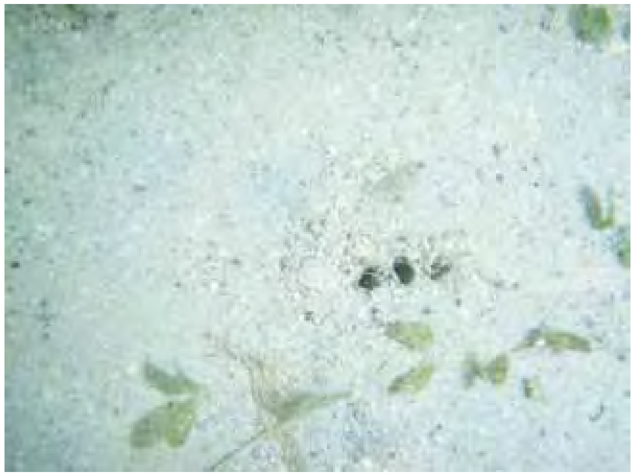
Distribution Analysis of *Lingula reevii* Abundance Throughout Kaneohe Bay, Oahu, Hawaii (2010)



Unique siphon openings formed by **Lingula reevii** ***burrows*.**

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Abstract

The inarticulated brachiopod, *Lingula reevii,* is listed as a National Oceanic and Atmospheric Association (NOAA) National Marine Fisheries Service (NMFS) Species of Concern (SOC). In the late 1960s, estimates of the *L. reevii* population within Kaneohe Bay on the Island of Oahu, Hawaii were as high as 500 individuals/m^2 in the southern areas of the bay (Worcester 1969). Successive surveys of the bay revealed declining population size of *L. reevii* with the lowest observed maximum density recorded in 2009 (0.09 individuals/m^2.) Despite past trends, the current study (July, 2010) found a larger *L. reevii* maximum density of 2.93 individuals/m^2. Although previous surveys have attributed the population decline to high levels of invasive algae cover, this study found no significant relationships between macroalgal cover and the densities of this species. It may be that macroalgae declined in the areas examined from 2009-2010, resulting in this finding. Other environmental parameters (temperature, water depth, sediment depth, salinity, and seagrass cover) were quantified and compared to the current densities of *L. reevii* in Kaneohe Bay; none showed significant relationships.

Introduction

Lingula reevii, a filter-feeding inarticulated brachiopod, is known to burrow in subtidal or lower intertidal reef flats with sandy or mixed sediments (Emig 1978; Hunter *et al*. 2008). *Lingula reevii* has been reported 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* was designated as a SOC by NOAA's NMFS in 2004 due to a decrease in density that has been observed in recent decades in Kaneohe Bay, Oahu, Hawaii (Hunter *et al*. 2008). NMFS uses the SOC list to identify species potentially at risk of further population decline. With this information, research efforts have been stimulated to identify data deficiencies to evaluate species' threats in order to prevent an Endangered Species Act (ESA) listing of threatened or endangered levels (US Federal Register 2004).

The density and distribution of *L. reevii* were first surveyed in Kaneohe Bay more than 40 years ago (Worcester 1969). According to data from multiple studies, a decrease in *L. reevii* density has occurred since the 1970s. Rapid population decline may be attributed to the reduction of available nutrients after sewage effluent was diverted from the south end of Kaneohe Bay in 1978-1979 (Worcester 1969; Emig 1978, 1981). Worcester (1969) noted *L. reevii* densities as high as 500 individuals/m^2, while Emig (1981) reported maximum densities of 100 individuals/m^2. Recent studies found maximum densities of 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, 2008, 2009), and 0.09 individuals/m^2 in 2009 (citation needed).

Factors contributing to reduced *L. reevii* densities may not solely be limited to the reduction of water column nutrients after sewage diversion. Past studies hypothesized a reduction of suitable habitat for *L. reevii* as a result of alien and invasive algal overgrowth by *Gracilaria salicornia*, *Acanthophora spicifera*, and *Kappaphycus/Eucheuma* spp. (Rodgers and Cox 1999; Woo 2000; Smith *et al*. 2002, 2004).

The objectives of this study were to compare abiotic habitat characteristics and percent algal cover to explore causal factors that may relate to observed *L. reevii* densities in Kaneohe Bay.

Materials and Methods:

Between July 17-31, 2010, surveys were conducted by University of Hawaii-Manoa Biology 403 students in selected areas of Kaneohe Bay for the purpose of assessing the population abundance, distribution, size class, and habitat of *Lingula reevii*. Sites were chosen based on highest abundance of *L. reevii* in the past two years. Sixty-eight transects were surveyed at 23 sites (Figure 1, Tables 1 and 2). Snorkel surveys were conducted on fringing reefs (FR) in the south bay and along the 1 m isobath at the Sand Bar (SB) at the middle section of the bay. Diving surveys were conducted at the Dredged Reef in the south bay, and the 3 m, 5 m and

7 m isobaths along the Sand Bar. Presence/Absence surveys were conducted at Goby Bay (GB), Fringing Reef L1 (FRL1), Fringing Reef L2 (FRL2) and Fringing Reef M (FRM).

Belt transect surveys were conducted on shallow fringing reefs in South Kaneohe Bay (n=36) and the Sandbar (n=3) by teams of three snorkelers each (Figure 1). At each site the central snorkeler slowly deployed a 50 m transect tape while accompanied by teammates on either side. Along the 50 m transect each team member scanned adjacent 1 m swaths while the tape was deployed. Team members recorded the abundance of "large" and "small" *L. reevii* within the 150 m^2 area (3m x 50m.) These size classes were based on the relative width of burrows, which are characterized by three consecutive siphon holes in the sediment (cover page photo). After *L. reevii* burrow counts, team members then recorded the water depth at the 0 m and 50 m marks of each transect. Sediment depth was assessed at the 0 m, 25 m, and 50 m marks of each transect by pushing a straight steel wire (2 mm diameter) into the sediment until it encountered hard substrate; the inserted length was measured against the transect tape. At the 25 m mark on each transect water temperature was recorded at the sediment surface; samples of water (for salinity) and sediment were also collected for later analysis. Sediment samples were collected by pushing a cylindrical specimen jar (h= 8 cm, d= 6 cm) into the sediment, then quickly recapping it. Water samples were collected by opening an empty 50 mL falcon tube under water near the sediment surface and quickly recapping it. Latitude and longitude were recorded at the 0 m and 50 m marks using a Garmin Geko model 201 GPS unit housed inside a water-tight carrying bag. In addition, macroalgal and seagrass abundances were estimated within 0.5 m x 0.5 m quadrats placed at 14 randomly determined points along the transect.

Deeper water sites at the Sandbar (n=27) and Large Dredged Reef (n=2) were surveyed on July 26 and 27, 2010, using SCUBA. These surveys were conducted slightly differently to accommodate the bottom topography at these sites. Three teams of two SCUBA divers were deployed at 3m, 5m, or 7m isobaths along the slope of the Sandbar at sites SBA, SBB, and SBC (Figure 7). At each site, teams completed three 50 m belt transect surveys set end-to-end along their assigned isobaths. During each survey one diver deployed the transect tape and simultaneously counted the numbers of “large” and “small” *L. reevii* within a 1 m x 50 m swath. The second diver followed behind and recorded water depth, sediment depth, temperature, algal cover and sediment and water samples at meter marks identical to the snorkel transects. A snorkeler positioned above the divers at the 0 m and 50 m marks of each transect recorded latitude and longitude.

At the Large Dredged Reef in south Kaneohe Bay (Figure 6) SCUBA divers assembled into two teams of three divers. Each team surveyed a 100 m^2 (2 m x 50 m) belt transect within sandy stretches of the reef at approximately 3 m depth. At this site one additional diver was present alongside the diver deploying the transect tape while the third diver followed, collecting data in the same fashion as at the Sandbar.

In addition to the 68 belt transect surveys, a team of three snorkelers conducted 15-minute presence/absence surveys at FR L, FR M, and PR 3. During these surveys, snorkelers simply recorded whether or not *L. reevii* was present at each of these locations.

Results:

Numbers of *Lingula reevii* found within single survey transects conducted in July, 2010, ranged from 6-670 individuals (Table 1). The highest density of *L. reevii* per quadrat was found at FR A-b (2.93 individuals/m^2) (Table 1, Figures 2 and 3). FR A-b also had the highest average *L. reevii* density per transect (1.49 individuals/m^2). The distribution of *L. reevii* was patchy in the adjacent sites (FR A-a and FR A-c) and had maximum densities of 0.29 individuals/m^2 and 1.07

m^2 slightly south of these sites (FR A-d). The lowest average density of *L. reevii* was found at FR E (0.02 individuals/ m^2). *L. reevii* was present (Table 3) although in low numbers (<5 found in 15' surveys) at FR L1, FR L2 and Goby Bay (Coconut Island).

