AN EVALUATION OF CAUSAL FACTORS AFFECTING CORAL REEF COMMUNITY STRUCTURE IN MA‘ALAEA BAY, MAUI, HAWAII

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Submitted to:

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EXECUTIVE SUMMARY

On March 16, 2010, the County of Maui provided funding to conduct research to investigate and identify point and non-point pollution and nutrient sources that may have led to drastic declines in coral heath and complexity of the benthic community and, subsequently, promoted excessive algal growth in Ma'alaea Bay. A second objective of the work was to provide information that could be utilized for developing planning tools to better protect coral reefs throughout the State of Hawaii through investigation, interpretation and publication of the causes and effects of the decline in Ma'alaea Bay's healthy and complex reef habitat.

Field studies were carried out to fully characterize the physical and biotic composition of the entirety of the Bay extending out to the limits of fringing reef growth. Methods were used that allowed rapid, but extensive, characterization of the reef communities that could then be applied to remote sensing imagery to produce habitat maps depicting areas of dominant benthic coverage. A total of 359 areas were evaluated, resulting in a good representation of the varied habitats of Ma'alaea Bay.

Results of the investigation revealed five clearly defined “reef zones” within the Bay. A nearshore reef flat extending from the eastern Harbor Breakwater to Haycraft Park (essentially the area where the shoreline is lined with condominiums) is characterized by a narrow region of high algal growth. Beyond this narrow nearshore zone, algal abundance on the reef flat declines while corals begin to occur. Beyond the reef crest on the outer edge of the reef platform an area of high coral cover, consisting mainly of large individual colonies and amalgamations of accreting corals, forms a robust and healthy reef that does not show effects of any kind of stress. Inside Ma'alaea Harbor, a similar unstressed community of large corals covers the remnant reef platform and slope adjacent to the East breakwater.

Along the eastern shoreline of Ma'alaea Bay, offshore of Kealia National Wildlife Refuge, narrow finger reefs occur parallel to shore. At the time of the survey, these reefs were partially covered by a fresh layer of fine-grained red mud that was apparently transported to the nearshore waters by wind. As these reefs were still partially alive, it is apparent that corals can recover from such periodic episodes of sediment deposition.

The reef zone off the eastern side of the harbor channel contains a far lower coverage of living coral and, while there was little fresh sediment visible on the reef surface during the period of fieldwork, it appears this region had been recently severely stressed by some type of physical factor. Algae were abundant in this area, as were multitudes of sea urchins that were effectively grazing these algae. A comparison of satellite images of this area from 2005 and 2010 suggests there have been large-scale changes to reef structure during that interval.

The second field effort involved a complete characterization of nutrient composition of the waters of Ma'alaea Bay. A total of 382 water samples were collected during six sampling periods. Samples were analyzed for various forms of nitrogen, as well as phosphorus, silicates and salinity. In addition, water was sampled from upland irrigation wells and three injection wells. Results of these surveys indicate a clear and consistent pattern of nutrient distribution within the bay. Elevated nutrient levels (N and P) consistently occur within a narrow zone (tens of meters) along the shoreline of the central bay. This narrow zone reflects the region of groundwater discharge to the ocean. Beyond this zone, nutrient concentrations drop rapidly through a transition zone that extends over the reef flat. Beyond the edge of the reef flat (corresponding to the region of highest coral cover) nutrient concentrations are consistent with values typical of open coastal waters. In addition, owing to the buoyancy of low salinity groundwater, higher nutrient water is confined to a

surface layer no more than 2 meters thick. Hence, beyond the nearshore zone, water with elevated nutrient concentrations does not come into contact with the reef surface.

Results of sample analysis coupled with estimates of hydrologic fluxes of groundwater in the Maʻalaea area reveal that, while injection wells contribute a relatively small amount of water to total groundwater discharge, they contribute about 17% of the nitrogen and 73% of the phosphorus to the shoreline area fronting the condominiums. As the injection well discharge is enriched in phosphorus relative to other sources of groundwater, it provides a good nutrient source for algal growth along the shoreline.

These results suggest that reduction of injection well effluent discharges may decrease the present biomass of algae in the nearshore zone fronting the condominiums. However, it is clear that such a reduction would have no effect on the reef beyond the nearshore zone. As the outer reefs directly off the condominiums are presently in an essentially pristine condition, reduction of any discharge will change this situation. As these pristine reefs lie between the source of the injection well discharges and the stressed reef off the harbor, it is clear that factors affecting the latter reefs are not emanating from the shoreline of the central bay.

All of the data collected in this study indicate that, while the injection wells are likely causing some enhanced algal growth in the inner bay, they do not appear to be a cause of the observed declines in coral communities. Rather, input of sediment from both wind and surface flow appear to be the primary factors impacting reef health in this area. While sediment impacts have been a longstanding issue in the Maʻalaea region, any recommendations for actions to improve conditions for enhanced coral growth should center on reduction of sediment stresses.

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I. INTRODUCTION

Pursuant to Chapter 102 D, HRS, the County of Maui requested proposals to: 1) identify point and non-point pollution and nutrient sources that may have led to drastic declines in coral heath and complexity of the benthic community and subsequently promoted excessive algal growth in Ma‘alaea Bay; and 2) provide the public with long-term planning tools to better protect coral reefs throughout the State of Hawaii through investigation, interpretation and publication of the causes and effects of the decline in Ma‘alaea Bay's healthy and complex reef habitat.

In order to respond to the request, a group of researchers with substantial expertise in various fields of coral reef science, including the study of causal factors of community structure and function of Hawaiian reef communities, as well as remote sensing technology as applied to mapping of coral reefs, joined together to provide a team approach to address the questions at hand. As many of the causal factors responsible for changes of nearshore marine systems have been attributed to nutrient loading from various land-based anthropogenic sources, a hydrologist with extensive experience in groundwater dynamics of Maui is also a member of the proposed team.

Presented below are the objectives, field and laboratory methods, results and conclusions for the evaluation of factors affecting coral community structure in Ma‘alaea Bay, Maui.

II. DESCRIPTION AND MAPPING OF MA‘ALAEA BAY MARINE HABITATS

A. Objectives and Methods

The major factor driving the present request to investigate Ma‘alaea Bay is the perceived decline in coral abundance and increase in algal abundance throughout the area. These changes in community composition have been reported in several documents, including "Status of Maui's Coral Reefs" prepared by the State of Hawaii Department of Aquatic Resources (DAR, no author listed), and "Final Project Report, NOAA Year 2005 Coral Reef Conservation Program" (no author listed). Both of these documents show data from two sites (DAR sites) in Ma‘alaea Bay that have been collected as part of the Hawaii Coral Reef Assessment and Monitoring Protocol (CRAMP) project that was initiated by the Hawaii Coral Reef Initiative in 1999 and, under the auspices of the University of Hawaii Institute of Marine Biology, has been monitoring approximately 50 selected sites throughout the main Hawaiian Islands. The locations of these two study sites on the eastern edge of the entrance channel to Ma‘alaea Harbor (DAR-3, DAR-6) are shown in Figure 1.

However, because of the limited coverage, it was not clear if all benthic communities within Ma‘alaea Bay are composed of the same type of community structures as occur at the two DAR sites. Virtually all coral reefs can be segregated into zones, or strata, consisting of multiple combinations of physical and biotic structures developed in response to variable physical and chemical factors. While the reported conditions from the two DAR sites appear to accurately represent the community structure of those two particular areas, the conditions do not provide an accurate representation of biotic composition of the entirety, or possibly even the majority, of Ma‘alaea Bay. As a result, prior to evaluating cause-and-effect relationships for any human-induced changes to biotic structure, the initial phase of the present program was to gain a good working knowledge of both the biotic composition and physical structure of the entire system under study. Thus, the initial objective of the project was to construct an accurate representation of the physical structure and benthic community composition of Maʻalaea Bay in the form of habitat maps produced using remote sensing techniques.

As no detailed benthic habitat maps of the region encompassing Maʻalaea (or most of Maui) presently exist, our objective was to create such a product using state-of-the-art methods based on accepted scientific and peer-reviewed remote sensing techniques. This method involved obtaining commercially available remote sensing images of the area of interest. Extensive ground-truth data were collected throughout Maʻalaea Bay, and a classification system based on the ground-truth data set was used to calibrate the spectral information contained in the remote sensing images. The resulting classification scheme can be translated on a pixel by pixel basis into area coverage of categories of living benthos (e.g., coral, algae and non-living bottom (e.g., sand, mud, rock). Bathymetry was also added to the maps using available LiDAR (Light Detection and Ranging) data. The resulting map product provides a unique tool for quantification of components of the entire marine setting that is a valuable asset for understanding the subsequent effects of human inputs.

Ground-truthing for map generation was conducted using methods developed specifically for classifying remote sensing images of coral reefs. A set of 359 randomized calibration/validation (CV) points was selected within the bounds of the mapping area. Locations of all sampling points are shown in Figure 2, while the locations (longitude/latitude) are shown in Table 1.

CV ground-truth surveys were conducted in the field by divers taking digital photographs at each of the random CV points covering an area of approximately 2.4 m^2 of sea floor (which is also the area coverage of one pixel of remote sensing data). Each photo-mosaic comprising 2.4 m^2 of bottom consists of six photographs taken with a digital camera equipped with a 14 mm lens attached to a platform centered over a quadrat with dimensions of 1 m x 0.6 m. For the present project, a substantial portion of the inner reef flat had water depths shallower than the height of the camera platform. In these areas, oblique photographs of the bottom were taken and bottom cover data was extracted from those images.

Following fieldwork, the digital images were processed to determine benthic cover of all coral species and other living and non-living strata. Each photo-quadrat was gridded into 100 equal segments and percent coverage of each bottom type was calculated by adding coverage from each segment. The mean value of cover of all photos from a CV site was used for the final analysis. Each ground-truth point was geo-located using a hand-held differential GPS in a waterproof housing. In addition to providing data for developing the remote sensing maps, the ground-truth investigations also provide a permanent photographic record of quantified data defining benthic community structure. The resulting data for all CV sites is shown in Table 1. Representative photo-quadrats are shown in Figure 3. Appendix A contains all photo-quadrats.

In the lab, map generation was accomplished by locating CV points on the geo-referenced satellite multispectral image that served as the basis for statistical image classification. "Training classes" (defined as the combination of geo-morphological zone and bottom cover) were created by assigning a class label to a survey point using the ground truth data for context. To spectrally define a "region of interest" for a training class, 20-30 adjoining pixels were isolated and included in the class. All training classes with the same spectral label were used to create a map showing the distribution of that particular bottom cover over the reef. The resultant analysis produced maps showing discrete classifications of coral, algal and sand/rock cover. In addition to benthic habitat classifications, maps incorporate depth contours based on available LiDAR data (Figure 4). The data used to create the maps are compatible with ArcGIS.

