii* population within Kaneohe Bay were as high as 500 individuals/m^2 in southern sectors of the Bay. Sewage was diverted from southern Kaneohe Bay in 1978-79 and highest densities of *L. reevii* declined to 100 individuals/m^2 (Emig 1981). Surveys in Kaneohe Bay in 2004, 2007, and 2008 yielded even lower population estimates. In 2004, quantitative surveys of approximately 2,950 m^2 yielded a maximum density of 4 *L. reevii*/m^2. In 2007, surveys of 2,420 m^2 found a maximum density estimate of 0.94 *L. reevii*/m^2. In 2008, surveys of 11,600 m^2 found a maximum density estimate of 0.87 *L.* reevii/m^2. The current study, covering 10,200 m^2, found only 166 total *L. reevii* individuals among 32 sites, with the lowest observed maximum density to date of 0.09 *L. reevii*/m^2. There was a negative correlation between invasive alien algae and abundance of *L. reevii*. ArcGIS was used to plot and examine the current spatial distribution of *L. reevii.* The continuing decline in *L. reevii* population may be due to the presence of mats of invasive algae covering suitable habitat and/or inhibiting the brachiopod's feeding and reproductive behavior. The current population appears to be a fraction compared to historical levels of *L. reevii* in Kaneohe Bay and may be in need of concerted recovery efforts.

Introduction:

Lingula reevii, a filter-feeding inarticulated brachiopod, is known to burrow in shallow reef flats with sandy or mixed sediments (Emig 1978; Hunter *et al*. 2008). *Lingula reevii* is known to occur in only three locations worldwide: 1) Kaneohe Bay, Oahu, Hawaii; 2) Ambon, Indonesia (Cals and Emig 1979); and 3) Japan (Emig 1997). *Lingula reevii* has been designated as a Species of Concern (SOC) by the National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS). NMFS uses the SOC list to identify species potentially at risk; increase public awareness about those species; identify data deficiencies and uncertainties in species' status and threats; stimulate cooperative research efforts to obtain the information necessary to evaluate species status and threats; and foster voluntary efforts to provide stewardship for the species before an Endangered Species Act listing as threatened or endangered becomes warranted (69 FR 19975). *Lingula reevii* has been identified as a SOC because a significant decrease in abundance has been observed in recent decades in Kaneohe Bay, Oahu, Hawaii (Hunter *et al*. 2008).

Monitoring is necessary to quantify *L. reevii* abundance in Kaneohe Bay and to improve understanding of possible factors for any decline in population size for this species. The collection of monitoring data from areas of known *L. reevii* occurrence with spatially predictive mapping will aid the NMFS Pacific Islands Regional Office (PIRO) in determining whether conservation methods are effective in preventing further decreases in *L. reevii* abundance in Kaneohe Bay. Conservation methods include removal of alien and invasive algae from SOC habitats, reintroduction of *L. reevii* specimens propagated in captivity to favorable habitats, and controlled breeding trials.

The abundance and distribution of *L. reevii* were first surveyed in Kaneohe Bay more than 35 years ago (Worcester 1969). According to data from multiple studies, a decrease in *L. reevii* abundance occurred, perhaps due to reduced nutrient availability in 1978-1979 after sewage effluent was diverted from the southern bay (Worcester 1969; Emig 1978, 1981). In 2004, approximately 2,950 m^2 were surveyed for *L. reevii* abundance in sandy reef flat habitats. This study found a maximum density of 4 individuals/m^2, a significant decrease from former maximum densities of 500 individuals/m^2 (Worcester 1969) and 100 individuals/m^2 (Emig 1981). A study performed in 2007 indicated that maximum abundance of *L. reevii* had decreased to 0.94 individuals/m^2, and that maximum abundance occurred in reef locations and sandy habitats at greater depths (Hunter *et al*. 2007). A similar study performed in 2008 indicated that the maximum abundance of *L. reevii* had further decreased to 0.87

individuals/m^2 (Hunter *et al*. 2009).

As part of continuing *L. reevii* abundance studies in Kaneohe Bay, additional surveys and spatially predictive modeling were conducted to determine if there was continuing decline in abundance, changes in distribution, and assess whether similar habitat characteristics from previous years (e.g. sediment type, water depth, and percent algal cover) continued to be indicative of *L. reevii* abundance trends. The 2009 survey also aimed to locate potential *L. reevii* habitats. These quantitative and qualitative analyses will provide information for future conservation efforts.

Two factors are likely to be causal for *L. reevii* abundance decline in Kaneohe Bay: decreased organic nutrient availability due to diversion of former sewage discharge, and reduced suitable *L. reevii* habitats caused by alien and invasive algal overgrowth of reefs by *Gracilaria salicornia*, *Acanthophora spicifera*, and *Kappaphycus/Eucheuma* spp. (Rodgers and Cox 1999; Woo 2000; Smith *et al*. 2002, 2004). Alien and invasive algae continue to spread over Kaneohe Bay reefs despite algae reduction efforts. One algae reduction program, the “Super Sucker”, uses large vacuum-like hoses to remove alien and invasive algae from the reef bottom. Since the alien and invasive algae problem is still growing (DAR 2009), monitoring of *L. reevii* abundance and further algae removal efforts are crucial to protect remaining *L. reevii* specimens in Kaneohe Bay.

The objectives of this study were to monitor *L. reevii* abundance and habitat trends, and to quantify the negative effects of the presence of alien and invasive algae on *L. reevii* abundance. Potential *L. reevii* habitats were also investigated through spatially predictive mapping. Future monitoring of *L. reevii* abundance will continue to provide detailed information for future management strategies and will contribute to efforts for decreasing the potential regional species extinction of *L. reevii* in Kaneohe Bay.

Materials & Methods:

Snorkeling surveys were conducted at a total of 32 sites on Kaneohe Bay fringing reefs, patch reefs, and the Sandbar. Chosen sites included those studied by Worcester (1969) and Emig (1981), sites surveyed in previous years, and other areas that appeared to have suitable habitat for *Lingula reevii*. SCUBA divers also surveyed deeper habitats that could not be surveyed by snorkeling.

The preferred habitat characteristics for *Lingula reevii* were qualitatively identified during past and present field observations. These preferred habitat characteristics were integrated into a GIS analysis to create a map of *L. reevii* preferred habitat in Kaneohe Bay. Habitat characteristics compiled in GIS included depth, slope, habitat type, and alien algae abundance.

Fifty meter transect lines were placed parallel to shore in sandy areas deemed as suitable habitat for *L. reevii*. After laying the transect, observers waited for 6 to 10 minutes to allow *L. reevii* to reemerge from the substrate in case they were disturbed by laying the transect line. During this waiting period, a water sample was collected, sediment type was assessed, water depth, sand depth, and a GPS reading of the start of each transect were recorded. Surveyors recorded three parallel holes indicative of *L. reevii* burrows. One team member swam along the transect and the other two team members swam parallel to the transect, approximately 5 meters on either side. A GPS point was recorded at the end of each 50 meter transect. Temperature data loggers were deployed at select sites to record seawater temperature for 24 to 36 hours. Percent cover of *Acanthophora spicifera*, *Gracilaria salicornia*, *Acanthophora/Gracilaria*, *Kappaphycus/Eucheuma*, *Halophila* spp., and *Padina* spp. were assessed in 14 randomly chosen 1 square meter quadrats. Random numbers were obtained using a random number generator (random.org). *Lingula reevii* abundance, locations, and habitat characteristics were integrated into GIS-based maps for analysis with environmental parameters.