For the first time since the current series of surveys was initiated in 2004, an abundance of small burrows was noted in the summer of 2010, suggesting a recent recruitment event. Small individuals predominated at the 1 m, 3 m, and 7 m isobaths at the Sand Bar, while the 5 m isobath had predominantly large individuals (Figure 4). Fringing reefs in the south end of the bay showed patchy distributions of small and large *L. reevii* among sites (Figure 5).

Densities of *L. reevii* were compared to several environmental site parameters in order to determine which factor(s) might be closely related to their abundance in Kaneohe Bay (Table 1, Figures 6-14). Pearson correlation analyses found no statistically significant correlations between *L. reevii* density and any of the environmental parameters tested (Table 2). However, there may be a more complex relationship between sediment depth (cm) and *L. reevii* density (Figure 14); further analysis is required in order to better understand this relationship.

Discussion

From a maximum recorded density of over 500 individuals/m^2 in 1969 to a recorded low of 0.09 individuals/m^2 in 2009 (Table 4), *Lingula reevii* density has decreased by about 99.9% over the past 40 years. In this study, however, *L. reevii* density was found to have "changed course", increasing by about 33% over 2009 estimates, with a maximum average density of 2.93 individuals/m^2. As in other recent surveys, abundance was extremely patchy, making it difficult to extrapolate to a estimate of overall bay-wide abundance. Although past estimates of *L. reevii* density cannot be directly compared due to varying survey techniques, results of this study signify the first recorded increase in maximum *L. reevii* density at any site in Kaneohe Bay.

No linear relationships were identified through correlation and regression analyses with salinity, sand depth, temperature, water depth, sediment composition, or algal cover versus *L. reevii* density. At FR A-b, the site with the highest average and maximum density of *L. reevii* in 2010, average sediment depth was 10.76 cm, average water depth was 0.83 m, and average salinity was 33.5 ppt (Table 1). In 2009 surveys, the Large Dredged Reef harbored the highest *L. reevii* abundance (0.09 individals/m^2) (Hunter *et al.* 2010). Sediment depth at FR A-3 in 2010 was deeper, and water depth was much shallower than at the Large Dredge Reef in 2009 (Hunter *et. al*. 2010). Deeper sediment may provide a more suitable habitat by allowing *L. reevii* to burrow further into the sand to evade predation.

Alien algal overgrowth in Kaneohe Bay (Rodgers and Cox 1999; Woo 2000; Smith *et al.* 2002, 2004; NOAA 2007) was thought to reduce the suitable habitat for *L. reevii*. A significant negative relationship was found between the invasive alien algae, *Gracilaria salicornia* and *Acanthophora spicifera*, and *L. reevii* density in 2009 surveys (Pearson Correlations of $r = -0.338$ and $r=0.323$, respectively; $p<0.05$). However, this study found no significant relationship between *L. reevii* density and overall algal cover ($r=-0.00258$, $p=0.569$). The percent cover of the native seagrass, *Halophila hawaiiana*, did not have a significant effect on *L. reevii* density ($p=0.254$).

From the early 1900s to the late 1970s high levels of sewage being released into the bay facilitated blooms of a then-dominant alga, *Dictyosphaeria cavernosa,* which was recorded to have covered entire reef faces (Maragos *et al.* 1985; Stimson *et al.* 2000). This native alga, however, was recorded to grow on hard substrata and over corals (Huisman *et al.* 2007), unlike sandy reef flats where *L. reevii* exhibited highest abundance in this study. *Dictyosphaeria cavernosa* appeared to be in highest abundance during the period of greatest *L. reevii* abundance

(Worcester 1969; Stimson and Conklin 2008). Filling different niches, *D. cavernosa* and *L. reevii* hold ecological positions in which neither organism competes for habitat with the other. Since *D. cavernosa* does not compete with *L. reevii* for habitat, invasive algae could have capitalized on the lack of algal competition on the sandy reef flat and, in effect, came to out-compete *L. reevii* (Hunter *et al.* 2008). To be noted, transects often missed incorporating large mats of *G. salicornia* and *A. spicifera*, among other native and alien algae, within the random 0.25 m^2 quadrats used for assessing algal cover. Had those large mats of algae, some of which covered greater than 0.25 m^2, been included, the affect of invasive algae upon *L. reevii* density through correlation and regression statistical tests may have illustrated a significant negative relationship between *L. reevii* density and algal cover, mirroring findings of a similar study in 2009 (Hunter *et al* 2010).

In future research, correlations should be examined between *L. reevii* abundance and reef locations that are exposed through parts of the year to open air during extremely low tides. Fringing reefs in the south bay experience periods of such low tides that sections surveyed and found to have the most *L. reevii* are occasionally exposed to the air. The distribution of hydrogen sulfide layers would be a helpful tool in determining if these areas exposed to air have a deeper anoxic layer than sites not exposed.

In future studies, a focus should be on sites of high invasive algae abundance and high native algae abundance in consideration of whether *L. reevii* display significant relationships with each algal group. Also, dissolved oxygen levels should be analyzed to determine whether there is a relationship to *L. reevii* abundance. Further exploration of the fringing reefs and the dredged reefs would be helpful in quantifying *L. reevii* densities within various isobaths and varying percent algal cover, as the Sandbar slope is made up of ideal fine sediment for *L. reevii*, without the interference of fringing coral heads.

Possible factors to consider in the future that may affect *L. reevii* abundance and density might also be land-based chemical pollution (e.g. run-off from adjacent paved surfaces, jet fuel exhaust) and water current patterns throughout the bay. As *L. reevii* rely on broadcast spawning for reproduction, water currents should be mapped in order to determine if *L. reevii* abundance is higher in places where water currents converge. This analysis may provide a possible explanation as to why presence and abundance have shifted over time and should be pursued in future studies.

Conclusions

Maximum *Lingula reevii* densities have increased for the first time since 2004. No environmental parameters were found to be related to this surprising result. Future research may benefit from surveying more and larger areas that include a wider range of environmental parameters. Surveying more areas, such as mid and northern areas of the bay might better determine the range of habitats that this species can occupy (Figure 15). Also, a larger total survey area would increase the statistical accuracy of data. Natural biological systems are difficult to fully characterize, and there is the possibility that the design of this study simply lacked the detail required to fully understand the complicated interactions that take place in the wild. Future studies may find that cryptic factors (e.g. sediment pollutants, hydrogen sulfide layers), overlooked in past studies, are responsible for the trends observed in *L. reevii* population dynamics within Kaneohe Bay. On-going monitoring of *L. reevii* densities will continue to provide detailed information for future management strategies that will contribute to efforts for avoiding a potential regional species extinction of *L. reevii*. In addition, understanding reproductive periodicity and larval survivorship might lead to effective management options through artificial propagation of this species.

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Table 1: *Lingula reevii* abundance (per 450 m^2), density (per m^2), and environmental parameters at each survey site.

Site	Abundance	Average Density/m^2	Maximum Density/m^2	Average sand depth (cm)	Average water depth (m)	Salinity (ppt)
Fringing Reef A-a	65	0.14	0.29	6.77	1.11	35.50
Fringing Reef A-b	670	1.49	**2.93**	10.76	0.88	33.50
Fringing Reef A-c	54	0.12	0.29	6.20	0.75	34.00
Fringing Reef A-d	25	0.06	1.07	7.38	0.45	33.33
Fringing Reef A3	54	0.12	0.22	9.29	1.08	35.00
Fringing Reef B1	85	0.19	0.37	11.69	0.90	33.67
Fringing Reef B2	75	0.17	0.47	7.42	1.19	33.00
Fringing Reef B3	93	0.21	0.59	11.24	1.15	33.67
Fringing Reef C	44	0.10	0.13	7.97	1.03	33.00
Fringing Reef E	39	0.02	0.03	7.91	1.00	33.67
Sand Bar A (1m)	13	0.09	0.09	21.00	0.94	34.00
Sand Bar A (3m)	77	0.51	0.64	no data	3.00	34.00
Sand Bar A (5m)	18	0.12	0.24	>40.00	5.00	34.33
Sand Bar A (7m)	85	0.57	0.76	19.19	7.00	33.33
Sand Bar B (1m)	23	0.15	0.15	21.33	1.03	33.50
Sand Bar B (3m)	74	0.49	0.60	11.67	3.00	33.00
Sand Bar B (5m)	56	0.37	0.40	>40.00	5.00	33.67
Sand Bar B (7m)	48	0.32	0.44	18.44	7.00	34.33
Sand Bar C (1m)	6	0.40	0.40	20.00	1.40	34.30
Sand Bar C (3m)	54	0.36	0.62	10.00	3.00	34.33
Sand Bar C (5m)	14	0.09	0.14	>40.00	5.00	35.00
Sand Bar C (7m)	47	0.31	0.60	18.61	7.00	33.67
Dredged Reef	83	0.42	0.66	10.33	3.00	34.50
Total	2173					
Average Density	0.32		Total area surveyed=	10,200 m^2		

Table 2: Pearson correlation analyses conducted between *L. reevii* density (per m^2) and environmental parameters at each survey site.