B. Results

1. *Descriptions of the Survey Areas*

Maʻalaea Bay, as defined for this study, extends along approximately 6.7 km (4.2 miles) of shoreline from the westernmost boundary of Kihei to approximately 1 km south of Maʻalaea Harbor. Of particular interest in this study is the 800-meter long area of the central Bay extending from the eastern edge of Maʻalaea Harbor to Haycraft Beach Park. Within this central zone, ten condominiums are built close to the shoreline.

Within the embayment there are multiple zones characterized by varied physical compositions and biotic communities. Presented below is a descriptive view of these zones from the shoreline to a water depth of about 10 m (30 feet). Example areas of each zone are labeled in Figure 5.

1. Nearshore Reef Flat Algae <u>Zone A</u>

The nearshore structure of the entirety of Maʻalaea Bay consists of a wide shallow area with water depth less than 5 m, which is evident in the bathymetric contours shown in Figure 4. Along most of the beach area east of Haycraft Park the nearshore area consists of a mixture of sand and beachrock. Within the central region of bay, the nearshore area is composed of a wide shallow reef flat. The underlying structure of the reef flat is a fossil calcium carbonate platform interspersed with sand pockets and channels. Water depth in this area is very shallow, not exceeding 2 m, and can be nearly exposed to the atmosphere at low tide. The reef flat is widest in the region of the eastern Harbor Breakwater, where it extends approximately 500 m from the shoreline. The inner region of the reef flat, particularly directly off of the condominiums, consists of an area of dense algae growth that nearly completely covers the benthic surface (Zone A in Figure 5). The two predominant species occupying this area are the red algae *Hypnea musciformis*, and several species of the green algae *Ulva* (Figure 6). Along the shoreline created by the placement of boulders adjacent to anchor seawalls, these algae occur in high density and masses of broken fronds were consistently observed collected in pockets along the shoreline. While algae occur along the shoreline in other areas of the Bay, the density is not as high as off the inner central Bay fronting the condominiums.

2. Mid Reef Flat Algae Limestone <u>Zone B</u>

Within approximately 25-50 m of the shoreline, algal abundance on the reef flat declines compared to the nearshore area, although abundance is still on the order of half the benthic surface. The remaining reef surface consists of exposed limestone pavement, coarse sand, and patches of coral rubble (Figure 7). This area also contains the reef crest, where the shallowest water depths occur. With increasing distance from shore, isolated coral heads occur, with the density of colonies increasing with distance seaward. The primary coral species in this area consist of *Pocillopora meandrina*, which occurs in a hemispherical growth form composed of short compact branches, and *Porites lobata*, which occurs either as flat encrustations or small dome-shaped colonies (Figure 8). In some areas of the reef flat, the bottom is covered with encrustations of purple-colored *Montipora flabellata* (Figure 9). The growth form of this coral is somewhat unusual in that it is growing below the level of surrounding algae. This growth form of *M. flabellata* was not observed elsewhere in Maʻalaea Bay. The mid-reef flat community is of interest in that it consists of a biotic community where corals and algae co-occur. While corals were only moderate in abundance, the colonies that were present appeared unaffected by the surrounding algae. Similar algal flats occur on the west side of the Harbor Breakwater.

3. Outer Reef Coral Mound Zone C

Moving seaward across the reef flat and seaward of the reef crest, algal occurrence ceases along a distinct margin parallel to the shoreline. The seaward edge of the reef flat off the central Bay grades into a zone of large amalgamated colonies of living corals that form a well-developed reef elevated off the bottom. This zone occupies a discrete area and extends as a narrow finger parallel to the shoreline, directly offshore of the surf line. The predominant coral species composing the coral mound zone are *Porites lobata, P. compressa, Montipora patula* and *M. capitata* (Figures 10-11). These reefs appear to be actively accreting, with coral growth adding to the vertical structure. The fact that many of the individual colonies exceed several meters in diameter, combined with the amalgamation of colonies into vertical structures, indicates that this reef has not been subjected to a level of wave stress that generally limits true reef development in other open coastal areas of Hawaii. The seaward edge of the reef terminates at the juncture of the coral structures and a sand plain that extends seaward to the limits of the study area (Figure 12). Throughout this zone, there was little evidence of any other kind of stress, as at the time of the surveys there was no indication of disease, bleaching or sediment deposition. While limited in area, and contrary to other areas of Ma‘alaea Bay discussed below, the biotic structure of this zone represents a habitat that does not reflect significant stress from land-based activities.

4. East Bay Finger Reefs Zone D

One of the other areas of Ma‘alaea where reef development has occurred is along the eastern side of the Bay adjacent to the wetland areas. In this area, narrow “finger reefs” extend parallel to shore at a depth of about 3-4 meters. Composition of reef species is similar to that of Zone C, dominated by large colonies of *Porites lobata* and *Montipora* spp. that merge to form mounded super-colonies. However, there is a major difference between the reefs in the East Bay and those off the central Bay: much of the surface of the living and dead coral colonies along the entire expanse of the East Bay finger reefs was covered with a layer of red mud (Figures 13-14). While many of the colonies had sections with living tissue, large areas of individual colonies were dead. Fanning motion over the surface of the corals resulted in resuspension of the fine grained mud, indicating that recent wave activity had not been sufficient to resuspend sediment and clean coral surfaces. As no streams occur in the area, it follows that the source of the mud is wind-transported soil from upland agriculture. Clouds of fine-grained soil lifted from the fields during strong tradewinds are commonly observed in south Maui. From the appearance of the reef, much of this material is deposited in the nearshore area. It was not within the scope of this study to determine the frequency or magnitude of wind-borne sediment deposition. However, it is not likely that these events have only occurred just prior to the present survey. As the reef still contains a substantial fraction of living coral, the observed sediment stress has not had a cumulative effect that has eliminated living coral from the reef. In fact, it appears that there is a component of recovery from the sediment stress as many juvenile corals were observed, indicating a potential for re-settlement and recovery of the reef (Figure 15).

5. Inside Harbor Coral Zone E

The eastern leg of the Harbor Breakwater was constructed over the reef flat and a portion was left intact inside the Harbor adjacent to the Harbor channel. The remnant reef bench inside the breakwater is presently populated by a well-developed community of corals that appear to be unaffected by the quality of water flowing out of the Harbor. As these corals are protected from wave action by the breakwater, colonies are large and robust, growing down to the sandy floor of the channel (Figure 16). The main species composing the inner Harbor reef are large hemispherical mounds of finger coral (*Porites compressa*) and a variety of growth forms of *Montipora capitata. M. capitata* is apparently well-adapted to colonize inner harbor environments as it has been observed covering virtually all available surfaces within Kahului Harbor, as well as pier pilings in Hana Bay. No algae occurred on the inner harbor reef.

6. Outer Harbor Reef Zone F

The outer region of the reef platform fronting the eastern breakwater and bounded to the west by the entrance channel represents a distinctly different reef community than the other reef zones. Bottom composition of this area consists of high relief bioeroded limestone platform interspersed with pockets of sand. Corals occurred in this area, although overall coverage was low compared to the central reef. Many colonies were partially dead and live tissue was interspersed with areas of bare limestone indicating recent mortality (Figures 17-18). While some areas of the benthic surface were covered with an algal turf, other areas were colonized by extensive growth of the invasive algae *Acanthophora specifera* (Figure 19). As *A. specifera* colonized much of the dead areas of partially living coral colonies, it is possible that it was causing some additional coral mortality resulting from contact with edges of living colonies. However, the overall appearance of the reef and the relatively limited distribution and abundance of algae compared to coral mortality was such that it did not appear that algae was the major cause of coral stress, but rather an opportunistic colonizer of substratum bared by other factors.

A unique feature of this zone was the abundance of the collector sea urchin, *Tripneustes gratilla* (Figures 20). Sea urchins occurred in clusters, often centered on a feature elevated off the bottom. In areas with urchin clusters it was apparent that they served as effective grazers on benthic algae, particularly *Acanthophora*. Around each cluster of urchins was a circular halo where the reef surface was grazed down, while the surrounding area was covered with abundant algae (Figure 21).

This region encompasses the DAR CRAMP sites that documented the decline of living coral in Maʻalaea Bay. Surveys of the area completed for the present study in 2010 report similar conditions as the DAR surveys.

2. *Habitat Mapping*

Figures 23-25 show satellite images of Maʻalaea Bay overlayed with color coded circles that represent percent bottom cover of coral, algae and mud (including turf-bound sediment) at each of the 359 CV sampling points. In addition, these figures also include maps of coral, algae and mud generated by computer software from the CV points. Overall, the maps provide a good representation of the spatial distribution of the zonal composition described in the section above. The densest coral cover can be seen in along the outer reef crest in the central Bay, inside the eastern breakwater, and along the finger reefs on the eastern side of the Bay (Figure 22). Algae are densest on the nearshore reef platform and along the shoreline of most of the Bay (Figure 23). These maps show the composition of the area in its entirety, with all areas given equal significance. Such comprehensive consideration provides views of the spatial relationships between areas of high algal and/or coral cover with respect to physical composition of the Bay system, as well as with respect to proximity of point source material input from land.

III. DETERMINATION OF NUTRIENT FLUXES TO MAʻALAEA BAY

A. Objectives and Methods

A widely perceived hypothesis is that changes to abundances of algae and coral in nearshore habitats of Maui are a result of additions of nutrients to the ocean originating from various human activities. Such nutrient additions occur mainly as subsidies to naturally occurring nutrient concentrations in groundwater that flows from land to the ocean (although input can also occur as surface flow during episodic storm events). In order to test this hypothesis, a sampling program was implemented throughout Maʻalaea Bay, as well as upland regions where human activities may affect the composition of groundwater and surface water reaching the Bay.

The intent of the sampling program was to collect water samples from available terrestrial sources (e.g., groundwater wells, agricultural irrigation sources, wastewater sources) that drain to the Maʻalaea coastal area. Samples were also collected throughout Maʻalaea Bay from the highest wash of waves at the shoreline to the open coastal ocean beyond the influences of land. Samples were collected by swimmers working from the shoreline and investigators working from a small boat or Jet Ski. Coordinates of all sampling locations were recorded by GPS. A total of 382 water samples were collected over the course of the project. Table 2 lists the time, locations, and results of all water sampling.

Water samples from the nearshore area and wells were collected in 2-liter bottles and filtered immediately through a glass fiber filter (GFC) into triple-rinsed acid-washed 60-ml Nalgene. Offshore water samples were pumped from the surface layer through an in-line glass fiber filter into similarly prepared 60-ml bottles. Deep water samples were collected using a Niskin bottle, which was lowered to the desired sampling depth where spring-loaded endcaps triggered by a messenger released from the surface shut the bottle. Following collection, all filtered samples were stored in a shaded, cool box for 5 hours before freezing. An aliquot of water was not frozen and kept in the refrigerator for the measurement of silicate and salinity.