At the Sandbar, transects were run along 3m, 5m, and 7m isobaths at three locations (Sandbar A, B, and C) by SCUBA divers. At the dredged reef in the south Bay, SCUBA was also used to survey *L. reevii*. A snorkeler swam above and took the starting and ending GPS coordinates of the transect lines. All other aspects of the deeper surveys were identical to the shallower surveys.

Results:

Historical comparisons of *Lingula reevii* in Kaneohe Bay for the past 40 years have shown a marked decrease in the maximum average density per meter squared (Table 1).

Table 1. Historical comparisons of *Lingula reevii* densities in Kaneohe Bay, Oahu, Hawaii.

Number of sites	Author	Year	Max Avg Density / m^2	Total Area*
2	Worchester	1969	500	N/A
N/A	Emig	1981	100	N/A
20	UHM	2004	4	2950 m^2
17	UHM	2007	0.94	2420 m^2
26	UHM	2008	0.87	11600 m^2
32	UHM	2009	0.09	10200 m^2

* Computed differently in each study

For each survey site, *L. reevii* abundance was compared to a variety of environmental parameters: sand depth, water depth, salinity, and sand type (Table 2).

Table 2. Number of *L. reevii* and environmental parameters at each survey site. Area surveyed was 150 m^2 for each transect.

Reef	*L. reevii*	*L. reevii*/m^2	Sand depth (cm)	Water Depth (m)	Salinity	Sand Type
Beach	0	0	4.75	0.5	--	Medium
Fringing Reef A**	2	0.004	5.75	0.75	35	Fine
Fringing Reef B**	12	0.027	5.75	5.6	37	Silty
Fringing Reef C	8	0.053	6.5	1.1	35	Silty
Fringing Reef D	3	0.020	4.25	1.1	36	Fine
Fringing Reef E	8	0.053	6	1.25	36	Fine
Fringing Reef F	0	0.000	3.75	1.5	37	Fine
Fringing Reef H	0	0.0000	3	1.8	36	Medium
Fringing Reef I (North)*	2	0.007	4.75	0.9	36.5	Coarse
Fringing Reef J*	7	0.023	7.25	0.9	37	Silty
Fringing Reef K*	0	0.000	4.75	0.9	37	Coarse
Fringing Reef L (North)*	0	0.000	4.5	1	37	Coarse
Fringing Reef L (South)**	0	0.000	7	1	37	Fine
Fringing Reef M*	1	0.003	5	1	37	Silty
Goby Bay*	1	0.003	6.75	0.5	37	Fine
Large dredge*	27	0.090	5.25	3	--	Fine
Patch Reef 15	4	0.027	20	1-3	--	Medium
Patch Reef 25	0	0.000	5.25	1	37	Medium
Patch Reef 3	3	0.020	6	0.7	37	Medium
Patch Reef 4*	6	0.020	4.5	0.8	37	Fine
Patch Reef 5*	0	0.000	4	0.9	37	Fine
Patch Reef 7**	0	0.000	4.25	1	--	Fine
Poolhouse**	2	0.004	4.75	1	37	Fine
Sandbar 1**	1	0.002	--	1-5	37	Coarse
Sandbar 2**	0	0.000	--	0.6	37	Medium
Sandbar A***	34	0.057	17.5	1-5	36	Fine
Sandbar B**	22	0.049	19	1-5	--	Medium
Sandbar C****	21	0.028	20	1-5	37	Coarse
Sandbar North**	0	0.000	4	1	36	Medium
Small Dredge	1	0.007	18.5	3	--	Fine
South Side*	1	0.003	4.75	0.6	--	Medium
Total *L. reevii*	166					
Avg density over all transects	0.016275					

Area covered at each site *=300m^2 **=450m^2 ***=600m^2 ****=750m^2

The preferred substrate type for *L. reevii* was found to be fine-grain sand (Figure 1).

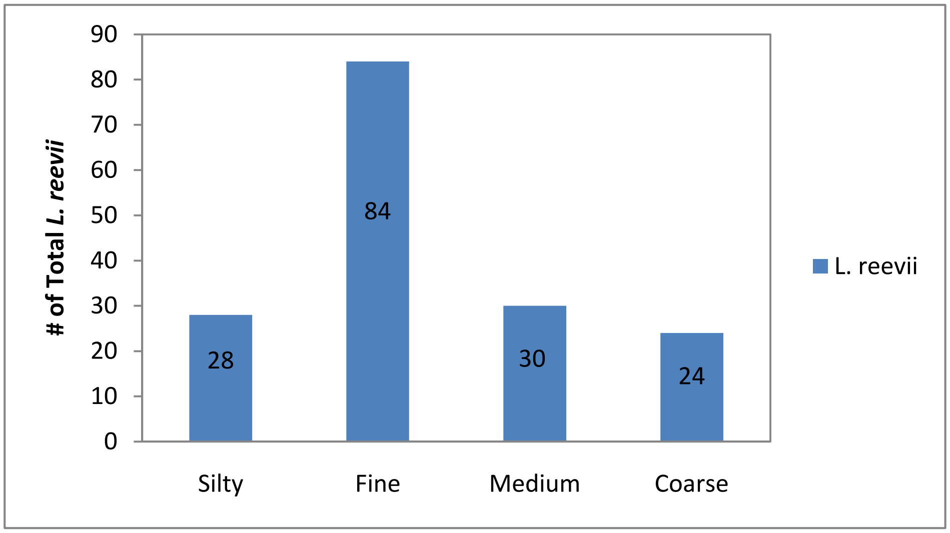

Figure 1. Number of *L. reevii* found in various sediment types at 32 sites in Kaneohe Bay.

Alien algae cover was negatively associated with *L. reevii* abundance (Figure 2).

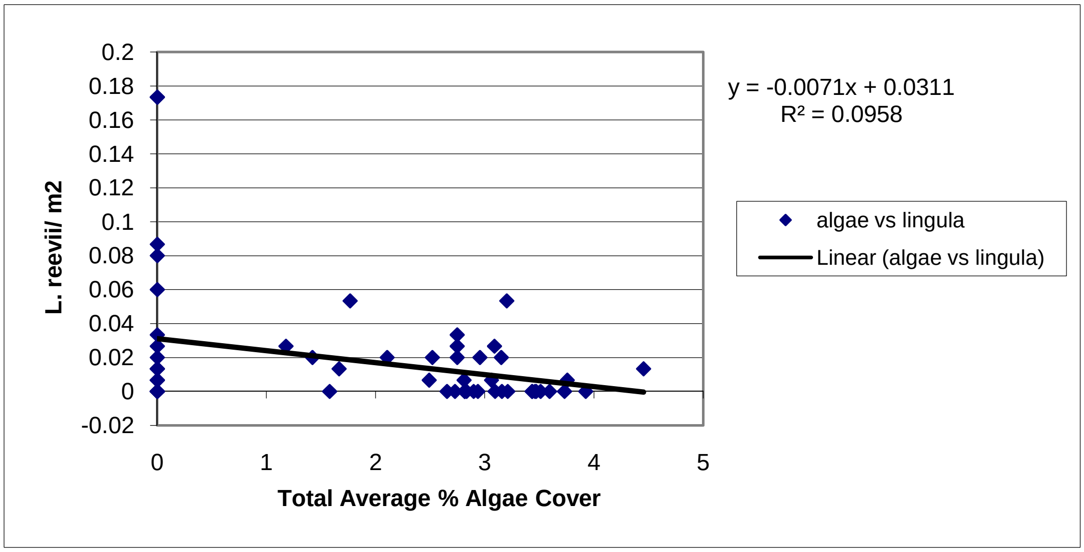

Figure 2. Simple linear regression analysis for total average percent algal cover versus *Lingula reevii*/m^2. Total average percent cover was normalized using ln(x+1).