Parameter	Pearson Correlation (r)	P-value
Algal Cover	-0.00258	0.569585
Water Depth	0.006931	0.774965
Sediment Depth	-0.00213	0.681859
Salinity	-0.05779	0.337551
Halophila spp.	-0.00531	0.254171

Table 3: Presence/Absence surveys were conducted at Fringing Reef M, L1, L2 and Goby Bay.

Site	Present vs. Absent
Fringing Reef L1	Present
Fringing Reef L2	Present
Fringing Reef M	Absent
Goby Bay	Present

Table 4: Historical comparisons between *Lingula reevii* density studies in Kaneohe Bay, Oahu, Hawaii.

Number of sites	Author	Year	Maximum Density / m²	Total Area* (m²)
2	Worchester	1969	500	N/A
-	Emig	1981	100	N/A
20	UHM	2004	4.00	2950
17	UHM	2007	0.94	2420
26	UHM	2008	0.87	11600
32	UHM	2009	0.09	10200
23	UHM	2010	2.93	10200

- Computed differently in each study

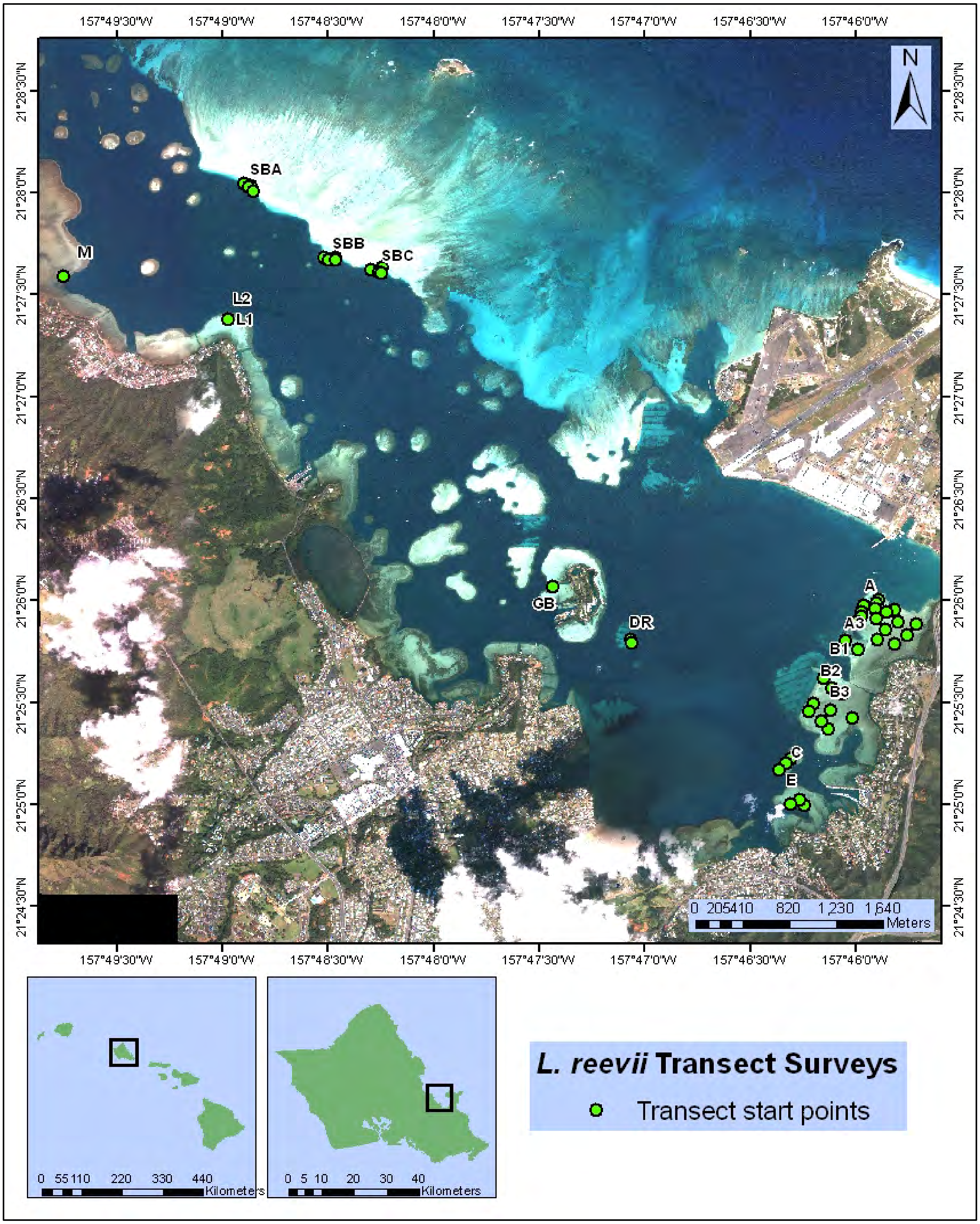

Figure 1: Locations of sixty-eight transects surveyed at 23 sites in Kaneohe Bay for *L. reevii* in July, 2010.

Figure 2: *L. reevii* density (per m²) for the surveys conducted at the south end of Kaneohe Bay, Oahu, Hawaii.

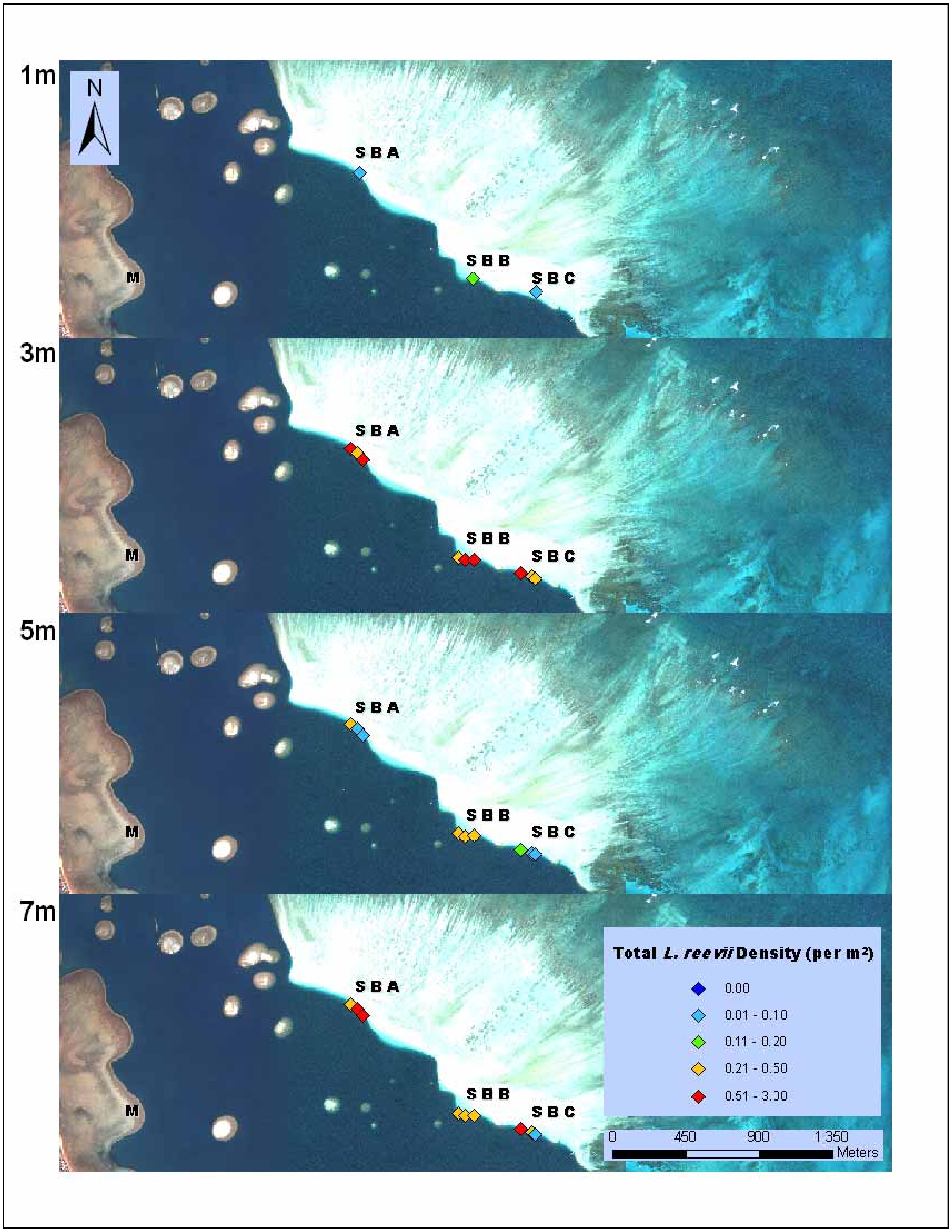

Figure 3: *L. reevii* density (per m²) for the surveys conducted at three sites along the Sand Bar (SBA, SBB and SBC) at the middle section of Kaneohe Bay, Oahu, Hawaii. Three surveys were conducted at the 3 m isobath, the 5 m isobath and the 7 m isobath.