Water samples were analyzed using standard colorimetric methods (Strickland and Parsons 1984): silicate and phosphate were measured using a phosphomolybdate complex in acid and a reduction to a blue color, nitrite was measured with sulfanilamide and n-1-n ethylenediamine pink dye, nitrate was reduced on a cadmium reduction column and then analyzed as nitrite, while ammonium was oxidized to nitrite with hypochorite and bromide and analyzed as nitrite.

The color for all reacted samples was measured using a 10-cm-pathlength, liquid core waveguide and an ocean-optics spectrometer, achieving relatively low detection limits (in µ): phosphate 0.01, nitrite 0.01; nitrate 0.02; silicate 0.5. Dilutions were performed on many of the lower salinity samples, ranging from 5 to 100 fold. Diluent-water was aged, filtered open-ocean water. The concentration of this water was routinely checked against 0-ohm MilliQ-Millipore water.

Algae samples (*Hypnea musciformis*) were also collected along the shoreline at 17 sites within the study area for analysis of stable isotopic signatures and nutrient composition. Samples were oven-dried (60°C, ~24 h), homogenized to a fine powder using a mortar and pestle and acid-fumed to remove carbonate (Hedges and Stern 1984). Bulk carbon and nitrogen isotopic compositions were determined using an on-line carbon-nitrogen analyzer coupled with an isotope ratio mass spectrometer (Finnigan ConFlo II/Delta-Plus). Isotope values are reported in standard □-notation relative to the international V-PDB and atmospheric N_2 for carbon and nitrogen, respectively. Glycine with known del^{13}C and del^{15}N values was analyzed approximately every 10 samples to ensure accuracy of all isotope measurements. Furthermore, several samples were measured in duplicate or triplicate and the analytical error in isotopic compositions associated with these measurements was typically $\leq$0.2‰ for both carbon and nitrogen.

Estimates of nutrient concentrations in injection well effluent were obtained from the Hawaii State Dept. of Health. The results of all water sampling, as well as the locations of all water samples, are shown in Table 1.

B. Results

1. Nutrient Sources From Land

Groundwater discharging at and below sea level along the Maʻalaea Bay shoreline comes from a groundwater body known at the Kahului Aquifer. The aquifer lies beneath the 27-square mile isthmus between Haleakala to the east and the West Maui Mountain to the west. Typical stratigraphy across most of the isthmus consists of a top layer of calcareous sand a few to a few tens of feet thick, a red-brown compacted silty clay, and unweathered volcanics from Haleakala which flowed across the isthmus and banked against the older West Maui Mountain.

Groundwater in the isthmus resides in the very permeable Haleakala volcanics as a basal lens. In this case the lens is a layer of fresh to slightly brackish groundwater floating on saline groundwater beneath it and in hydraulic contact with seawater at the Maʻalaea and Kahului Bay shorelines. The 20 inches of annual rainfall on the isthmus provides about five (5) million gallons per day (MGD) [3.8×10^6 liters per day] recharge to the basal lens. Historically, however, pumpage by the HC&S Plantation well batteries averaged 45 MGD for decades and is currently about 25 MGD, all without causing an increase in salinity of the aquifer's water. Such a level of pumping without increase in salinity is made possible by the additional sources of recharge to the aquifer which are shown schematically in Figure 25. These include: leakage of surface water imported in ditches from East Maui; leakage of surface water imported from West Maui; groundwater underflow from both Haleakala and the West Maui Mountain; and agricultural irrigation return, primarily from the more than 10,000 acres of HC&S sugar cane fields across the isthmus. Based on pumping records, combined recharge from these other sources are an order of magnitude greater than direct rainfall recharge.

With respect to discharge of groundwater at the shoreline, there are three distinct zones within the study area of Maʻalaea Bay. Based on mapping of the mud and on low tide salinity measurements made along the shoreline, the three zones of differing groundwater discharge have been determined as shown in Figure 26. A thick and pervasive mud layer along much of the Maʻalaea Bay shoreline significantly influences the amount and location of groundwater discharged into the marine environment. Section A shown in Figure 26 is about 12,000 feet long and spans the width of the Kealia National Wildlife Refuge (NWR). Within the NWR, the mud layer extends to 40 feet below sea level, confining the basal groundwater beneath it. Along this and the other coastline segments, the rate of groundwater discharge can only be approximated. Using reported well water levels and apparent gradients and an assumed permeability coefficient of 2,500 feet/day, groundwater discharge from Section A is estimated at 2.4 MGD per mile or about 5.4 MGD. However, because of the layer of mud, groundwater is not detectable along the shoreline. The confining mud layer apparently forces the discharge into the marine environment further offshore.

Section B in Figure 26 is a 2500-foot long transitional section between the confining mud of Section A and the virtual absence of mud to the west along Section C. Shoreline discharge along this section is estimated to be about 1.4 MGD and starts to be evident as slightly lowered salinity of seawater at the shoreline. Shoreline discharge of groundwater along Section C at the west end of Maʻalaea Bay does not appear to be in any way impeded by overlying alluvium. Lowered salinity along this shoreline demonstrates the free discharge of groundwater at the shoreline itself. The estimated discharge of groundwater along this 3000-foot length of shoreline, exclusive of the estimated 0.15 MGD of treated wastewater discharges from the ten resort condominiums and Maʻalaea Triangle wastewater treatment plant, is estimated to be 2.0 MGD.

2. Nutrient Input to Ma‘alaea Bay

One intent of this report is to assess the effects of groundwater nutrients and injection well nutrients on the near-shore marine ecosystem at Ma‘alaea Bay. Inorganic nutrients are the compounds of nitrogen and phosphate that are utilized by marine plants (e.g., algae) to grow. Inorganic compounds of the element nitrogen are nitrate, nitrite and ammonium. Phosphate is the only inorganic form of the element phosphorus. These inorganic nutrients typically occur in high concentrations in naturally occurring groundwater relative to ocean water, and are the major nutrients that are added to groundwater by leaching of agricultural sources (i.e., fertilizers). Organic forms of nitrogen and phosphate compounds are only a small component of the groundwater nutrient pool. Organic forms of nitrogen and phosphate were not measured during this study because their uptake into algae is relatively slow compared to that of inorganic nutrients. Algae also take up other trace elements from the water for growth, but these trace elements are minor and were not considered in this study.

Concentrations of dissolved silicate in groundwater are also high relative to ocean water because of the weathering of rock. However, silicate is not readily utilized by tropical marine algae. Thus, the concentration of silicate serves as a useful conservative tracer of groundwater. Nitrate in groundwater is also very high because of the decay of organic matter in soils, and the addition of nitrogen fertilizers. Nearly all nitrogen compounds are oxidized to nitrate leaving only minor amounts of nitrite and ammonium (Table 1).

Groundwater flows into the coastal water near the shoreline of Ma‘alaea Bay. As groundwater is always relatively high in both nitrate and phosphate compared to the ocean, there is a continual and pervasive nutrient input into the near-shore ocean; this is true for all high tropical islands. In the case of Ma‘alaea Bay, nutrients in groundwater can come from natural inputs, as well as agricultural and injection wells. Here we quantify the different fluxes of nutrients into the coastal zone near the reef. Calculations to evaluate nutrient input and utilization are shown in Appendix B.

Groundwater flows to the coastal marine environment primarily in sections B and C (Figure 26) at a rate of 7.6 $m^3\ d^{-1}\ m^{-1}$ (cubic meters per day per meter) of shoreline. The water originates upslope and flows under agricultural land increasing in nitrate concentration (150 to 370 mmol N m^{-3} [millimoles N per m^3]); however, this water is relatively low in phosphate (3.2 mmol P m^{-3}). Near the shoreline, effluent from injection wells is added to groundwater further increasing nutrient concentration to about 1,300 mmol N m^{-3} and 140 mmol P m^{-3} (Table 1; Appendix B). Thus, nutrient concentrations in injection well discharge are at least 1,000-fold higher than normal offshore ocean water. The amount of water flushed through the injections wells is about 6% of the amount of water flowing as groundwater, or 0.46 $m^3\ d^{-1}\ m^{-1}$ of shoreline. A mixture of groundwater and injection well water in this proportion of the volume discharge gives a discharge of inorganic nitrogen and phosphate to the shoreline in the central bay fronting the condominiums of 3,400 mmol N $d^{-1}\ m^{-1}$ (millimoles N per day per meter) of shoreline and 90 mmol P $d^{-1}\ m^{-1}$ of shoreline (Eq 1A & 1B for inorganic nitrogen; Eq 2A & 2B for phosphate; Appendix B). The corresponding shoreline concentrations of the freshwater mixing into the ocean are 420 mmol N m^{-3} for nitrogen and 11 mmol P m^{-3} for phosphate.

Thus, the total amount of nitrate plus ammonia versus phosphate in groundwater gives an N:P ratio of 115 for groundwater wells (Eq 3 Appendix B), while the N:P in injection well effluent is 8.91 (Eq 4 Appendix B). Hence, injection well effluent is substantially enriched in P relative to N compared to groundwater. The mixture of groundwater and injection well water gives an N:P ratio of 38 at the shoreline (Eq 5A & B: Appendix A). N:P ratios of 20-40 are commonly found in marine macro-algae. The similar N:P ratios of groundwater discharged at the shoreline and algal tissue indicate that groundwater is an highly utilizable source of nutrients for algal growth. This water mixes with the coastal water within minutes to hours and the N:P ratio then tends to 1.

Nitrogen compounds from the injection wells sum to about 17% of the total inorganic nitrogen in groundwater flowing into the coastal environment (Eq 6; Appendix B) while phosphate from the injection wells is about 73% of the total phosphorus in groundwater (Eq 7; Appendix B).

3. Distribution of Nutrients Within Ma'alaea Bay

Figures 27-31 show satellite images of Ma'alaea Bay overlayed with the surface collection locations of all water samples distinguished by different symbols representing different sampling dates. Concentrations of nutrient constituents (NO_3^-+NO_2^-, NO_2^-, PO_4^{3-}, NH_4^+, Si) and salinity are color coded on each symbol into three "bins," each of which represents a distinct class of nutrient concentrations and salinity with respect to influence from land to the ocean (see Table 3 for concentrations that bound each bin). Blue symbols depict nutrient concentrations and salinity that are typically found in open coastal waters with little or no influence from land. Green symbols represent typical values found over nearshore reefs throughout the world, and indicate a mixing or transition zone between land and the ocean. Red symbols indicate substantial input from land, in this case through groundwater discharge near the shoreline. While we label this bin "impact" it is important to understand that naturally occurring groundwater, as well as groundwater subsidized by human actions, will fall into this bin.

Inspection of these figures reveals similar patterns for all nutrient constituents. Within the narrow nearshore area (about 100 m) between the eastern leg of the Harbor breakwater and Haycraft Park, there is a distinct zone of increased nutrients and decreased salinity. This area is also defined as the shoreline fronting the ten Ma'alaea condominiums and downslope from the Ma'alaea Triangle. Nutrient concentrations are occasionally also elevated within the Harbor basin.