Increasing water and sand depths had a positive influence on *L. reevii* abundance (Figures 3 and 4).

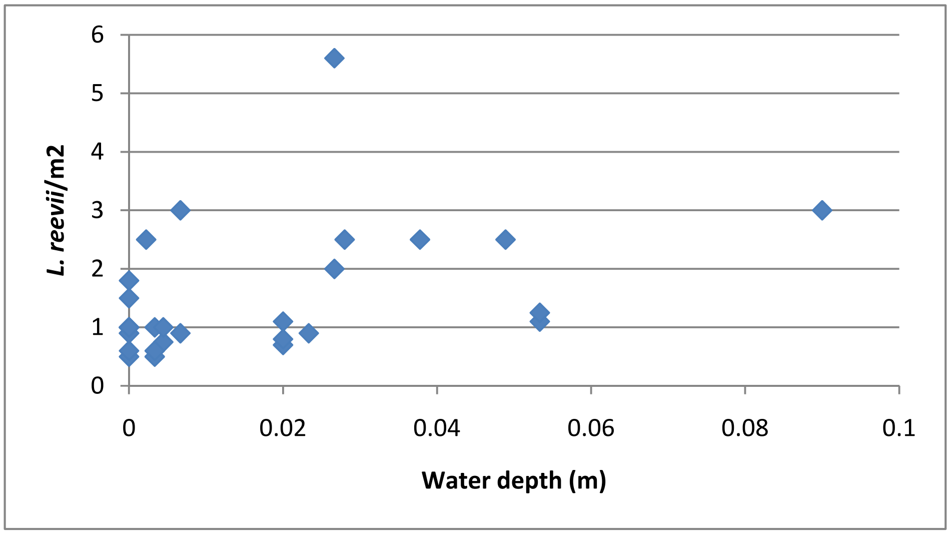

Figure 3. Water depth (m) versus *L. reevii*/m^2.

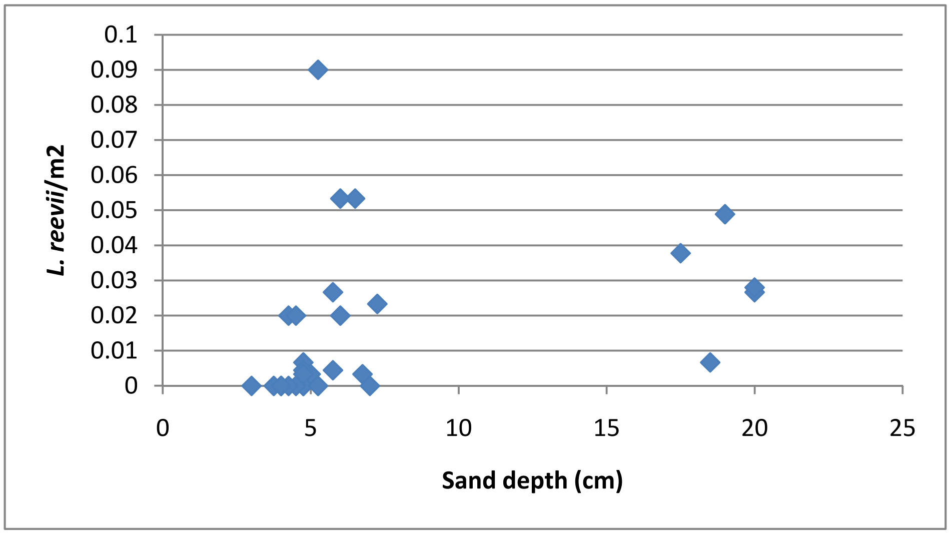

Figure 4. Sand depth (cm) versus *L. reevii*/m^2.

All data conformed to assumptions of normality; as such, a Pearson correlation analysis was used for comparisons. *Lingula reevii* showed a strong positive correlation with increasing water and sand depth ($r=0.632$, $P<0.05$; $r=0.553$, $P<0.05$ respectively) (Table 3). *Lingula reevii* showed a weak, but positive correlation with presence of *G. salicornia*, *A. spicifera*, and a combination of *G. salicornia*/*A. spicifera* ($r=0.338$, $P<0.05$; $r=0.323$, $P<0.05$; $r=0.344$, $P<0.05$ respectively).

Table 3. Pearson correlation for *L. reevii* based on various environmental parameters. All correlations were found to be statistically significant at a P-value of less than 0.05.

Parameter	Pearson Correlation (r)	P-value
L. reevii vs. Sand Depth	0.553	<0.05
L. reevii vs. Water Depth	0.632	<0.05
L. reevii vs. *G. salicornia*	0.338	<0.05
L. reevii vs. *A. spicifera*	0.323	<0.05
L. reevii vs. Combination	0.344	<0.05

A GIS habitat map was informed using the NOAA benthic habitat maps. This map can be used to predict potential habitat for *L. reevii*.