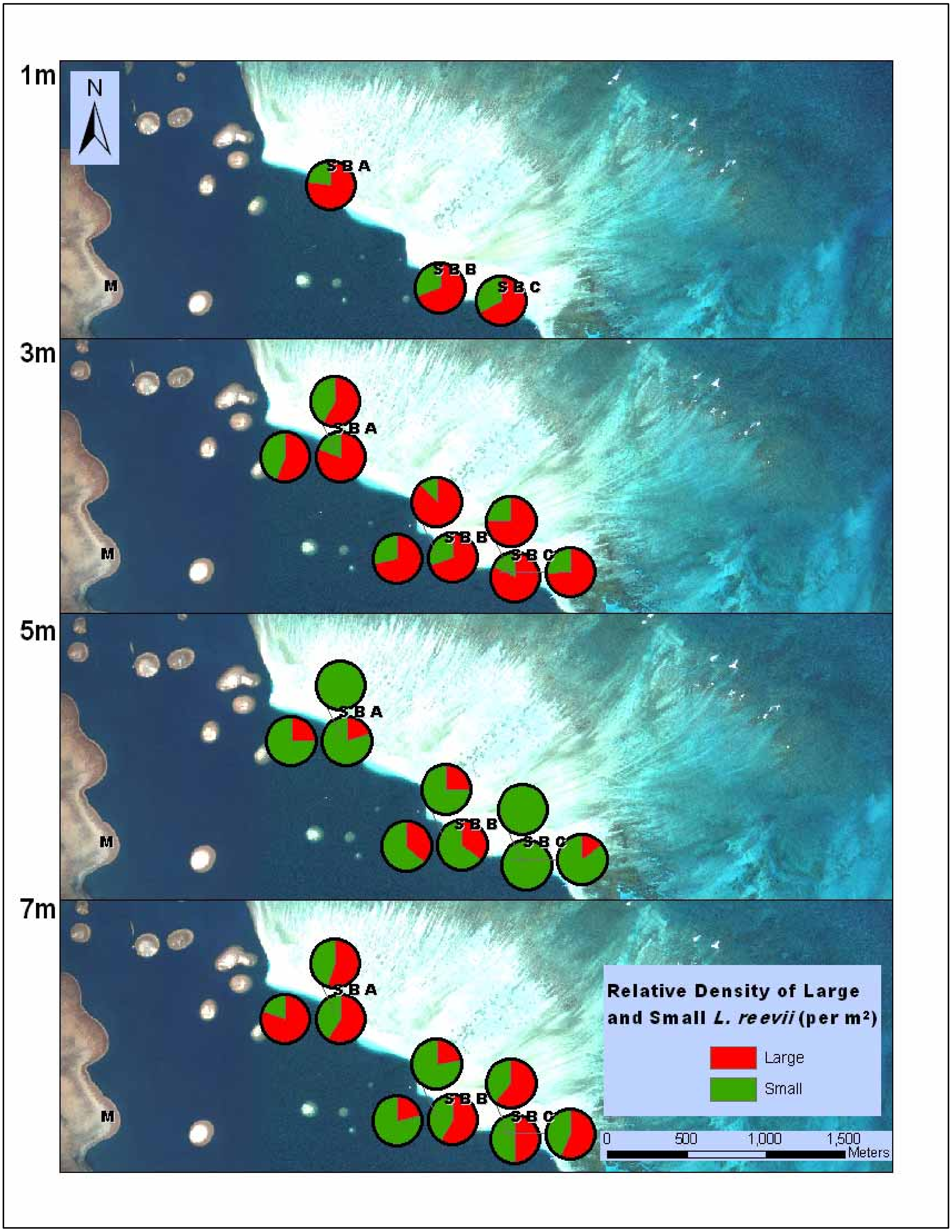

Figure 4: Densities (per m²) of 'large' versus 'small' *L. reevii* at the Sand Bar in Kaneohe Bay, Oahu, Hawaii.

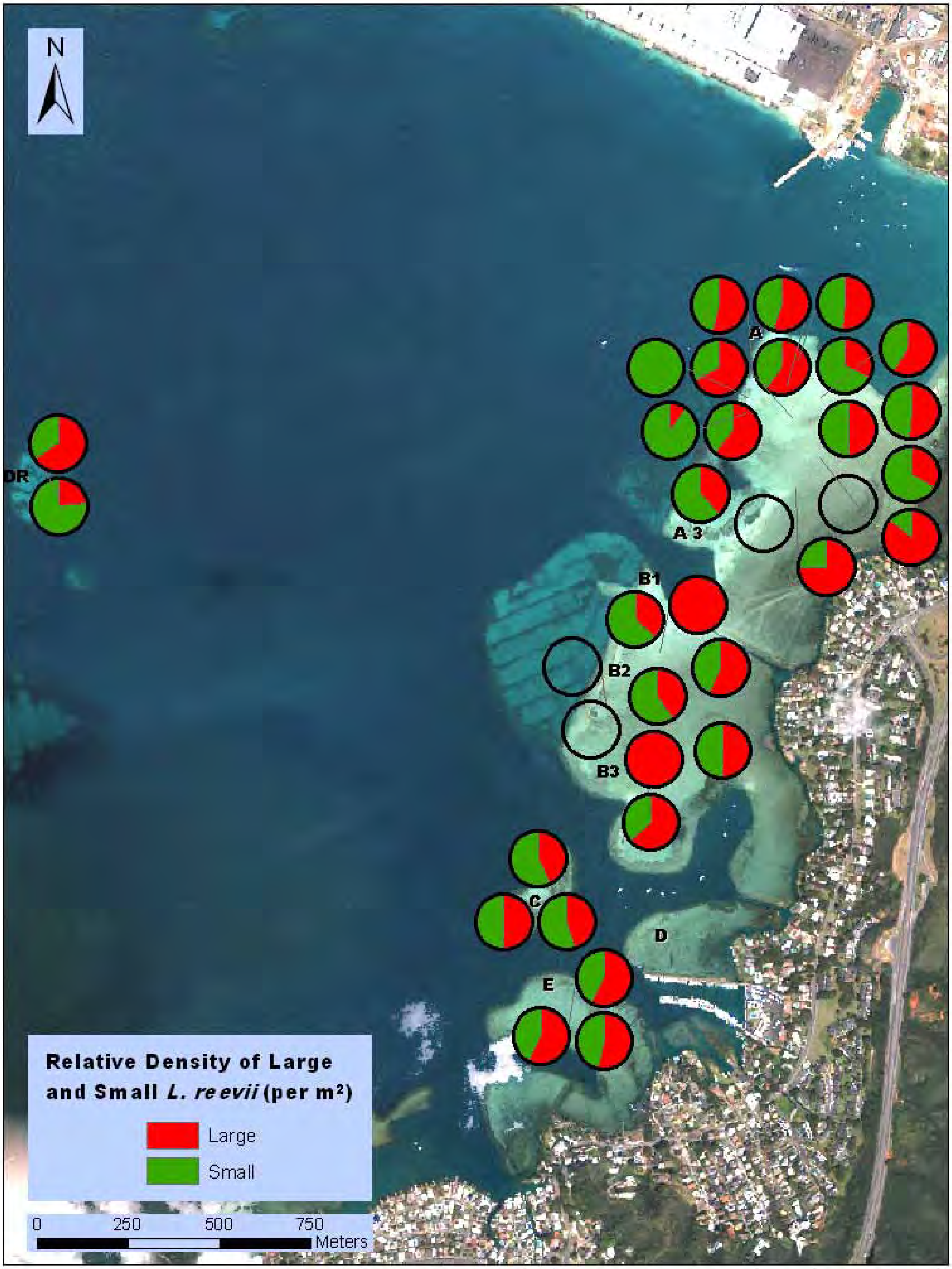

Figure 5: Densities (per m²) of 'large' versus 'small' *L. reevii* at the south end of Kaneohe Bay, Oahu, Hawaii. Colorless circles indicate transects where no *L. reevii* were observed.