Beyond the nearshore "impact" zone, most sample concentrations fall within the "reef" or transition bin over the shallow reef platform. Very few impact level concentrations occurred over the reef flat or the outer reef face. It is also evident that eastward of Haycraft Park, with the exception of a single sample of NH_4^+, none of the nutrient concentrations, even those collected at the shoreline, were of a magnitude high enough to fall into the impact bin. This pattern of low concentrations corresponds to the geologic structure of the area, which consists of a thick sand plug that restricts groundwater flow at the shoreline. To the south of Harbor, occasional higher nutrient concentrations occur at the shoreline, but do not extend over the reef flat. Beyond the reef flat, at a distance of about 200-500 m from shore, nutrient concentrations and salinity generally occur within the open coastal ocean range, indicating that the influence of land does not extend beyond the reef flat.

It is also important to note that the patterns represented by these data can be considered the "worst-case" scenarios in terms of seaward mixing of nutrients emanating from land. For practicality and safety, sampling was conducted on days with relatively small surf. During periods of large surf, which breaks directly on the reef edge fronting the area of high shoreline concentrations, nutrients fluxing to the ocean at the shoreline would be more rapidly and thoroughly mixed to background ocean concentrations by wave energy. Hence, if sampling was conducted during periods of high surf, it is likely that elevated nutrient concentrations would be more restricted in space and lower in magnitude than was measured for the present study.

In terms of evaluating nutrient contribution to the reef from the condominium injection wells, the most applicable nutrient is nitrite (NO_2^-). This species of nitrogen exists as an intermediate oxidation state between ammonium (NH_4^+) generated from metabolism of organic material and the most stable oxidative form of nitrate (NO_3^-). As a result, nitrite is generally a small component of the pool of dissolved nitrogen. In addition, because naturally occurring groundwater entering the ocean at the shoreline has a long residence time in the aquifer, all of the nitrite is oxidized to nitrate. On the other hand, breakdown of organic material during the sewage treatment process and subsequent discharge to the ocean through shallow injection wells located close to the shoreline is a relatively rapid process, resulting in un-oxidized nitrite. Hence, the pattern of elevated nitrite in samples close to the shoreline directly off the condominiums can be considered a good tracer of injection well effluent. It is also of interest that there are unambiguous different patterns of nitrite distribution on different sampling days. These differences may reflect both differences in hydrodynamics (e.g., surf, wind, tide and current conditions) or temporal differences in discharge volumes from the various injection wells.

4. Nutrient Uptake by Coral Reefs

Our calculations show that the amount of inorganic nitrogen compounds and phosphate discharged into the nearshore environment per day is approximately equivalent to the amount of nutrients taken up by a natural reef of 100 m^2 m^{-1} of shoreline, which can be conceptually viewed as a strip of reef one meter wide that extends 100 m either offshore or along the shoreline. This statement is based on natural uptake rates of about 20-30 mmol N m^{-2} d^{-1} (millimoles N per m^2 per day) and 1 mmol P m^{-2} d^{-1}. The influence of the injection wells would be 17% for inorganic nitrogen and about 73% for phosphate. This statement, however, assumes that *all* the nutrients are removed from the water. However, only a percentage of these nutrients is taken up by the bottom communities, which confines the effect of these nutrients to a few tens of meters from the beach.

As nutrients enter the coastal environment from groundwater they begin to mix with ocean water. The mixing is confined to a relatively thin layer of the upper 1-2 meters of the water column because freshwater is 2.5% lighter than seawater (Figures 32-35). Groundwater mixes outward on top of the ocean water, moving horizontally with the current and mixing vertically with energy from the waves and wind. The surface layer is also confined to within about 100 m from the shore (Figures 32-35). Thus, the high nutrient water barely reaches the bottom even in 2 meters of water and does not reach the surface of the outer reefs at all.

There is a physical limit to how much of a nutrient can be removed by bottom communities consisting of coral and algae. It is shown in the scientific literature that this physical limit is about 0.1% of the horizontal movement of nutrients with the currents, thus nutrients mix with the open ocean water and are taken away by currents from the shoreline faster than they are taken up by the coral reef (Atkinson and Falter 2003; Atkinson 2011). Groundwater, however, is a steady source of nutrients, and if groundwater is not mixed with ocean water fast enough, the near-shore water increases in nutrient concentrations. Higher concentrations of nutrients in water denote proportionately higher uptake of nutrients into the bottom communities.

Plots of nutrients versus salinity show a decrease of the nutrients from shore as salinity increases (Figures 36, 37). Conservative mixing lines created by joining endpoint concentrations of open coastal water and both injection well effluent and groundwater provide a basis to evaluate the fate of nutrients once they reach the ocean. The concentrations of phosphate, nitrate and ammonia as functions of salinity are all well below the injection well mixing line and above the groundwater groundwater mixing line. This result is consistent with our calculations confirming that nutrients in the ocean are a mixture of the two groundwater sources (Figures 36, 37). The data also fall below the line extrapolating to the theoretical shoreline concentrations (N and P calculated as a proportional mixture of the two sources). This relationship further implies that within the nearshore zone there has been some net removal of nutrients and conversion to biomass. The nitrate data extrapolate to a concentration of 160 mmol N m^{-3}, which is about 38% of the estimated shoreline concentration of 420 mmol N m^{-3} (Ns: Appendix A) The extrapolation of ammonia data to the shoreline value is only 7 mmol N m^{-3}, which is small compared to nitrate+nitrite. Similarly, phosphate extrapolates to 3.8 mmol P m^{-3}, which is about 35% of the shoreline value of 11 mmol P m^{-3} (Ps: Appendix A). The differences between the values measured at the shoreline and the calculated values on input represent nutrients that are likely taken up by the high algal biomass near the shoreline.

Uptake of nutrients into coral reefs can be described as a function of the bottom friction, water velocity and nutrient concentration (Atkinson and Falter 2005). Estimates of maximum nutrient uptake can be predicted. At ambient nutrient concentrations, coral reefs take up approximately 20-30 mmol N m^{-2} d^{-1} and 1 mmol P m^{-2} d^{-1}. They also produce inorganic nitrogen through nitrogen-fixation, contributing to the ammonia and nitrate uptake (Cuet et al. 2011). It is possible that. with sufficient living reef biomass, the uptake of nutrients could be enhanced. An estimate of the maximum nutrient uptake in the high nutrient zones at Ma'alaea can be made assuming an appropriate rate constant and then multiplying times the concentration shown in Figures 27-30. Rate constants decrease when reef organisms are grown under high nutrient concentrations (Bilger and Atkinson 1995). We thus estimate that in the areas of impact denoted in Figures 27-30, there are more nutrients than necessary to maximize both the growth of algae and the production of organic carbon. As nutrients are not in limited supply, algae are limited by light, substratum and/or water movement.

Given sufficient available surface area, the nearshore reef exposed to the high nutrients will take up about 2 m d^{-1} x 1 mmol m^{-3} , which translates to (360 C:P x 2 mmol P m^{-2} d^{-1} = 720 mmol C m^{-2} d^{-1}). This is a maximum production of algal biomass and is a sufficient amount to support 1 kg of fish m^{-2}. Unfortunately, there are few fish and other large grazers in this region of the reef to consume the growth of algae. Sea urchins, which have been shown to be effective grazers on the outer reefs, cannot survive in the high energy nearshore area. As a result, whatever algae grows seems to accumulate in the nearshore zone.

If we assume a net removal of 2 mmol P m^{-2} d^{-1}, and about 60% of the N and P is taken up based on the mixing lines in Figures 36 and 37, the uptake is confined to an area of 30 m^2 m^{-1} of shoreline. This area does not have to be immediately adjacent to shore, but must be within the impact area delineated in Figures 27-31. Because the N:P ratio of the nutrients at the shoreline is about the same value as the N:P ratio in the algae (37 vs. 33), a similar calculation for nitrogen yields the same result. The greatest impact of the injection wells is the addition of phosphate to the nearshore environment. If the injection well phosphate were not present, the input of phosphate to the nearshore environment would decrease by a factor of 5 and the algal production would decrease by a factor of 3. However, there still would be algae present and most people would not see a dramatic difference to the community structure on the reef flat near the impact areas.

5. Comments on Nutrients and Coral Reefs

There is a pervasive, although incorrect, notion that corals and coral reefs can only survive in low nutrient water, and that any addition of nutrients is detrimental to corals. This viewpoint arose from the observation that nutrient concentrations over coral reefs are typically low. This observation was explained by assuming that nutrients were tightly “recycled” between plants and animals or that they were rapidly recycled through the water column. It is now known that neither explanation is true. Corals require nutrients to grow and they are very good at extracting nutrients from low nutrient concentration water; however, this does not have to be the case. For example, nearly 90 species of corals grow in the Waikiki Aquarium at nutrient concentrations similar to the highest concentrations found in Ma'alaea Bay beyond the impact zone: phosphate 0.7 mmol P m^{-3} ; nitrate 5-7 mmol N m^{-3} ; and ammonia 2-4 mmol N m^{-3} (Atkinson et al. 1995).

Furthermore, it has recently been shown that *Acropora muricata* growing in groundwater plumes of relatively high nitrate have more zooxanthellae, photosynthesize faster, calcify faster and show fewer effects of aragonite saturation state than the same species of coral growing in areas of the reef _not_ exposed to groundwater (Chauvin et al. 2011). It has also been shown that moderate nutrient loading to reefs enhances photosynthesis and calcification of corals (Landon and Atkinson 2005, Atkinson and Cuet 2009). Well-developed, highly-productive coral reefs harboring fast growing coral species thrive with elevated nitrate from groundwater input (Cuet et al 2010).

So, while the continued delivery of nutrients creates a perpetual mixing gradient from relatively high to low within Ma'alaea Bay, the levels beyond the nearshore area cannot be considered detrimental to reef growth, and they may even enhance growth.

6. ^{15}N and C:N:P Ratios in Algae

^{15}N has been used as an indicator of sewage input. Values of ^{15}N in algae collected along the beach fronting Ma'alaea Bay ranged from 2.8 to 6.4$^{o}/_{oo}$ (parts per thousand) (Table 4, Figure 38). However, the pattern of distribution of values along the shoreline does not suggest higher values in closer proximity to the condominiums. Rather, some of the lowest values occur directly in front of the condominiums. All of these values are sufficiently low enough that the nitrogen source could be completely marine or even a mixture of low ^{15}N agriculture nitrogen and groundwater. The low value is consistent with a relatively low percentage of nitrogen coming from the injection wells. If approximately 1/5 of the nutrients entering the coastal zone are removed by algae, then only 3% of the injection well N and 15% of P would be in the algae. Thus, the ^{15}N signal from the injection wells is greatly diluted by the ^{15}N from marine and fertilizer sources.

While the values of ^{15}N in algae along the shoreline do not provide an indication of substantial injection well effluent into algal biomass, the nutrient content of the algae does provide such a signal. Values of C, N, and P per unit algal biomass all prescribe a pattern with maximum values in the vicinity of the condominiums (Table 4, Figures 39-41). Comparison of the ratios of C:N, C:P and N:P (Figures 42-44) do not show a similar pattern of high values off the center of the Bay, likely because both N and P are in sufficient supply such that neither is limiting and both are utilized to maximum extent.