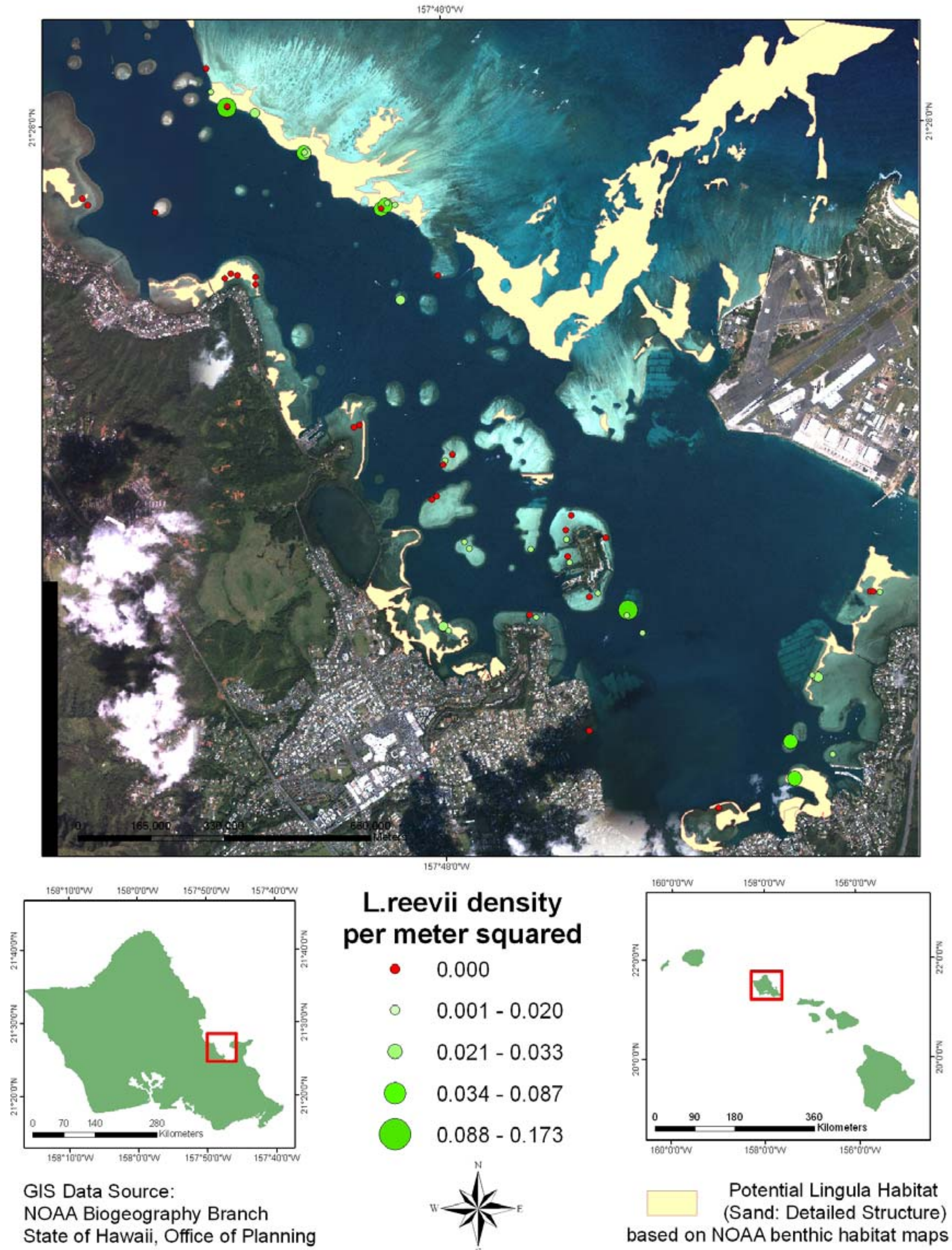

Figure 5. Map of potential *L. reevii* habitat in Kaneohe Bay showing spatial coverage of survey locations across the geographic extent of Kaneohe Bay.

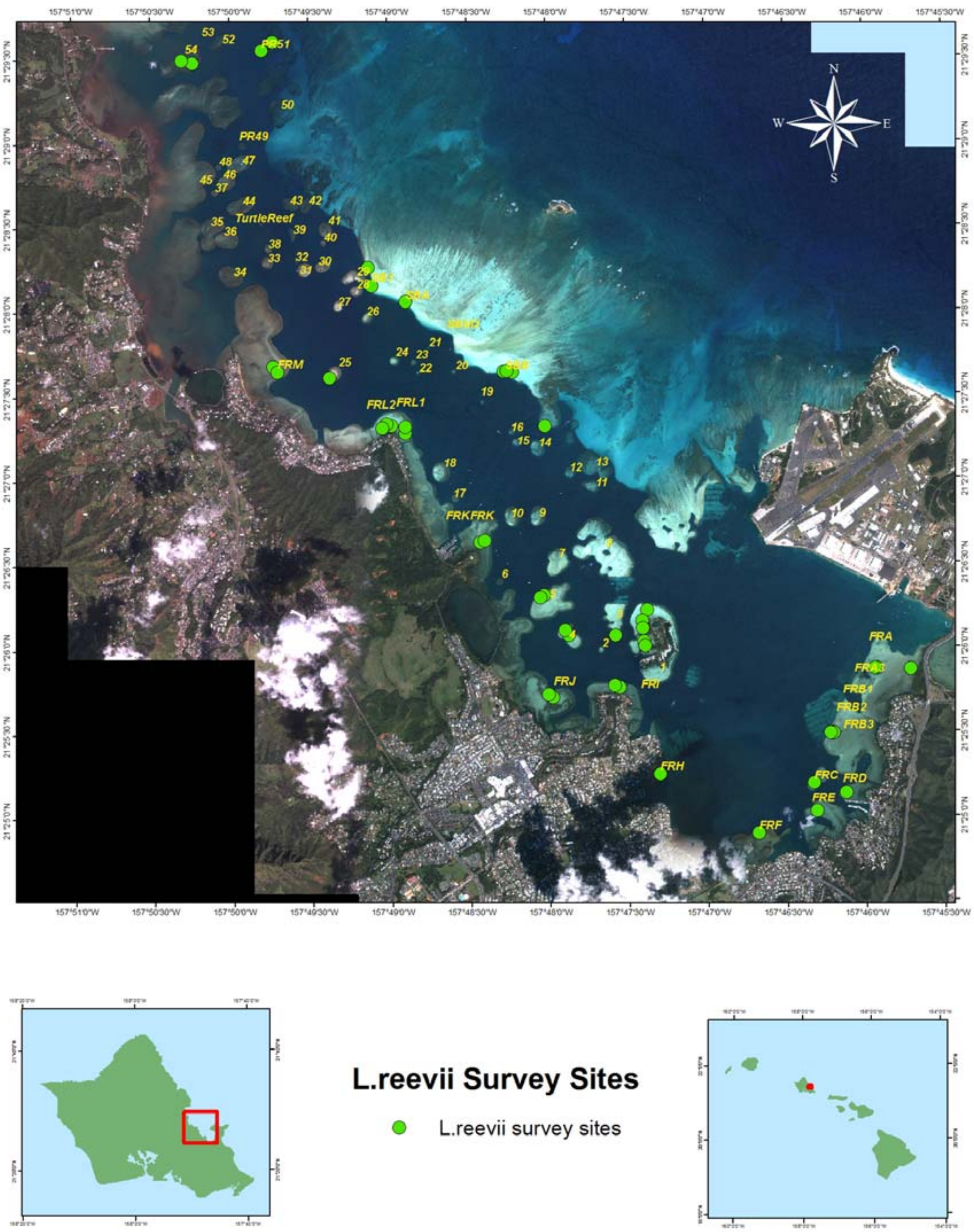

Figure 6. Spatial coverage of survey location in Kaneohe Bay, Oahu, Hawaii.

Maps were constructed based on abundance of *L. reevii*, survey area, and average percent algal cover per survey site.