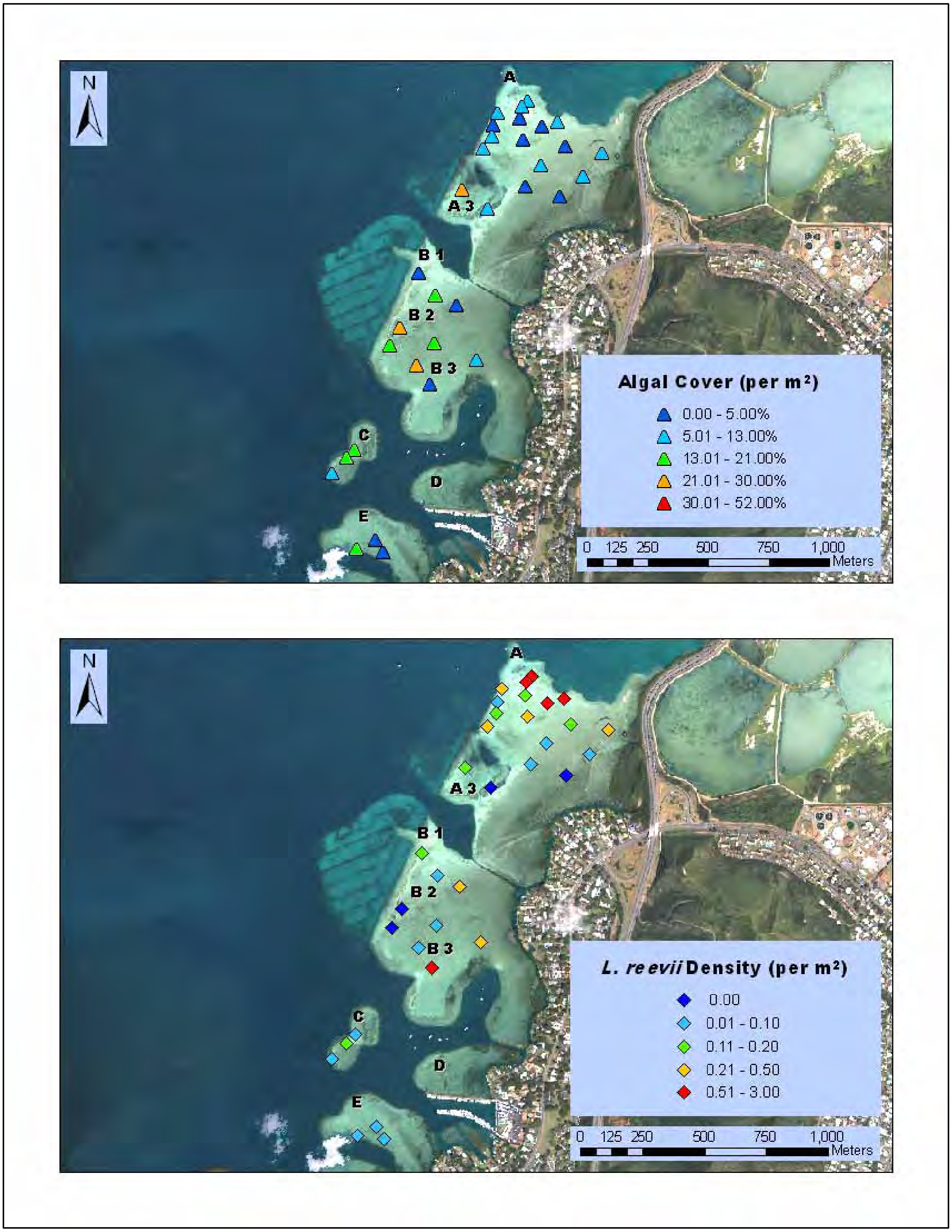

Figure 6: Average percent algal cover and *L.* reevii density (per m²) at the south end of Kaneohe Bay, Oahu, Hawaii.

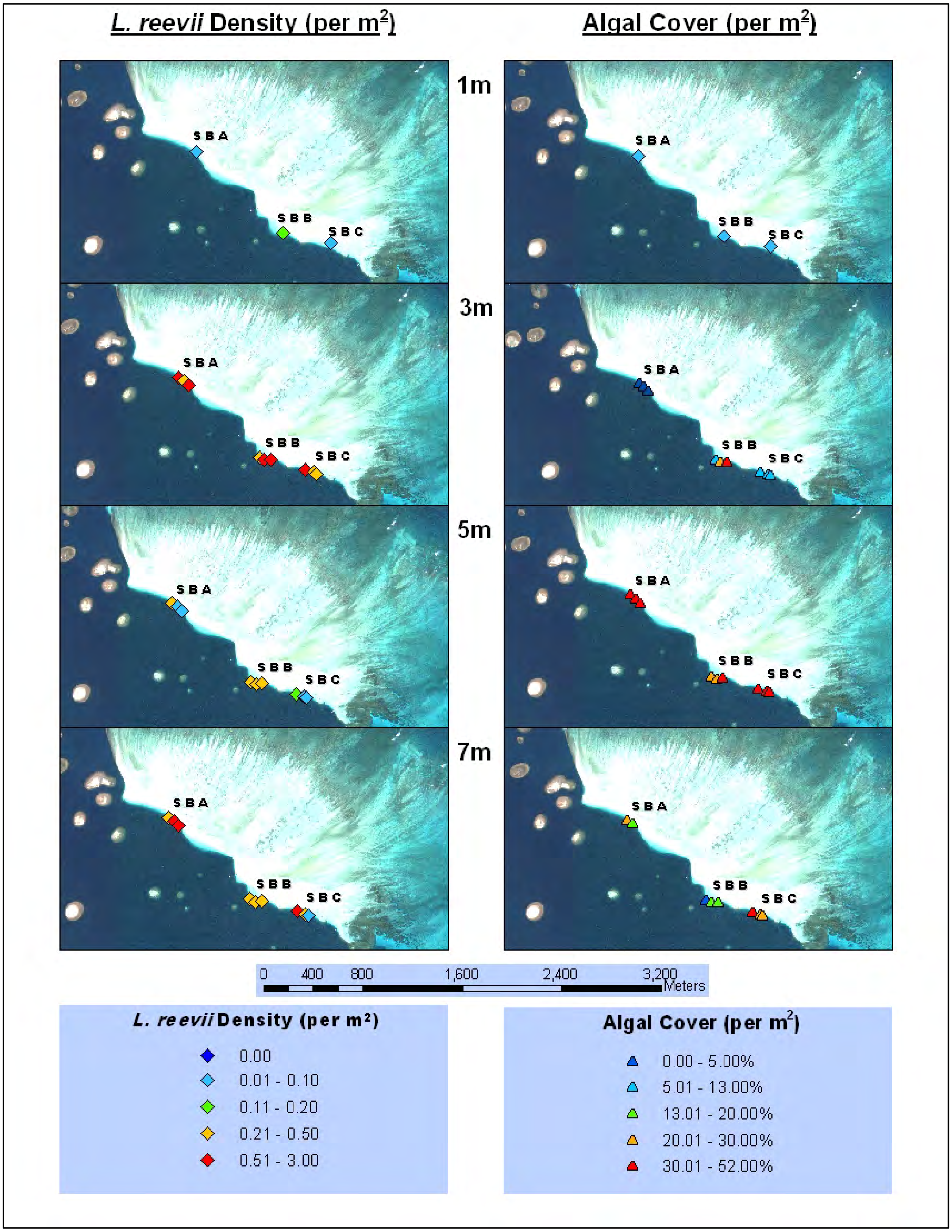

Figure 7: Average percent algal cover and *L. reevii* density (per m²) at the Sand Bar (SB) in Kaneohe Bay, Oahu, Hawaii.