IV. CONCLUSIONS AND RECOMMENDATIONS

The main purpose of this study was to evaluate factors that may be responsible for significant declines in coral reef abundance in Ma'alaea Bay. This study was prompted by publication of results of an ongoing state-wide survey (DAR survey) of coral reefs that reported the demise of reefs in Ma'alaea Bay. Inherent in this purpose was to evaluate the role that injection wells, which serve the residential and business community of Ma'alaea, played in the perceived degradation of the reefs. Our extensive and intensive investigation of both the biotic and chemical composition of the nearshore marine environment revealed several important facts discussed below.

While the composition of the reef documented by the DAR survey does indeed appear to have been subjected (or is being subjected) to some form of stress sufficient to change the biotic character of the reef, these conditions do not occur uniformly throughout the Bay. Hence, extrapolation of the DAR results to the entire Bay cannot be considered valid. However, it is also apparent that while the surveys do not extend throughout the entirety of Maʻalaea, the DAR study has documented detrimental changes to reef community structure. Comparison of satellite images of Maʻalaea Bay from 2005 and 2010 reveals distinct changes to the reef, particularly on the eastern side of the harbor channel (Figure 45). While it is not possible in hindsight to determine what the composition of the entire reef community was in 2005, it appears to be substantially different than in 2010.

Analysis of water chemistry indicates there is a narrow zone (on the order of tens of meters wide) where groundwater with relatively high subsidies of nutrients enters the ocean, although this zone is restricted to the central portion of the Bay. Owing to the complicated hydrological structure of central Maui, determination of what could be considered "natural background" groundwater that is unaffected by the activities of man is not possible. However, it is evident that groundwater entering the ocean in central Maʻalaea is substantially subsidized in nutrients by leaching of fertilizers from large-scale agriculture that occupies the central region of Maui. This agricultural groundwater subsidy is further augmented with high nutrient sewage effluent from shallow injection wells located near the shoreline. The concentration of nutrients in the injection well effluent is higher than from agricultural sources, and the ratio of nitrogen to phosphorus indicates that the effluent is a larger source of phosphorus than agricultural sources. Hence, even though the nutrient subsidies from agricultural sources are far higher than injection wells in terms of volume, the injection wells contribute about 17% of the nitrogen and 74% of the phosphorus flowing to the shoreline in the central portion of Maʻalaea Bay.

The nearshore habitat in the central Bay subjected to these increased fluxes consists of dense algal communities; about 2/3 of the biomass of this algae can be attributed to response to injection well nutrient subsidies. The physical structure of the region (shallow water, hard bottom, abundant light) provides ideal conditions for species that occur in the area to flourish. As only two species comprise almost the entire algal community, it is evident that the physical conditions of the area are not suitable for a diverse algal community. It is likely that nutrients are not a limiting factor at present, nor would they likely be without the injection well inputs. With the elimination of the injection wells it is likely that dense algal cover would still exist in the shallow nearshore area, although probably not in the amount that occurs at present. However, as the region of maximum algal growth is not even remotely suitable for coral colonization, the possible reduction of algal mass with reduction of injection well nutrients is not likely to result in significant increases in coral occurrence on the nearshore reef flat.

A reef zone of large, reef-building corals with little indication of stress occurs directly off the area of the central Bay where nutrient input is documented to be maximal. Mixing of the nutrient subsidies entering the ocean at the shoreline to background open coastal ocean conditions occurs over the reef flat and does not extend to areas of optimal reef growth. In addition, the nutrient subsidies are confined to a surface layer within the upper two meters of the water column; hence, it never comes in contact with the reef. There is no reasonable mechanism for groundwater, regardless of what has affected its composition, to affect the offshore reef.

The reef surveyed by DAR, located at the edge of the Maʻalaea Harbor entrance channel, lies between the "healthy" reef offshore of the central Bay and the areas of peak groundwater input. If there are no effects from the groundwater inputs to the healthy reef, it is not likely they could be affecting the DAR sites. Rather, the DAR reef sites are far more likely to be affected by water discharging from the mouth of the Harbor, which has not been affected by injection wells. In addition, as discussed above, episodes of severe rainfall and sediment discharge that occurred after the present study may have impacted all of the reefs in the Bay. Comparison of this area in satellite images from 2005 and 2010 reveals distinct changes to reef structure over this interval, suggesting that some level of physical disturbance has altered the reef outside the harbor entrance (Figure 45).

Surveys of the reefs on the eastern side of the Bay reveal substantial damage to corals from deposition of wind-borne terrigenous sediment originating from agricultural fields. While the condition of the reef during the survey revealed recent high rates of deposition, the existence of living corals suggests that the cumulative level of stress has not been of a magnitude to be completely lethal over the many decades of agricultural operations. Further study would be required to determine the frequency and intensity of sediment depositional events. However, it is clear that sediment stress is exerting a negative effect to reefs in the east Bay, and any reduction in this stress would have a positive effect on reef structure.

While beyond the scope of this study to document or quantify sediment input to waters of Maʻalaea Bay resulting from severe rainfall events, anecdotal evidence suggests that such occurrences clearly occur. Satellite images from 2002, 2010 and 2011 following periods of high rainfall graphically depict the dispersion of stream-borne sediment plumes throughout the Bay (Figure 46). In fact, the winter of 2010-2011was characterized by several episodes of unusually high rainfall followed by flooding in the Maʻalaea area and substantial runoff to the ocean. Hence, the reef at present may be different in composition from what it was during the ground truth surveys carried out in 2010. In addition to stream-borne sediment, wind-transported sediment has also been documented as a source of impact to some of the reefs in Maʻalaea. While it is apparent that this stress has not caused total mortality, and that the reef has been able to withstand these inputs to date, it is likely that the reefs on the eastern Bay are not what they would be without the sediment stress.

The appearance of the reef outside of the harbor channel is consistent with the effect of peak storm events and subsequent high runoff. Partial and complete mortality of corals, bared substratum, and colonization by invasive algae are typical responses to episodes of sediment discharge and deposition. The location of the affected reef just outside the entrance channel to a harbor that serves as a central collection point for drainage also suggests the likelihood of such an event (although it is enigmatic that the coral community existing within the Harbor is thriving). A similar situation was documented in Honolua Bay on West Maui, where approximately 30% of the living coral within the inner bay was smothered as a result of runoff from a single rainfall event (Dollar and Grigg 2004).

While it is widely believed that reduction of injection well effluent disposal would be of benefit to the reef communities of Maʻalaea, the data gathered in this study do not support this belief. Based on our work, reduction of injection well discharge to the coastal ocean would likely have no effect on coral communities for several reasons (although it could result in reduced algal abundance in the nearshore zone). First, while the contribution of the wells to the total groundwater nutrient pool is sizeable, it is restricted to a very narrow nearshore zone that does not extend to the area of maximum reef growth. As a result, there is no potential for any change related to reducing algal growth through reduced nutrient growth. Within the restricted area where algae are extremely abundant, coral would not occur as a result of other environmental conditions. Hence, while there may be valid reason to recommend changes to the present injection well scenario in order to reduce algal abundance, such an action could not be recommended as a mechanism to promote coral reef growth (at least on ecological terms).

There are, however, substantial impacts to the reefs at east Maʻalaea resulting from episodes of high sediment input. While this documented input is through wind transport, and is a known historical occurrence, it is difficult to suggest remedial actions. Upland sources of sediment are extensive (Figure 47). While the apparent alteration of the reef may be a result of episodes of sediment input, it is certain that such events cause other damaging effects such as landside flooding and degradation of water quality. Hence, even if the decline in reef structure in the channel entrance area is not a direct response to sediment input, reduction of such events will have an overall benefit to the marine environment. Based on the results of this study, recommendations for changes in land uses aimed at benefiting the reefs should focus primarily on reduction of sediment input to the ocean.

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Appendix B: Calculations of nutrient input into Maalaea Bay

Variables:

Qg = total volume discharge of groundwater to the coast = 7.6 (m^3 d^{-1})/m of shoreline in sectors B and C (see Fig 26).

Ng = average of nitrate + nitrite +ammonium in groundwater.
Ng = 368 mmol N m^{-3} (Table 2)

Pg = average phosphate in groundwater
Pg = 3.2 mmol P m^{-3} (Table 2)

Qi = total volume discharge of the injection wells = 0.46 (m^3 d^{-1})/m of shoreline based on a length of shoreline from the west harbor at the boat ramp to the end of the condominiums near the Haycraft Park.

Ni = average concentration of nitrate + ammonium + nitrite in the injection wells.
Ni = 1357 mmol N m^{-3} (measured during this report; n=6)
Ni = 1168 mmol N m^{-3} (DOH injection well data; n=87)

Pi = average concentration of inorganic phosphate in the injection wells
Pi = 152 mmol P m^{-3} (data measured during this report; n=6)
Pi = 131 mmol P m-3 (DOH injection well data; n =87)

Ns = calculated concentration of inorganic nitrogen coming from groundwater plus injection wells at the shore (Eq 1A & Eq 1B)
Ps = calculated concentration of phosphate coming from groundwater plus injection wells at the shore (Eq 2A & Eq 2B)

Ns/Ps is the dissolved inorganic nitrogen to phosphate ratio of groundwater plus injection wells at salinity of groundwater.

Eq 1: Calculation of inorganic nitrogen input to near-shore water. Eq 1A is with the data measured during this study, and Eq 1B is with the data from DOH injection wells. In the text, for simplicity of the presentation, we take an average of the two values.

Eq 1A: Qi (Ni) + (Qg)Ng = (Qg+Qi)(Ns) = 0.46(1357) + (7.6)(368) = (7.6+0.46) (Ns) = 3421 mmol N d^{-1}/ m of shoreline. Ns = 424 mmol N m^{-3} at a salinity of groundwater

Eq 1B: Qi (Ni) + (Qg)Ng = (Qg+Qi)(Ns) = 0.46(1168) + (7.6)(368) = (7.6+0.46) (Ns) = 3334 mmol N d^{-1}/m of shoreline. Ns = 413 mmol N m^{-3} at a salinity of groundwater

Eq 2: Calculation of phosphate input to near-shore water. Eq 2A is with the data measured during this study, and Eq 2B is with the data from DOH injection wells. In the text, for simplicity of the presentation, we take an average of the two values.

Eq 2A: Qi (Pi) + (Qg)Pg = (Qg+Qi)(Ps) = 0.46(152) + (7.6)(3.2) = (7.6+0.46)(Ps) =
94 mmol P d^{-1}/ m of shoreline. Ps = 11.7 mmol P m^{-3} at a salinity of groundwater

Appendix B. continued.