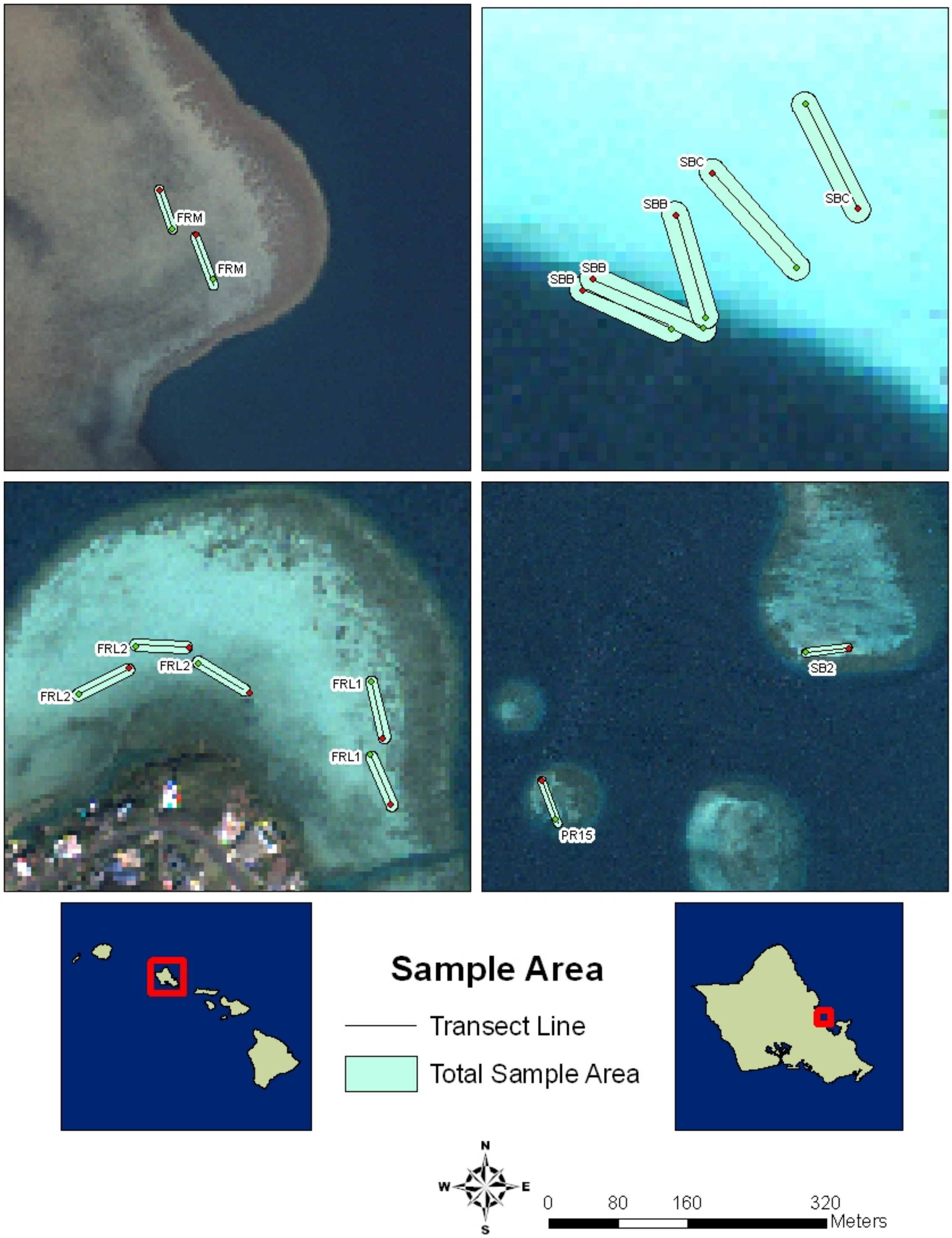

Figure 7. Survey area for North Kaneohe Bay. Each buffer includes the 150 m^2 survey area.

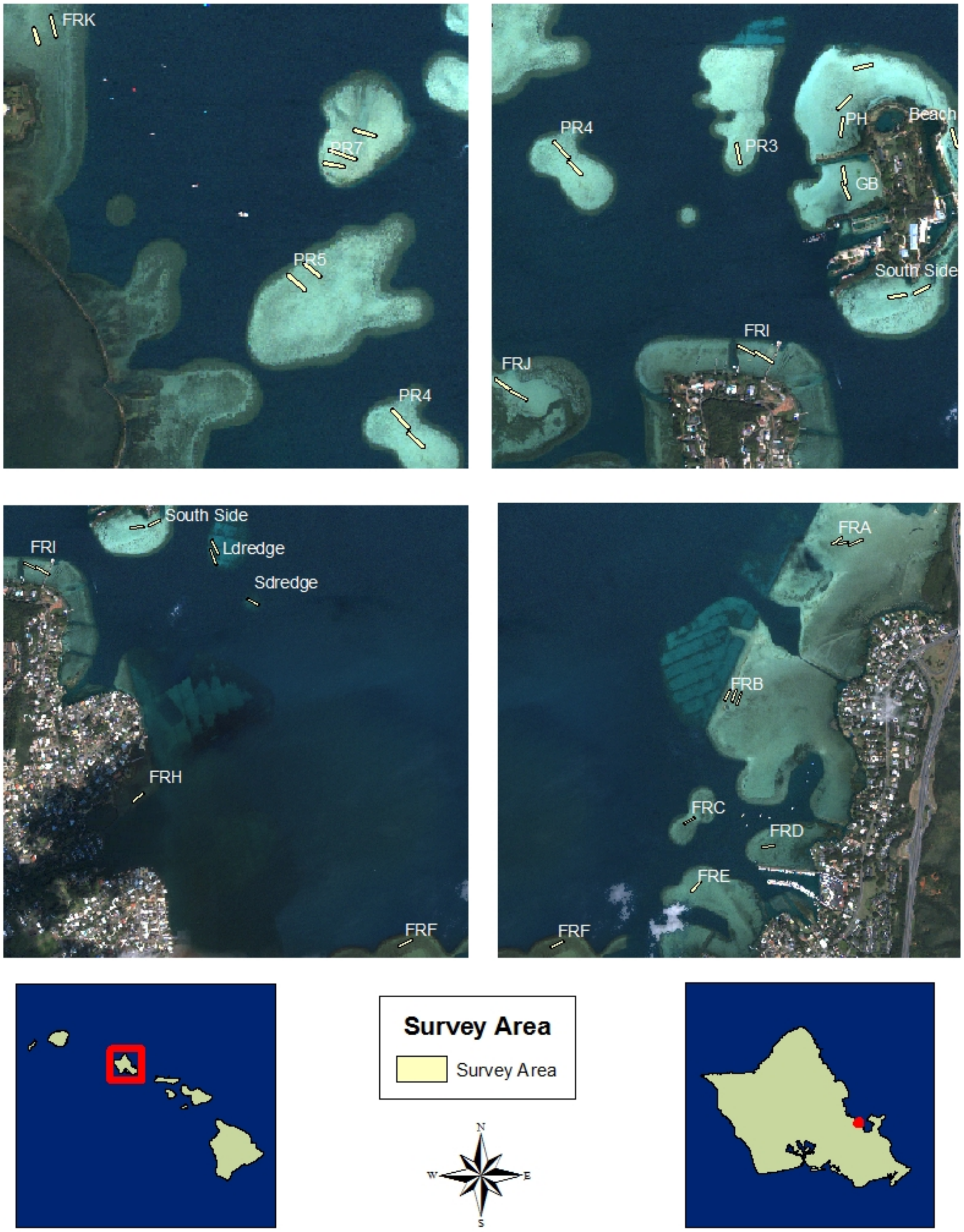

Figure 8. Survey area for South Kaneohe Bay. Each buffer includes the 150 m^2 survey area.