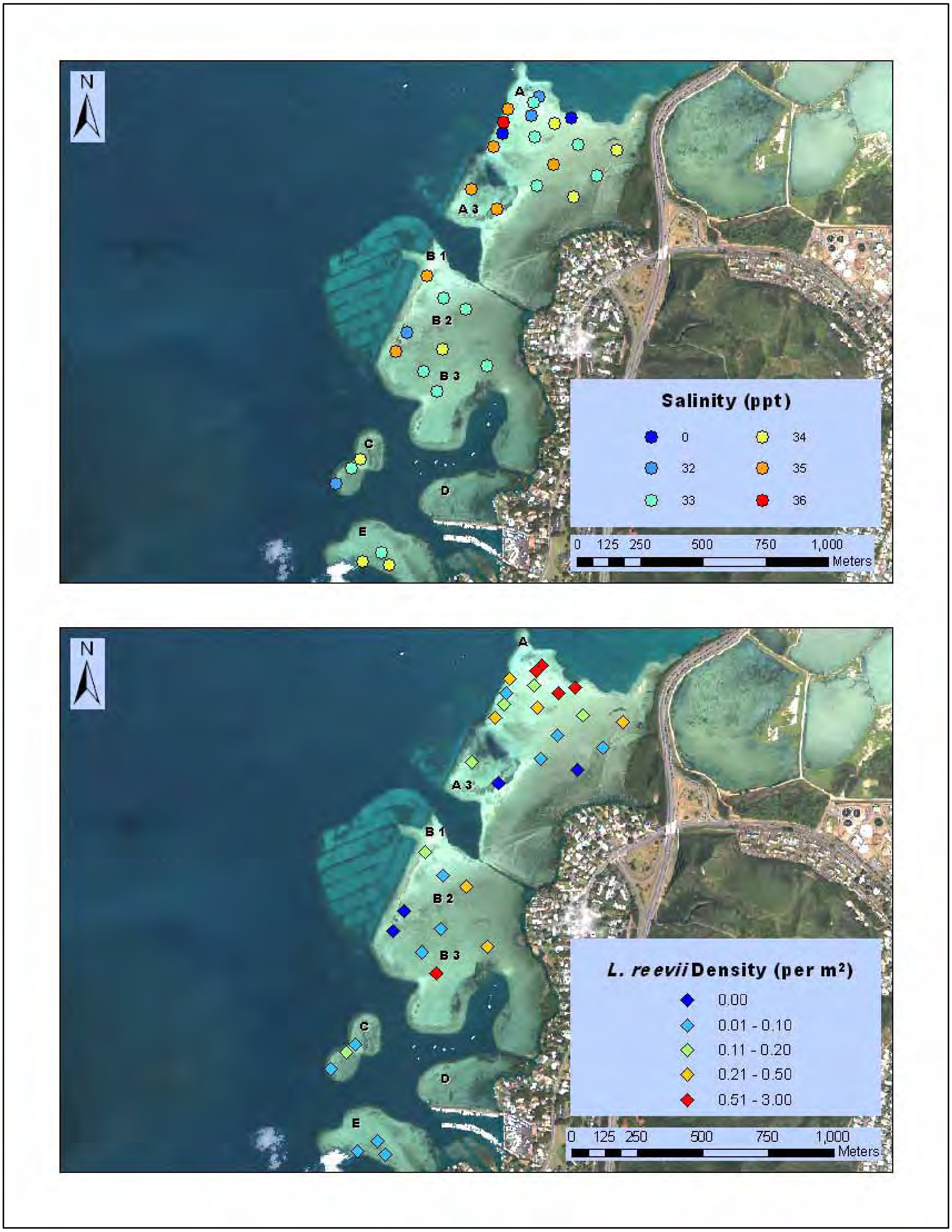

Figure 8: Salinity (ppt) and *L. reevii* density (per m²) at the south end of Kaneohe Bay, Oahu, Hawaii.

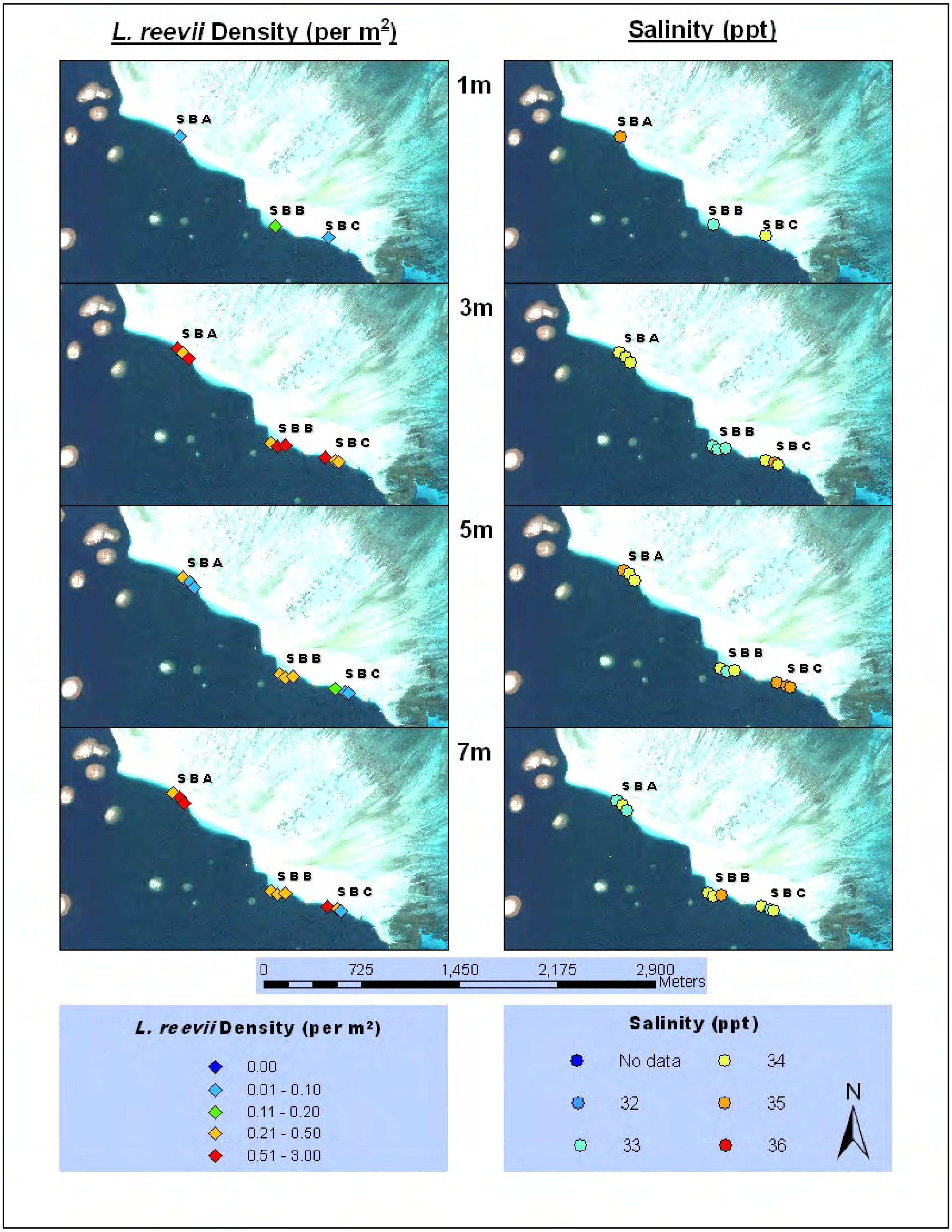

Figure 9: Salinity (ppt) and *L. reevii* density (per m²) at the Sand Bar (SB) in Kaneohe Bay, Oahu, Hawaii.