Eq 2B: Qi (Pi) + (Qg)Pg = (Qg+Qi)(Ps) = 0.46(131) + (7.6)(3.2) = (7.6+0.46)(Ps) = 85 mmol P d^{-1}/m of shoreline. Ps = 10.5 mmol P m^{-3} at a salinity of groundwater

Eq 3: Inorganic nitrogen to phosphate ratio of groundwater.

Ng/Pg = 368/3.2 = 115

Eq 4: Inorganic nitrogen to phosphate ratio of injection well.

Eq 4A: Ni/Pi = 1357/152 = 8.9 data measured during this study
Eq 4B: Ni/Pi = 1168/131 = 8.9 DOH data

Eq 5: Calculation of inorganic nitrogen to phosphate ratio on near-shore water. N:P ratio can be used as a tracer of the injection well.

Eq 5A: Ns/Ps = 424/11.7 =36 data measurements during this study
Eq 5B: Ns/Ps = 413/10.5 =39 DOH data

Eq 6: Calculation of percent inorganic nitrogen from injection wells entering the shoreline

Qi(Ni) / 3378 = 0.46((1357+1168)/2)/(3421+3334)/2 =17%

Eq 7: Calculation of percent phosphate from injection wells entering the shoreline.

Qi(Pi) / 90 = 0.46(131+152)/2)/(85+94)/2 = 73%

TABLE 1-1. Locations (site # and longitude/latitude) and benthic cover estimates of calibration/validation points for Maalaea Bay reef mapping collected on June 25, 2010. Abbreviations are: LS=limestone; CCA=crustose coralline algae; TBS= turf-bound sediment; INV=invetebrates such as sponges; DEAD=dead coral.

25-Jun-2010

SITE	LONGITUDE	LATITUDE	TIME	CORAL	ALGAE	TURF	SAND	LS	DEAD	CCA	RUBBLE	TBS	MUD	INVERT
101	-156.5111	20.7889	8:24:44	6	0	18	35.2	0.4	0	0	0	40	0	0.4
102	-156.5114	20.7888	8:26:58	1.4	0	6	64.4	2	0	0	0	25	0	1.2
103	-156.5117	20.7887	8:28:07	0	0	6	53	0	0	0	0	41	0	0
104	-156.5121	20.7886	8:31:17	0	0.2	4	37	0.4	0	0	0	58.2	0	0.2
105	-156.5121	20.7883	8:32:52	0	0	9	51	0	0	0	0	39.6	0	0.4
106	-156.5123	20.7880	8:35:15	0	0	3	67	0.6	0	0	0	29	0	0.4
107	-156.5124	20.7878	8:37:48	0	24	0	67	0	0	0	0	9	0	0
108	-156.5126	20.7874	8:40:30	0.8	18	0	74.2	0	0	0	0	7	0	0
109	-156.5127	20.7871	8:42:39	0.2	5	55.8	25	0	0	0	0	14	0	0
110	-156.5128	20.7868	8:44:40	0	10.4	0	28.6	0	0	0	0	61	0	0
111	-156.5129	20.7865	8:46:35	0	0	0	91	0	0	0	0	9	0	0
112	-156.5131	20.7864	8:48:38	0	11	3	39	0	0	0	0	47	0	0
113	-156.5133	20.7862	8:50:42	0	0	0	100	0	0	0	0	0	0	0
114	-156.5135	20.7860	8:53:00	0	7	0	75	0	0	0	0	18	0	0
115	-156.5137	20.7859	8:54:37	0	5.4	1	61	0	0	0	0	32.6	0	0
116	-156.5139	20.7858	8:56:25	0	5.4	0	53	0	0	0	0	41.6	0	0
117	-156.5141	20.7856	8:58:07	0	6.2	6.2	45	0	0	0	0	42.6	0	0
118	-156.5142	20.7855	9:00:08	0	12	0	55	0	0	0	0	32.4	0	0.6
119	-156.5144	20.7855	9:02:02	0	5	4	59	0	0	0	0	32	0	0
120	-156.5017	20.7945	9:29:50	0.2	0	2	73	0	1	0	0	23	0	0.8
121	-156.5020	20.7943	9:31:31	0	11	0	89	0	0	0	0	0	0	0
122	-156.5023	20.7943	9:33:13	3.6	0	0	5	0	0	0	0	0	90.4	1
123	-156.5028	20.7942	9:36:24	5.2	0	0	35.8	0	0	0	0	57.8	0	1.2
124	-156.5029	20.7941	9:38:24	18.6	0	0	4.8	0	0	0	0	0	75	1.6
125	-156.5033	20.7941	9:40:40	0	0	8	92	0	0	0	0	0	0	0
126	-156.5035	20.7936	9:44:17	0.4	15.4	0	28	0	0	0	0	55.2	0	1
127	-156.5039	20.7934	9:48:25	0	7	0	91	0	0	0	0	2	0	0
128	-156.5044	20.7934	9:51:51	23.2	0	0	18.8	0	0	0	0	58	0	0
129	-156.5049	20.7935	9:54:42	75.4	0	0	0	1.4	0	0	0	0	23	0.2
130	-156.5051	20.7933	9:56:39	48.6	0	0	1	0	2	0	0	0	48.2	0.2
131	-156.5053	20.7932	10:00:06	0	0	16	52.8	0	0	0	0	31	0	0.2
132	-156.5057	20.7932	10:02:53	80.6	0	0	0	0	0	0	0	0	18.2	1.2
133	-156.5058	20.7930	10:05:13	57.4	0	0	14	0	0	0	0	0	28.4	0.2
134	-156.5058	20.7930	10:15:06	83.6	0	0	3.4	0	0	0	0	0	12	1
135	-156.5058	20.7928	10:16:32	88.4	0	0	0	0	0	0	0	0	11.6	0
136	-156.5059	20.7927	10:17:47	95.7	0	0	0	0	0	0	0	0	3	1.2
137	-156.5058	20.7926	10:19:35	64	0	0	6.6	0	14	3	0	6	6	0.4
138	-156.5058	20.7924	10:21:50	40.8	0	0	2.6	0	7.4	0	0	7.4	39.4	2.4
139	-156.5058	20.7922	10:23:24	45	0	0	0	0	0	0	0	53.8	0	1.2
140	-156.5060	20.7921	10:25:32	58.4	0	0	2	0	4.8	0	0	0	34.6	0.2
141	-156.5061	20.7921	10:27:21	0	0	0	99.5	0	0	0	0	0.5	0	0
142	-156.5063	20.7920	10:30:04	71	0	0	0	9	0	0	0	0	18.4	1.6
143	-156.5063	20.7918	10:31:45	77.8	0	0	11	0	0	1.4	0	0	9.6	0.2
144	-156.5065	20.7918	10:34:08	68.8	0	0	1	0	8	0	0	0	21.4	0.8
145	-156.5066	20.7917	10:35:29	90.8	0	0	0	0	6	0	0	0	2	1.2
146	-156.5067	20.7915	10:38:09	54.8	0	0	0	0	6	0	0	0	37	2.2
147	-156.5066	20.7913	10:39:50	34	0	0	1	0	6	0	0	0	58.2	0.8
148	-156.5066	20.7912	10:42:00	32.2	0	0	3	0	4.2	0	0	0	58.4	2.2
149	-156.5066	20.7911	10:43:32	22.6	0	0	2	0	4.8	0	0	0	69	1.6
150	-156.5068	20.7910	10:45:25	33.8	0	0	10	0	5	0	0	10	40	1.2
151	-156.5069	20.7910	10:47:06	34.4	0	0	26	0	3	0	0	27	9.4	0.2
152	-156.5072	20.7909	10:49:02	33.4	0	0	6.8	0	5.6	0	0	54	0	0.2
153	-156.5074	20.7908	10:51:14	15	0	0.4	2	0	3	0	0	79.4	0	0.2
154	-156.5075	20.7906	10:53:19	0.8	0	0	5.6	11.4	0	0	0	81.2	0	1
155	-156.5075	20.7904	10:55:42	0	0	0	10	1.4	6	0	0	80.6	0	2
156	-156.5077	20.7903	10:57:00	1	0	0	0	35	1	0	0	62	0	1
157	-156.5079	20.7903	10:59:00	1.4	0	0	12	5	0	0	0	81	0	0.6
158	-156.5082	20.7903	11:01:08	48.6	0	0	0.6	0	5.6	10	0	35.2	0	0
159	-156.5082	20.7901	11:03:02	15	0	0	6	6	0	0	0	72	0	1
160	-156.5084	20.7899	11:05:27	0	0	0	0	37	0	0	0	61.6	0	1.4
161	-156.5086	20.7898	11:07:24	1.4	0	0	0.6	25	0	0.6	0	71.2	0	1.2
162	-156.5089	20.7898	11:10:39	7.6	0	72.2	0	15	1	2	0	0	0	2.2
163	-156.5090	20.7898	11:12:10	40.4	0	26.6	2	0	4.8	1	0	25.2	0	0
164	-156.5091	20.7897	11:13:41	40	0	2	7	0	2	1	0	50	0	0
165	-156.5093	20.7897	11:15:42	39.8	0	34.4	1	0	7	0	0	17	0	0.8
166	-156.5095	20.7896	11:17:40	6.4	0	16	0	16	3.4	0	0	58	0	0.2
167	-156.5097	20.7896	11:19:52	2.8	0	73	8	2	0	0	0	14.2	0	0

TABLE 1-2. Locations (site # and longitude/latitude) and benthic cover estimates of calibration/validation points for Maalaea Bay reef mapping collected on on June 26, 2010. Abbreviations are: LS=limestone; CCA=crustose coralline algae; TBS= turf-bound sediment; INV=invetebrates such as sponges; DEAD=dead coral.