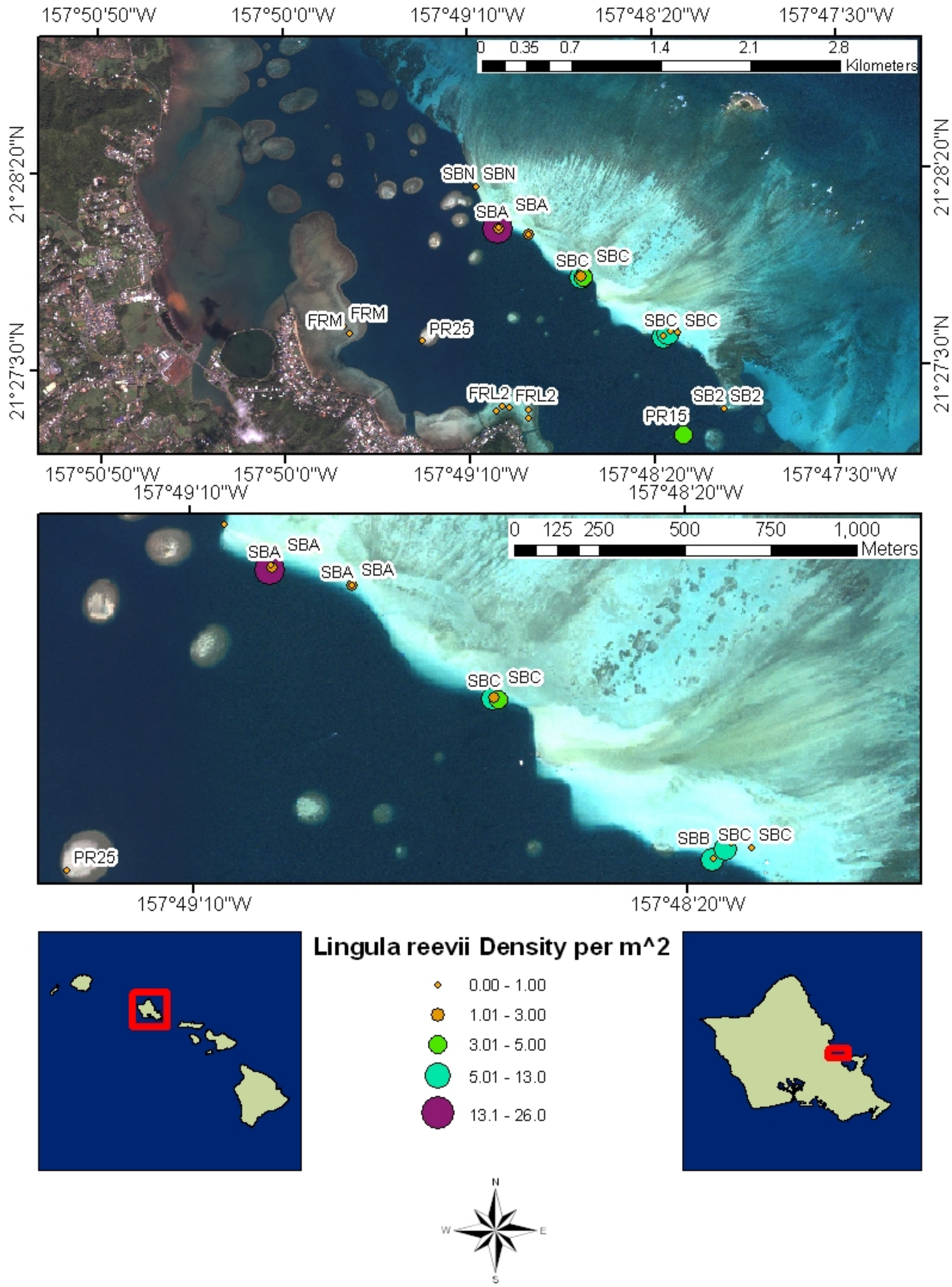

Figure 9. Abundance of *L. reevii* in North Kaneohe Bay.

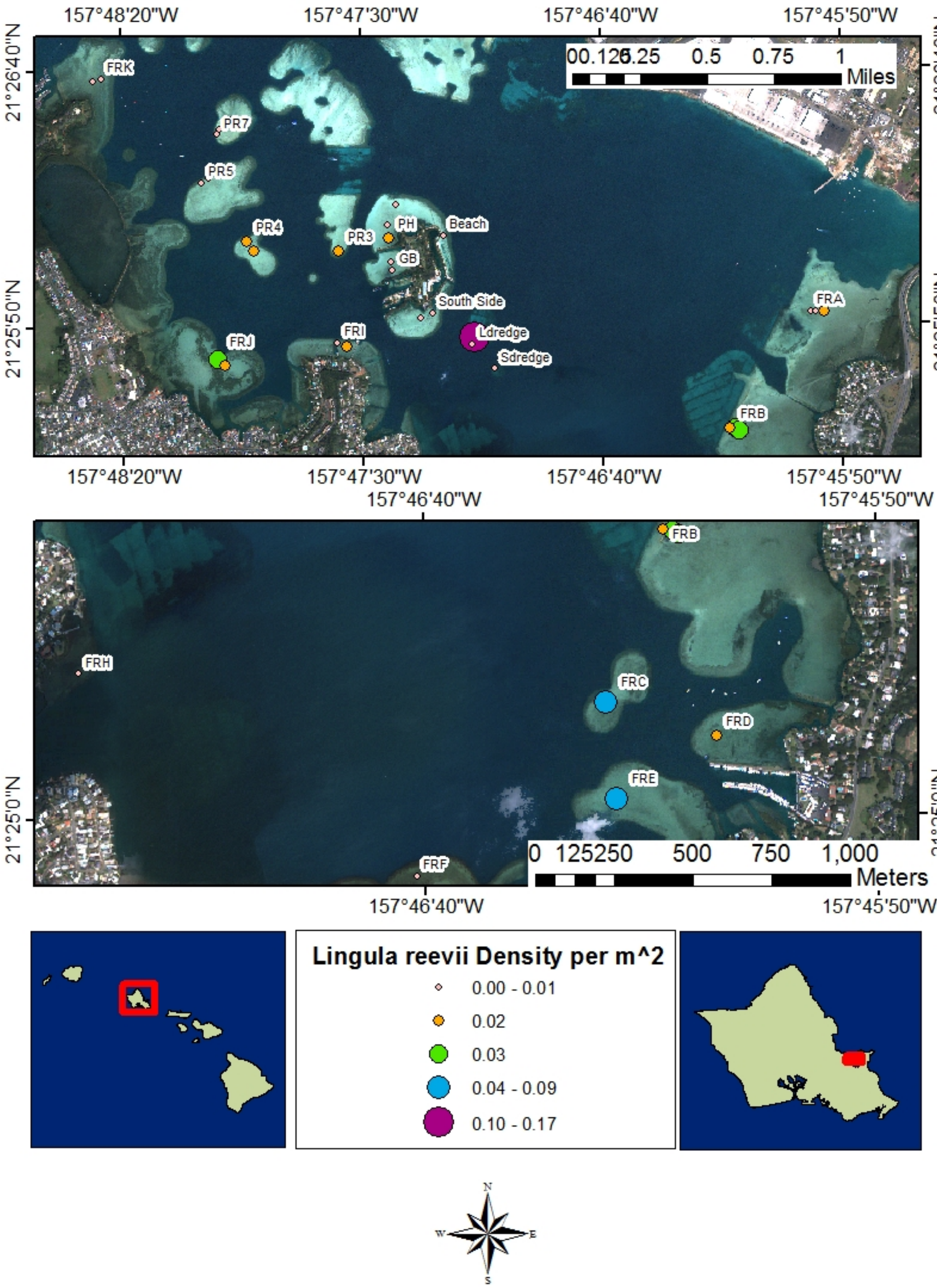

Figure 10. Abundance of *L. reevii* in South Kaneohe Bay.