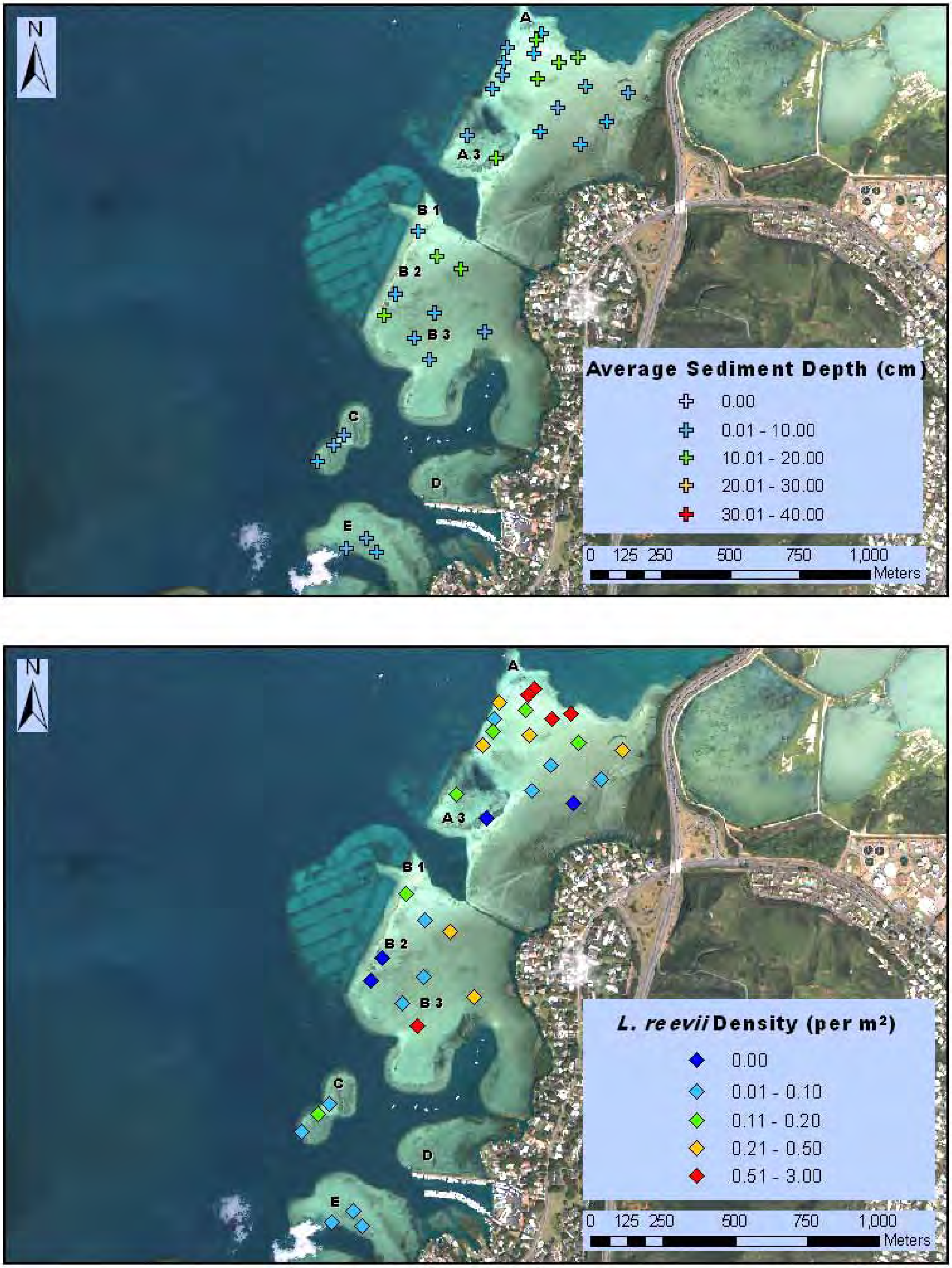

Figure 10: Average sediment depth (cm) and *L. reevii* density (per m²) at the south end of Kaneohe Bay, Oahu, Hawaii.

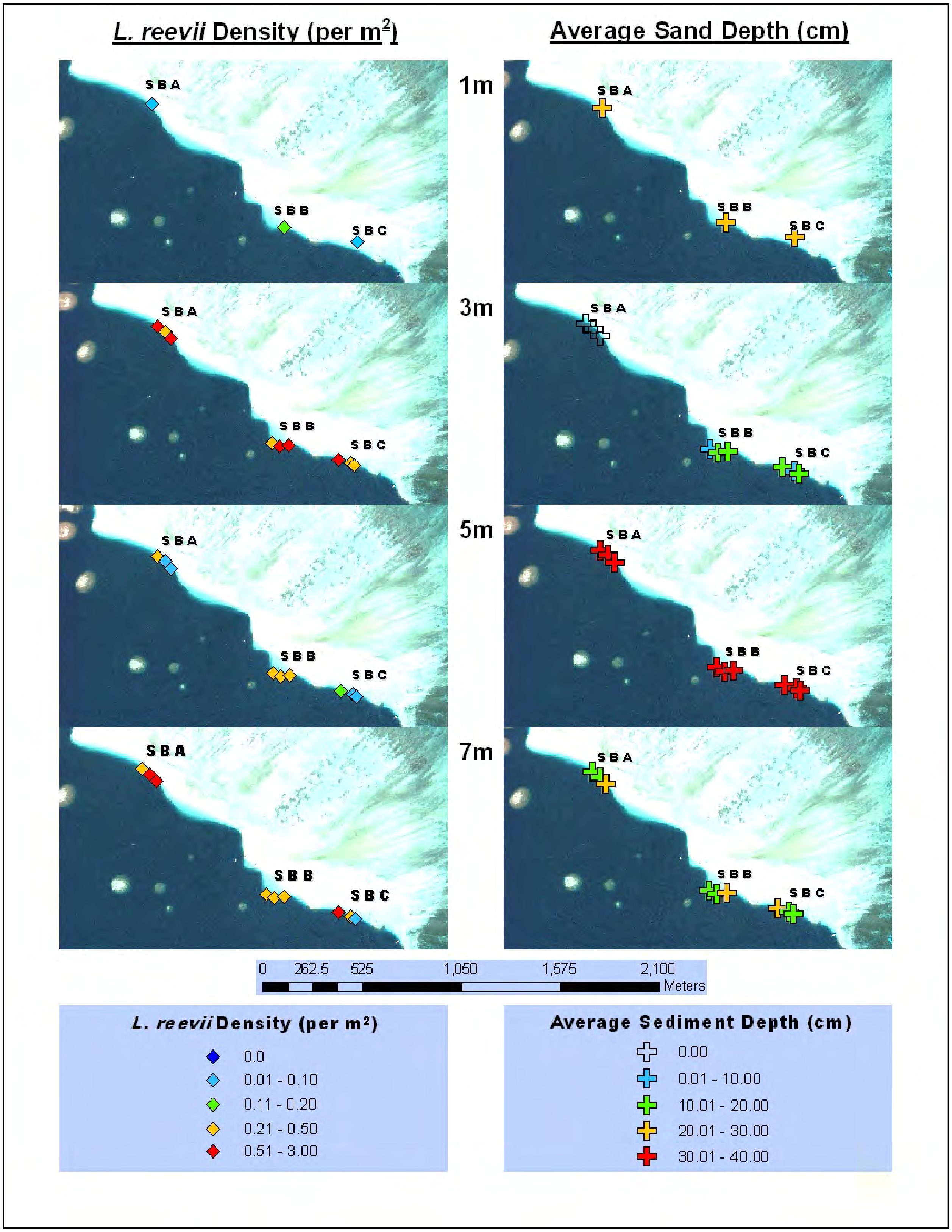

Figure 11: Average sediment depth (cm) and *L. reevii* density (per m^2) at the Sand Bar (SB) in Kaneohe Bay, Oahu, Hawaii.

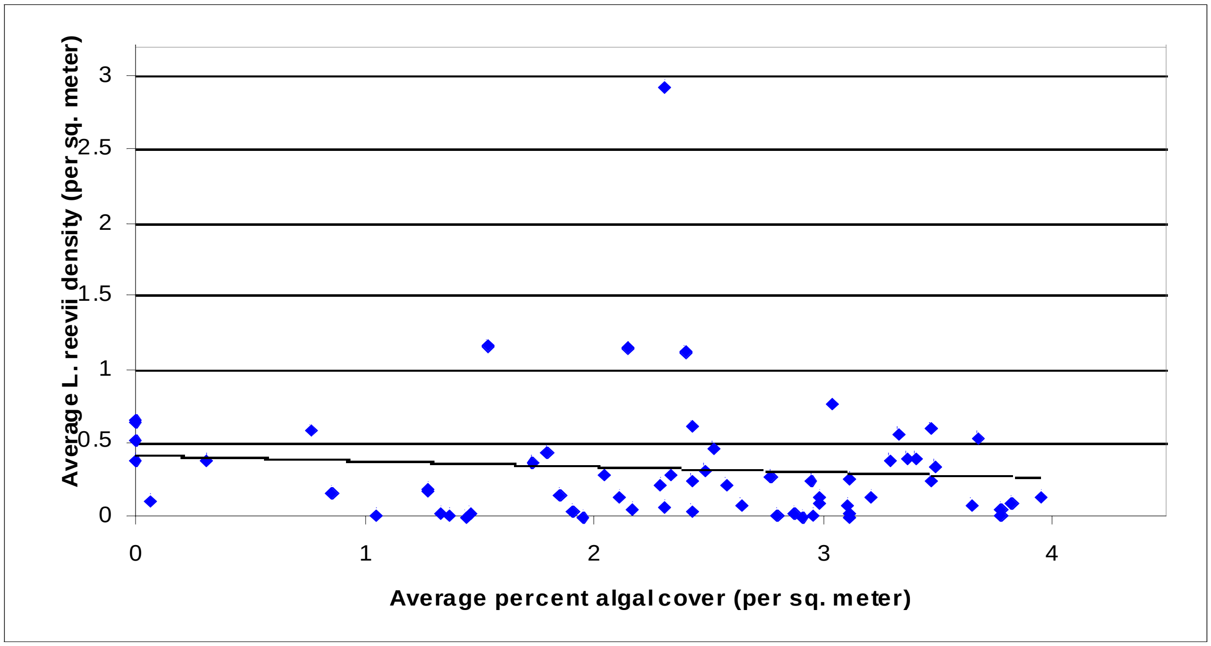

Figure 12: Simple linear regression analysis for the average percent algal cover versus average *L. reevii* density (per m^2) at each transect. Average algal cover was normalized using ln(x+1).