26-Jun-2010

SITE	LONGITUDE	LATITUDE	DATE	TIME	CORAL	ALGAE	TURF	SAND	LS	DEAD	CCA	RUBBLE	TBS	MUD	INVERT
201	-156.4766	20.7891	6/26/2010	7:46:00	40.8	0	0	2	0	0	2	0	0	55.2	0
202	-156.4768	20.7892	6/26/2010	7:47:07	86.4	0	0	0	0	0	1.6	0	0	12	0
203	-156.4768	20.7893	6/26/2010	7:49:58	71.8	0	0	0	0	0	0.6	0	0	28	0.2
204	-156.4770	20.7892	6/26/2010	7:52:44	58.6	0	0	1	0	0	1	0	0	39.4	0
205	-156.4772	20.7893	6/26/2010	7:55:12	51.4	0	0	4.6	0	0	0	0	0	43.6	0.4
206	-156.4773	20.7895	6/26/2010	7:57:05	71	0	0	0	0	0	0	0	0	29	0
207	-156.4773	20.7897	6/26/2010	7:59:45	60.8	0	0	1	0	0	0.8	0	0	37.2	0.2
208	-156.4776	20.7896	6/26/2010	8:01:33	73.2	0	0	0.8	0	0	0	0	0	26	0
209	-156.4778	20.7897	6/26/2010	8:04:45	69.4	0	0	0	0	0	0	0	0	30.6	0
210	-156.4780	20.7897	6/26/2010	8:07:09	9.8	0	0	6.8	1.4	0	0	0	1	79.8	1.2
211	-156.4781	20.7899	6/26/2010	8:09:35	71.2	0	0	1	0.6	0	0	0	0	27	0.2
212	-156.4782	20.7901	6/26/2010	8:12:33	74	0	0	0	0	0	0	0	0	26	0
213	-156.4784	20.7901	6/26/2010	8:14:22	8.4	0	0	11	0	13	0	0	0	66.4	1.2
214	-156.4786	20.7902	6/26/2010	8:16:54	2.5	0	0	8.8	0	0	0	0	26.2	61.8	0.8
215	-156.4788	20.7902	6/26/2010	8:19:18	3.4	0	0	1	3.2	0	0	0	90.2	0	2.2
216	-156.4789	20.7905	6/26/2010	8:22:12	1.4	0	0	26	3.2	0	0	0	68.8	0	0.6
217	-156.4791	20.7907	6/26/2010	8:25:02	14.8	0	5	11	0.4	0	0	0	68	0	0.8
218	-156.4889	20.7944	6/26/2010	9:05:11	0	0	0	100	0	0	0	0	0	0	0
219	-156.4891	20.7945	6/26/2010	9:06:03	16.2	0	0	9.2	0.8	0	0	0	72.8	0	1
220	-156.4893	20.7948	6/26/2010	9:07:41	20	0	0	0	5.6	5	0	0	68.4	0	1
221	-156.4895	20.7948	6/26/2010	9:09:46	11.8	0	0	0	2.2	0	0	0	84.8	0	1.2
222	-156.4897	20.7949	6/26/2010	9:11:51	45.2	0	0	25	0	0	0	0	18.5	11.2	0
223	-156.4899	20.7948	6/26/2010	9:14:42	38.8	0	0	4	0	1	0	0	0	55.8	0.4
224	-156.4902	20.7947	6/26/2010	9:18:17	36.2	0	5	0	0.6	2	0	0	55.4	0	0.8
225	-156.4904	20.7947	6/26/2010	9:20:56	15.8	0	9	0	0.6	2.2	0	0	71.4	0	1
226	-156.4906	20.7946	6/26/2010	9:23:00	15.6	0	3	2	0.6	0	0	0	77.8	0	1
227	-156.4908	20.7947	6/26/2010	9:27:05	15.8	0	1	3	0	6.4	0.4	0	73	0	0.4
228	-156.4910	20.7949	6/26/2010	9:28:42	48.2	0	0	0	0	7.5	0	0	0	44	0.2
229	-156.4913	20.7950	6/26/2010	9:32:04	16	0	1	5.6	2.4	3	0	0	71.2	0	0.8
230	-156.4916	20.7950	6/26/2010	9:34:37	13	0	4	2	1	0	0	0	79.6	0	0.4
231	-156.4918	20.7949	6/26/2010	9:37:05	13.4	0	0	8	1	0	0	0	68.2	9	0.4
232	-156.4921	20.7948	6/26/2010	9:39:16	19.2	0	1	0	1	0	1	0	26.6	50.4	0.8
233	-156.4922	20.7947	6/26/2010	9:43:58	20.6	0	0	3.2	0	0	0	0	53.4	22	0.8
234	-156.5012	20.7940	6/26/2010	10:05:26	0.8	0	0	42.5	2	0	0	0	51.8	0	3
235	-156.5014	20.7940	6/26/2010	10:06:59	0	3	0	66	0	0	0	0	30.2	0	0.8
237	-156.5019	20.7938	6/26/2010	10:12:11	0	0.3	0	0	0	0	0	0	6.7	90.7	2.3
241	-156.5031	20.7938	6/26/2010	10:25:09	3.2	0	0.2	43	0	0	0	0	43.3	0	1
242	-156.5033	20.7936	6/26/2010	10:27:14	0	0	0	50	0	0	0	0	5	45	0
245	-156.5041	20.7933	6/26/2010	10:35:32	0	17.5	0	0	0	0	0	0	0	82.5	0
246	-156.5043	20.7933	6/26/2010	10:37:24	0	2.6	0	89.2	0	0	0	0	8	0	0.2
247	-156.5046	20.7932	6/26/2010	10:39:58	0	15	0	85	0	0	0	0	0	0	0
248	-156.5049	20.7931	6/26/2010	10:42:36	0	0	0	100	0	0	0	0	0	0	0
249	-156.5051	20.7931	6/26/2010	10:44:51	49.2	0	0	23.2	0	0	0	0	15.8	11	0.8
250	-156.5054	20.7930	6/26/2010	10:47:09	0	0.8	0	86.5	0	0	0	0	12.5	0	0.2
251	-156.5055	20.7929	6/26/2010	10:50:43	0	2.6	0	72.2	0	0	0	0	25	0	0.2
252	-156.5056	20.7927	6/26/2010	10:53:17	55.2	0.4	0	13	0	0	0.6	0	14.4	16.4	0
253	-156.5057	20.7925	6/26/2010	10:55:47	8	0.4	0	46	0	0	0	0	44.6	0	1
256	-156.5059	20.7920	6/26/2010	11:04:05	3.4	0	3.6	13	3	2	0.4	0	72.2	0	2.4
258	-156.5061	20.7917	6/26/2010	11:08:40	0	0	0	100	0	0	0	0	0	0	0
259	-156.5064	20.7916	6/26/2010	11:10:41	50.4	0	1	11.6	0	4	0	0	27	0	0.2
260	-156.5065	20.7914	6/26/2010	11:12:33	28.4	0	5	7	0	3.4	1	0	53.6	0	1.6
261	-156.5065	20.7913	6/26/2010	11:15:06	0	0	0	40	0	0	0	0	59.2	0	0.8
262	-156.5065	20.7911	6/26/2010	11:17:08	3	0	0	13.4	1.6	0	1	0	80.6	0	0.4
263	-156.5066	20.7910	6/26/2010	11:19:26	5.6	0.4	1	10	1.2	0	1.4	0	79	0	1.4
264	-156.5066	20.7908	6/26/2010	11:22:09	4.4	0	0	65.8	0	0	0	0	29	0	0.8
265	-156.5068	20.7908	6/26/2010	11:24:27	7	1.2	1	36.2	1	0	0	0	52	0	1.6
266	-156.5071	20.7907	6/26/2010	11:26:26	27.2	0	3	5	0	0	0	0	64.2	0	0.6
267	-156.5071	20.7905	6/26/2010	11:28:37	2	0	2	21	2	0.6	0.6	0	70.4	0	1.4
268	-156.5073	20.7906	6/26/2010	11:30:33	25.6	3	2	8.8	0	3.4	0	0	56.6	0	0.6
269	-156.5074	20.7905	6/26/2010	11:33:05	19.6	0	8	11	2	0	0	0	58.6	0	0.8
270	-156.5074	20.7903	6/26/2010	11:34:52	8.6	1	2.6	12	3.8	7	0.6	0	61.4	0	3

TABLE 1-3. Locations (site # and longitude/latitude) and benthic cover estimates of calibration/validation points for Maalaea Bay reef mapping collected on June 27, 2010. Abbreviations are: LS=limestone; CCA=crustose coralline algae; TBS= turf-bound sediment; INV=invetebrates such as sponges; DEAD=dead coral.