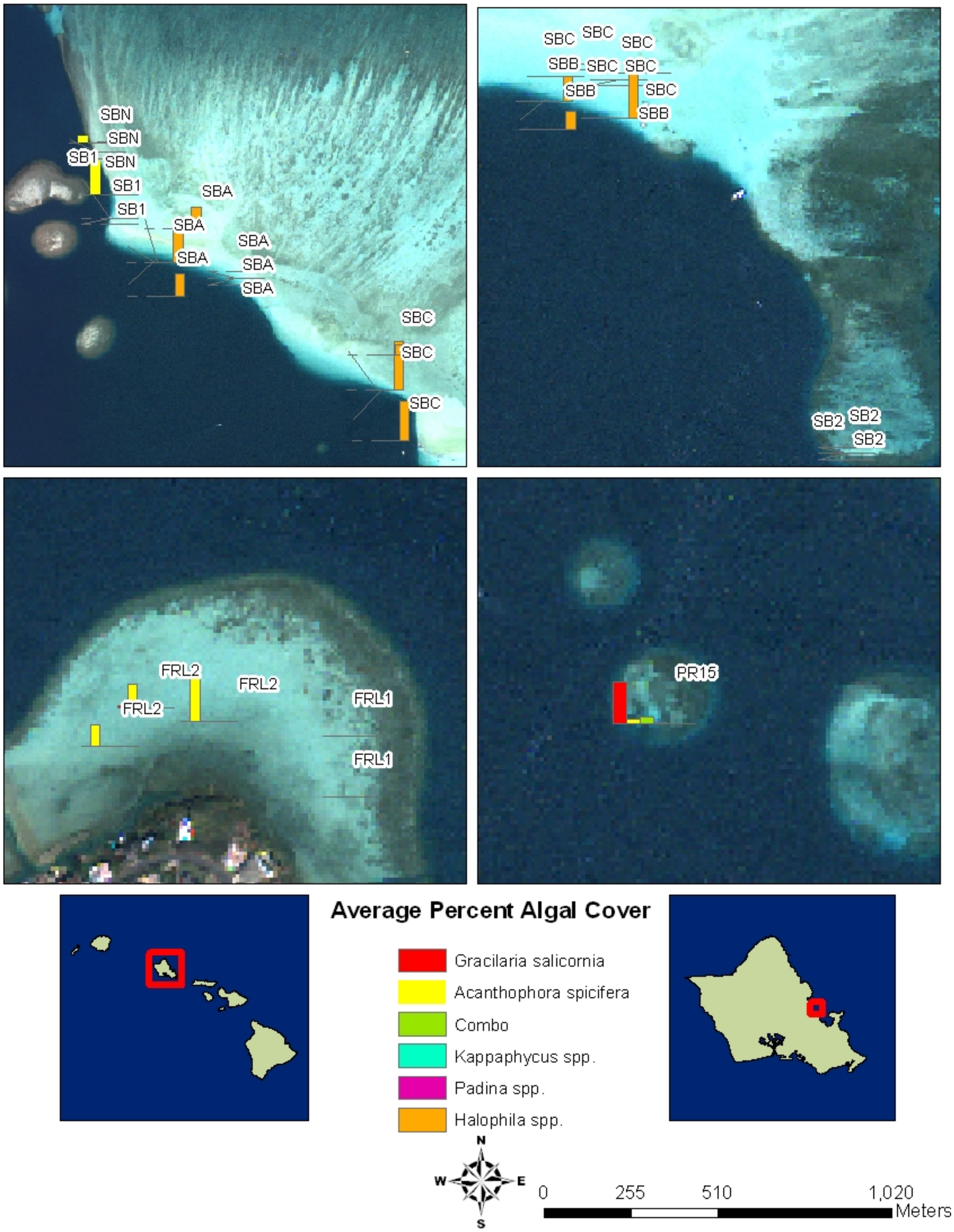

Figure 11. Average algal cover per species for each survey site in North Kaneohe Bay. "Combination" described an aggregation of *G. salicornia* and *A. spicifera*.