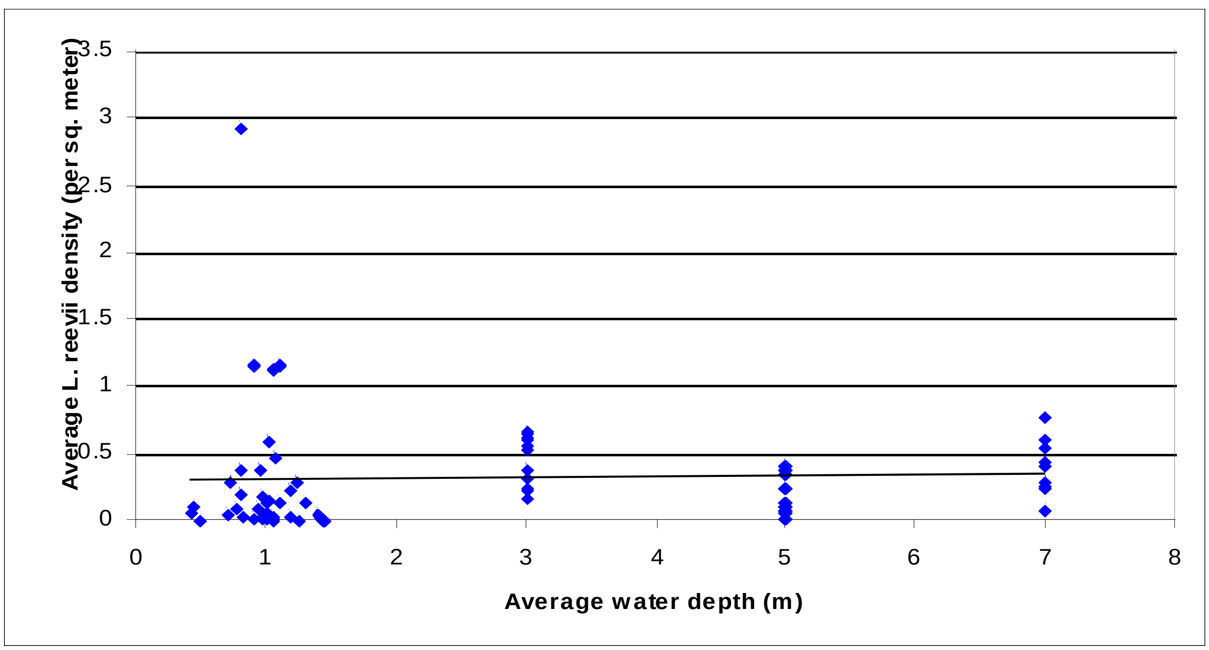

Figure 13: Simple linear regression analysis for the average water depth (m) versus *L. reevii* (per m^2) at each transect.

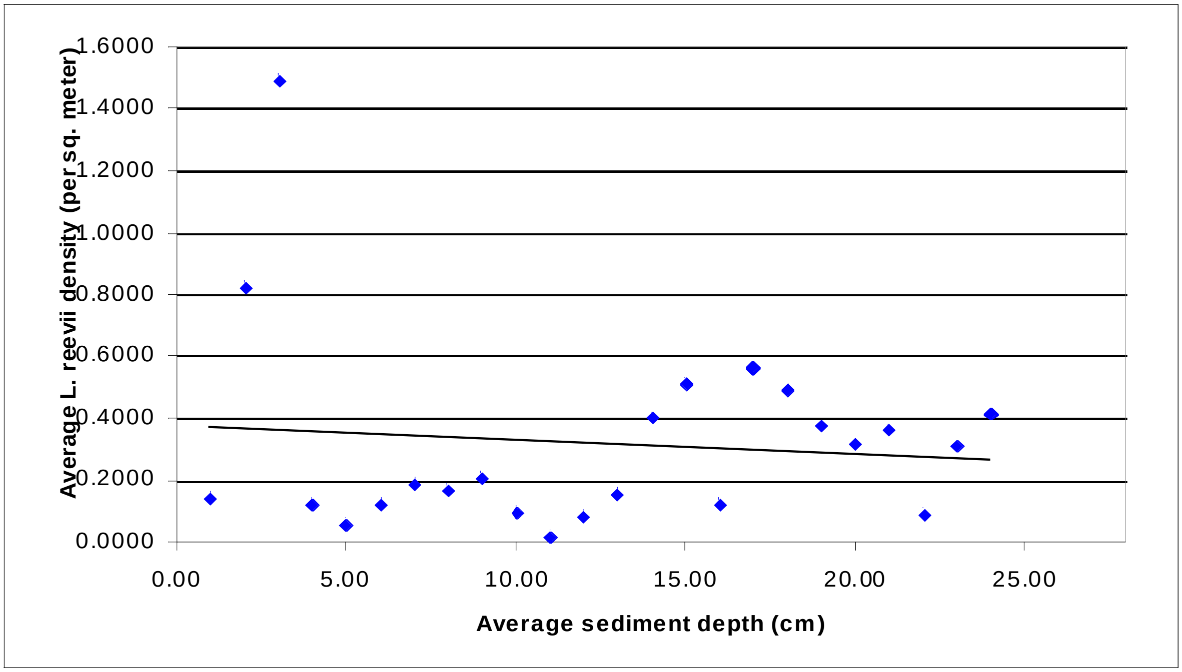

Figure 14: Simple linear regression analysis for the average water sediment (m) versus *L. reevii* (per m^2) at each transect.

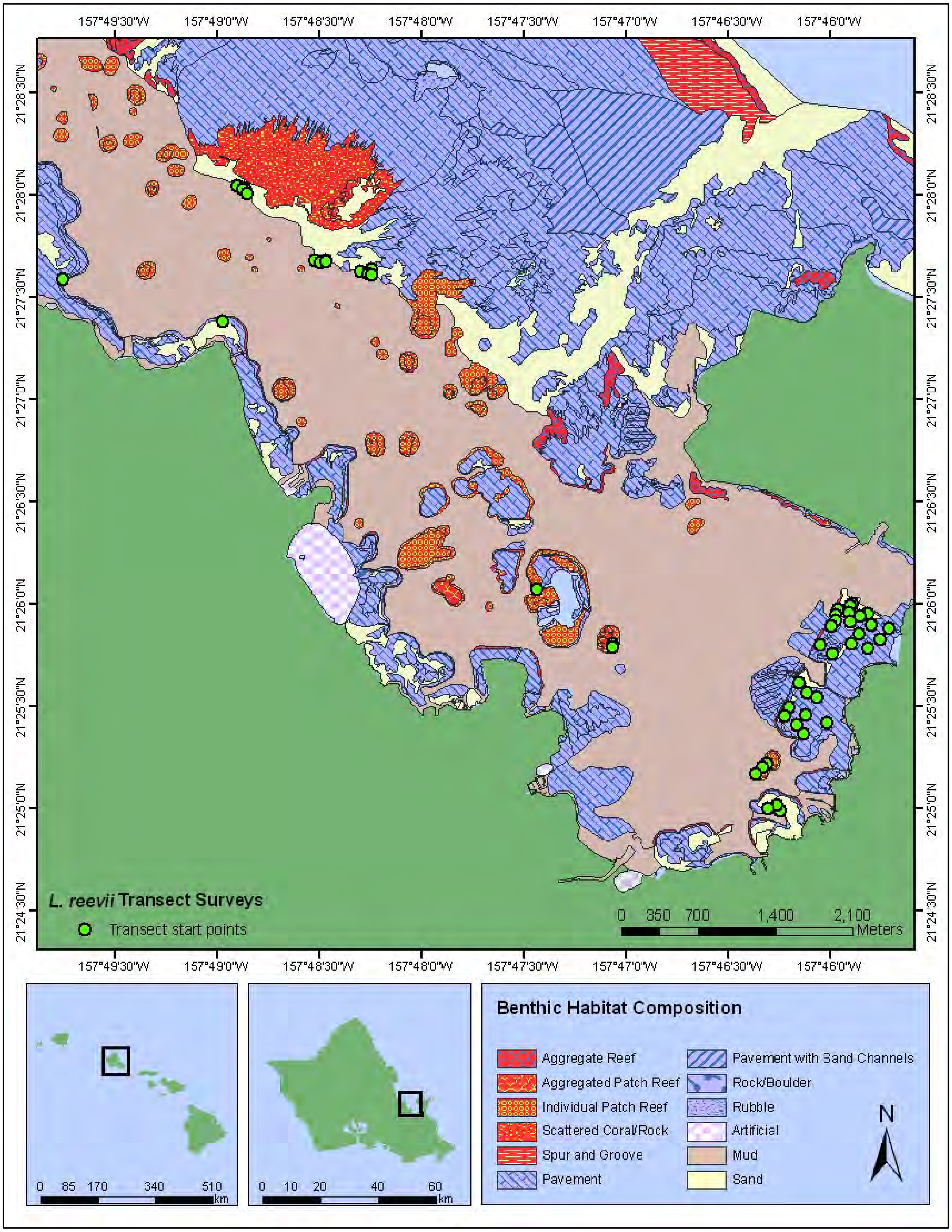

Figure 15: Benthic habitat composition of Kaneohe Bay Oahu, Hawaii provided by NOAA: Center for Coastal Monitoring and Assessment (CCMA), and the transect locations of *L. reevii* surveys in 2010.