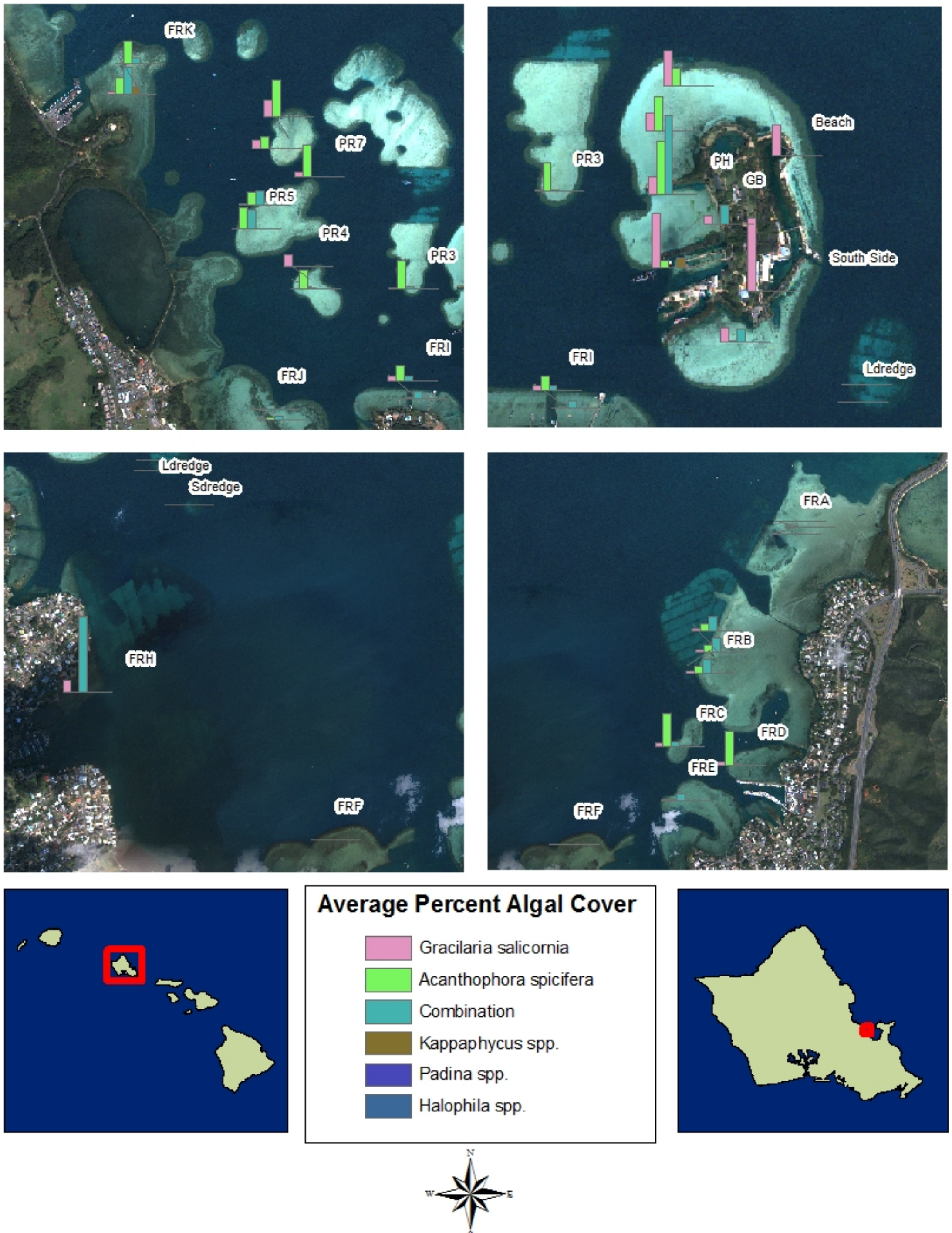

Figure 12. Average algal cover per species for each survey site in South Kaneohe Bay.

Discussion:

Lingula reevii maximum densities in Kaneohe Bay have been estimated in the past as 500 individuals/m^2 (Worcester 1969) and 100 individuals/m^2 (Emig 1981). Reported maximum densities declined to 4 individuals/m^2 in 2004, 0.94 individuals/m^2 in 2007, and 0.87 individuals/m^2 in 2008 (Hunter *et al*. 2007, 2009). The present study found a maximum density of 0.09 individuals/m^2 in 2009, an apparent decrease in abundance by an order of magnitude in one year. The past estimates cannot be directly compared due to differences in data collection techniques, e.g. quadrats, approximations, transects, free swim counts, and variable amounts of survey sites and total area surveyed. However, the overall data indicated that *L. reevii* population density continues to decline. Two additional sites outside of Kaneohe Bay (Kailua and Lanikai) were surveyed for potential *L. reevii* habitats, although no *L. reevii* were found.

This year's data collection technique consisted of visual surveys of 32 sites via quantitative transects which amounted to a total area of 10,200 m^2. Sites were chosen based on previously studied areas from records, as well as areas that appeared to have suitable *L. reevii* habitat. *Lingula reevii* are typically observed in reef flats of various sand/sediment types (Worcester 1969). The 2008 and 2009 surveys covered over three times the area of earlier studies. Although similar total areas were surveyed, the 2009 data consisted of significantly less *L. reevii* density compared to 2008.

Statistical analyses revealed significant positive correlations ($P<0.05$) for multiple parameters. *Lingula reevii* abundance was positively correlated with sediment depth and water depth. Greater sediment depths may allow a larger niche for *L. reevii* to burrow or occupy, and can also provide enough space for larger individuals to fully burrow and/or retract into the sand. Greater sand depths may allow *L. reevii* of various lengths to burrow or retract completely, thus preventing predation and potentially increasing abundance in areas with greater sand depth. Compared to shallow waters, greater water depths are able to resist large temperature fluctuations. Also, greater water depths have less wave action, keeping the sand bottom stable.

There was a significant positive correlation between percent cover of sand to the number of *L. reevii* present. More specifically, there was greater *L. reevii* abundance in fine sand (84 individuals) compared to silty, medium, and coarse (28, 30, and 24 individuals respectively). Fine sand may be easier for *L. reevii* to move vertically within the sand column and provide better conditions for filter feeding. Also, accumulation of fine sand in a specific location may be indicative of diminished wave action.

The abundance of *Gracilaria salicornia* and *Acanthophora spicifera* had a significant negative correlation ($P<0.05$) to the population density of *L. reevii*. In general, the presence of alien algae seems to have a negative effect on *L. reevii* abundance. These findings indicate that the rapid spread of alien algae over Kaneohe Bay (Rogers and Cox 1999; Conklin and Smith 2005) may be encroaching on *L. reevii* habitat and may be responsible for the decrease in population density over the past several years.

There are several possible explanations for this trend. Since *L. reevii* is sedentary, it retreats under the sand when startled by large organisms or overgrowing alien algae mats. The alien algae taking over the preferred habitats and obstructing water flow above the three siphonal openings could cause a decrease in average *L. reevii* density by preventing the *L. reevii* from filter feeding. Also, *L. reevii* fertilize externally, broadcasting their gametes into the water column (Hyman 1959). Mats of alien algae covering *L. reevii* may repress the release of gametes and therefore inhibit the fertilization process. The presence of invasive algae may also prevent settlement or recruitment of *L. reevii* larvae into the substrate. Although these alien algae species seemed to interfere with *L. reevii* habitat, not all marine plants affect *L. reevii* abundance. At the Sandbar sites, patchy distributions of *Halophila hawaiiensis* (native Hawaiian seagrass) were observed within areas of higher *L. reevii* abundance. *Lingula reevii* does not seem to be affected by the presence of *H. hawaiiensis*. The native seagrass on Oahu's reefs existed before the arrival of alien algae, providing the implication that *L. reevii* are able to survive better with *H. hawaiiensis* than with invasive and alien algae.

SCUBA was utilized to survey sites at difficult depths to survey using snorkeling equipment alone. Deeper depths were explored at sites Sandbar A, B, and C, Small Dredge reef, and Large Dredge reef. *Lingula reevii* were found up to depths of 7m, which gives future studies incentive to investigate other areas where there may be sandy slopes or deeper sand patches. Documenting these suitable habitats at greater depths adds to the recorded habitat range of *L. reevii* throughout Kaneohe Bay.

Sandbar A and B, Fringing reefs C and E, and Large Dredge reef exhibited higher *L. reevii* abundances (approximately 0.05 individuals/m^2) than other survey sites. Sandbar A and B exhibited greater abundances than most sites, perhaps due to greater sand depth, water depth, and the dominant sand type. The difference in *L. reevii* abundance between Sandbar A and B may have occurred due to different sand types. Sandbar A possessed fine sand, whereas Sandbar B possessed medium sand. The Large Dredge reef exhibited the greatest *L. reevii* abundance of 0.09 individuals/m^2, and Fringing reefs C and E both showed *L. reevii* abundance of 0.53 individuals/m^2. While the Large Dredge reef had habitat that is typically considered favorable for *L. reevii* (water depth and fine sand), compared to other sites with greater *L. reevii* abundance, the sand depth was less suitable. Fringing reefs C and E with similar sand and water depths had the same *L. reevii* density, even though the sediment types differed. Theoretically, Fringing reef E (fine sand) should possess a higher *L. reevii* abundance than Fringing reef C (silty sand) due to different sediment types. These may have resulted from other factors that have not been assessed in this study (e.g., geographic locations, food availability, temperature, and wave action). Further research is therefore required to determine which factors influence *L. reevii* distribution and abundance.

In future surveys, researchers should focus on sites Sandbar A and B, Fringing reef C and E, and Large Dredge reef to monitor *L. reevii* abundances in Kaneohe Bay. Also, future studies should explore deeper depths at these and other sites to determine whether *L. reevii* occur at these locations.

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