27-Jun-2010

SITE	LONGITUDE	LATITUDE	TIME	CORAL	ALGAE	TURF	SAND	LS	DEAD	CCA	RUBBLE	TBS	MUD	INVERT
301	-156.5097	20.7885	7:41:59	0.2	12	0	87.6	0	0	0	0	0	0	0.2
302	-156.5098	20.7886	7:43:59	2.6	12	0	20.8	3	0	0	0	60	0	1.6
303	-156.5098	20.7887	7:48:00	8.2	0.8	0	1	0	6.4	0	0	80	0	3.6
304	-156.5098	20.7888	7:50:59	0.2	0	14	2	2	0	0	0	80.6	0	1.2
305	-156.5098	20.7890	7:52:00	35.4	0	6	2	1	2	0	0	50.4	0	3.2
306	-156.5098	20.7891	7:56:00	23.2	1.2	3.8	0	0	3.5	1.2	20.5	43.2	0	3.2
307	-156.5098	20.7892	7:57:59	9.8	0.6	4	1.4	18	0	0	3	60.8	0	2.4
308	-156.5099	20.7893	7:59:59	15.4	0.4	10	1	0	14	3	5.4	50.4	0	0.4
309	-156.5099	20.7894	8:01:00	21.8	0	3	0	3	0	2	13	56.4	0	0.8
310	-156.5099	20.7894	8:03:59	31.6	0	4	0	2	0	3	15	44.2	0	0.2
311	-156.5100	20.7896	8:06:00	18.8	2	1	0	5.4	2	4	0	66.8	0	0
312	-156.5099	20.7897	8:08:59	7.8	0	68.2	18	0	0	0	0	6	0	0
313	-156.5098	20.7896	8:10:59	4	3	66	23	0	0	0	4	0	0	0
314	-156.5097	20.7895	8:12:59	3.4	1	2	0	0	0	0	30	62.8	0	0.8
315	-156.5096	20.7894	8:14:00	15.8	0	10	1	25	0	1	1	44.6	0	1.6
316	-156.5095	20.7893	8:15:59	0	14	45	41	0	0	0	0	0	0	0
317	-156.5095	20.7892	8:17:59	0	45	25	30	0	0	0	0	0	0	0
318	-156.5094	20.7891	8:19:00	0	29	35	36	0	0	0	0	0	0	0
319	-156.5093	20.7889	8:21:00	0.4	28	15	54.6	0	0	0	2	0	0	0
320	-156.5092	20.7887	8:23:00	0	19	42	39	0	0	0	0	0	0	0
321	-156.5091	20.7885	8:24:59	0	28	0	72	0	0	0	0	0	0	0
322	-156.5089	20.7888	8:26:59	0	32	0	68	0	0	0	0	0	0	0
323	-156.5090	20.7890	8:28:59	1	46	9	44	0	0	0	0	0	0	0
324	-156.5090	20.7892	8:30:00	0	35	2	63	0	0	0	0	0	0	0
325	-156.5090	20.7894	8:32:00	10	0	13.8	1.2	3.8	0.8	0	0	69.8	0	0.8
326	-156.5092	20.7895	8:33:00	2.6	0	6	8	6	2	0	7	65.6	0	2.8
327	-156.5091	20.7897	8:35:59	22.2	0	9	0	0	14	4	1	49	0	0.8
328	-156.5089	20.7897	8:37:59	26.4	0	10	2	5	8	0	0	47	0	1.6
329	-156.5087	20.7896	8:39:59	0	17	14	69	0	0	0	0	0	0	0
330	-156.5086	20.7898	8:42:59	0	0	9	52.2	0	0	0	0	37.6	0	1.2
331	-156.5087	20.7899	8:44:59	5	0	13	0	10	0	0	4	67.4	0	0.6
332	-156.5085	20.7900	8:46:00	6	0.6	37.4	0	3	2	0.6	3	46.6	0	0.8
333	-156.5085	20.7903	8:48:59	2.6	2	67.4	9	1	0	0.6	0	17.4	0	0
334	-156.5083	20.7903	8:51:59	57	0	16.2	1.6	0	0	15	0	10	0	0.2
335	-156.5081	20.7902	8:53:59	10.6	0	10	0	1	1	3	2	71.8	0	0.6
336	-156.5079	20.7902	8:55:00	3.4	1.2	11.8	0	5	0	0	1	76.8	0	0.8
337	-156.5078	20.7903	8:57:59	1.6	1	11	19.4	7	0	0	1	57.8	0	1.2
338	-156.5087	20.7890	9:20:00	0.2	8.4	25.6	31	1	0	0	0	33.4	0	0.4
339	-156.5087	20.7892	9:24:00	0	20	6	67.4	0	0	0	0	6	0	0.6
340	-156.5086	20.7895	9:24:59	14.7	0	41.8	0	0.8	0	0.5	1.2	40.2	0	0.8
341	-156.5084	20.7896	9:27:00	0.2	0	23	35	0	0	0	1	40.6	0	0.2
342	-156.5083	20.7895	9:29:59	1	12	15	39	0	0	0	0	33	0	0
343	-156.5082	20.7894	9:33:00	32	0	12.5	1.2	0	2.5	1.2	0	47.5	0	3
344	-156.5079	20.7894	9:35:00	0.6	25	30.4	43.8	0	0	0	0	0	0	0.2
345	-156.5078	20.7895	9:36:59	1	3.2	0	0	0	8	0	1	81.8	0	5
346	-156.5079	20.7897	9:38:59	0	7.5	45	37.5	0	0	0	0	10	0	0
347	-156.5080	20.7900	9:42:00	3.8	0	24	0	2.6	0	0.4	2.6	66.2	0	0.4
348	-156.5079	20.7902	9:44:00	3.2	0	8	0	18	2	0.6	4	63.2	0	1
349	-156.5077	20.7901	9:45:59	1.2	0	34	0	4.6	0	0	0	59.6	0	0.6
350	-156.5075	20.7901	9:49:00	3.6	0	41.6	4	0	2	0	0	48.2	0	0.6
351	-156.5074	20.7899	9:51:59	0.4	7	13	32	0	0	0	0	46.8	0	0.8
352	-156.5076	20.7896	9:54:00	0.2	8.2	57.2	30	0	0	0	0	4	0	0.4
353	-156.5076	20.7898	9:56:59	0	8	61	17	2	0	0	0	11.6	0	0.4
354	-156.5077	20.7900	9:58:59	3.8	0	23	14	0	10	0	0	48.2	0	1
355	-156.5108	20.7879	10:12:00	0.4	5	46.6	39	0	0	0	0	9	0	0
356	-156.5109	20.7881	10:14:00	0.6	1	28	70	0	0	0	0	0	0	0.4
357	-156.5111	20.7883	10:16:00	0.2	0	29	62.4	0	0	0	0	8	0	0.4
358	-156.5113	20.7884	10:18:00	0.8	0	10	4	6	0	0	2	74.6	0	2.6
359	-156.5114	20.7882	10:21:00	0	12	4	84	0	0	0	0	0	0	0
360	-156.5112	20.7882	10:23:00	0	7	28	65	0	0	0	0	0	0	0
361	-156.5111	20.7879	10:25:00	0	7	39	53.4	0	0	0	0	0	0	0.6
362	-156.5111	20.7877	10:27:00	0	10	31	57.6	0	0	0	0	1	0	0.4
363	-156.5109	20.7875	10:29:00	1	2	28	6	0.6	1.2	0.4	0	59.6	0	1.2
364	-156.5107	20.7875	10:32:00	0.8	8	26	20.8	1.6	1.6	0	0	39.6	0	1.6
365	-156.5105	20.7876	10:34:00	6	1	0	22.4	1.6	0	0.4	0	65.8	0	2.8
366	-156.5103	20.7878	10:36:00	0	10	15	69	0	0	0	0	6	0	0
367	-156.5103	20.7881	10:39:00	0.8	7	1	56.6	1	0	0	0	32.8	0	0.8
368	-156.5102	20.7884	10:41:00	0	10	8	76.8	0	0	0	0	5	0	0.2
369	-156.5100	20.7882	10:43:59	0	11	8	71	0	0	0	0	10	0	0
370	-156.5100	20.7879	10:47:00	0	5.5	5.8	38.8	0	0	0	0	50	0	0
371	-156.5100	20.7877	10:48:59	0	37	0	63	0	0	0	0	0	0	0

TABLE 1-4. Locations (site # and longitude/latitude) and benthic cover estimates of calibration/validation points for Maalaea Bay reef mapping collected on November 4, 2010. Abbreviations are: LS=limestone; CCA=crustose coralline algae; TBS= turf-bound sediment; INV=invetebrates such as sponges; DEAD=dead coral.

4-Nov-2010

SITE	LONGITUDE	LATITUDE	TIME	CORAL	ALGAE	TURF	SAND	LS	DEAD	CCA	RUBBLE	TBS	MUD	INVERT
483	-156.5000	20.7953	9:36:59	26.8	1	0	5	0	11	1	0	52.6	0	2.6
484	-156.5001	20.7953	9:38:00	35.6	0	12.6	5	0	20.2	2	0	23.2	0	1.4
485	-156.5003	20.7953	9:40:00	47.6	0	2	9	0	7.8	1	0	32.6	0	0
487	-156.5004	20.7955	9:42:00	12.8	0	24	0	0	50.6	5	0	6	0	1.6
488	-156.5004	20.7956	9:44:00	3	0	16.7	1.7	5	0	1	0	72.3	0	0.3
489	-156.5005	20.7958	9:45:00	0.2	32	41.8	3	0	0	0	0	23	0	0
490	-156.5005	20.7959	9:49:00	0	40	55	0	0	0	0	5	0	0	0
491	-156.5008	20.7959	9:51:00	1.7	51.7	33.3	10	0	0	0	0	3.3	0	0
492	-156.5010	20.7957	9:53:00	0	31	50.8	12	0	0	0	0	6	0	0.2
493	-156.5011	20.7955	9:54:59	0	38	29	2	18	0	0	0	13	0	0
494	-156.5011	20.7954	9:56:59	0.6	0	0	0	19	0	0	0	79	0	1.4
495	-156.5012	20.7952	9:58:59	11	0.5	0	0	3.8	6.8	0	0	75	0	3
496	-156.5012	20.7950	10:00:59	7	0	1	17	1.4	3.4	0	0	68.6	0	1.6
497	-156.5013	20.7949	10:02:00	8.6	0	5	2	1	7	0	0	73.2	0	3.2
498	-156.5014	20.7947	10:03:59	0	0.6	0	48	0.6	0	0	0	50	0	0.8
499	-156.5015	20.7948	10:05:00	0	0	0	60.5	0	0	0	0	39.2	0	0.2
500	-156.5017	20.7949	10:07:00	0	0.2	0	94.2	0	0	0	0	5.6	0	0
501	-156.5017	20.7953	10:09:00	20	0	1.4	10.2	0	20.8	2	0	42.8	0	2.8
502	-156.5017	20.7955	10:11:00	1.8	1	0	10	6.8	0	0	0	78.8	0	1.6
503	-156.5018	20.7956	10:12:59	0.4	29	25.6	22	2	0	2	0	19	0	0
504	-156.5017	20.7958	10:14:59	1.2	65	26.2	6.2	0	0	1.2	0	0	0	0
505	-156.5018	20.7960	10:16:00	0	40	50	7.5	0	0	0	0	2.5	0	0
506	-156.5020	20.7958	10:18:59	0	35	41	20	0	0	0	0	4	0	0
507	-156.5022	20.7957	10:21:00	0	24	30	13	0	0	0	0	33	0	0
508	-156.5022	20.7954	10:21:59	0	0	0	100	0	0	0	0	0	0	0
509	-156.5026	20.7957	10:25:00	10.2	0.8	0	36.2	4	0	0	0	47	0	1.7
510	-156.5030	20.7960	10:27:59	0	0	0	100	0	0	0	0	0	0	0
511	-156.5032	20.7960	10:29:00	0	8	0	21.2	0	0	0	0	70.8	0	0
512	-156.5033	20.7961	10:30:59	0	71.2	0	15	13.8	0	0	0	0	0	0
513	-156.5035	20.7959	10:34:00	0.2	45	12	0	42.8	0	0	0	0	0	0
514	-156.5037	20.7958	10:36:00	0	16.8	0	53.2	0	0	0	0	30	0	0
515	-156.5039	20.7958	10:38:00	0	14	0	82.6	0	0	0	0	3.4	0	0
516	-156.5041	20.7953	10:43:00	0	25	0	12.5	1.2	0	1.2	0	60	0	0
517	-156.5044	20.7951	10:45:00	0.8	0	0	50.6	5	0	0	0	43	0	0.6
518	-156.5047	20.7952	10:47:00	0.2	33.8	0	20	0	0	0	0	46	0	0
519	-156.5048	20.7953	10:48:59	12.5	16.2	25	13.8	0	0	0	0	32	0	0.5
520	-156.5048	20.7950	10:52:59	14	32	0	52.6	0	0	0	0	1	0	0.4
521	-156.5049	20.7946	10:56:00	0	8.2	19.8	47.8	0	0	0	0	24	0	0.2
522	-156.5049	20.7942	10:59:00	24.8	0	0	2.2	1	13.8	0	0	57	0	1.2
524	-156.5048	20.7941	11:01:00	42.2	0	6.2	8.8	0	7.5	0	0	34.8	0	0.5
525	-156.5067	20.7913	12:09:59	53.4	0	0	1	0	14.2	0	0	29.6	0	1.8
526	-156.5067	20.7914	12:11:00	73.2	0	11	0	0	5	0	0	9.8	0	1
527	-156.5067	20.7915	12:13:00	54.4	0	10	0	0	19	0	0	16	0	0.6
528	-156.5067	20.7917	12:15:00	57	0	9	0	3.8	7	0	0	23	0	0.2
529	-156.5068	20.7918	12:17:00	31	13.8	28	2	4.6	0	0	0	20.6	0	0
530	-156.5069	20.7920	12:18:59	12.2	35	34.2	4	2	0	0	0	12.4	0	0.2
531	-156.5071	20.7920	12:20:59	1.6	83.4	7	8	0	0	0	0	0	0	0
532	-156.5070	20.7917	12:24:00	13.6	40	26.4	5	2	0	0	0	11	0	2
533	-156.5070	20.7915	12:26:00	20.6	27	36.8	2	3	0.6	0	0	10	0	0
534	-156.5069	20.7914	12:27:59	66.8	0	21	0	0	11	0	0	0	0	1.2
535	-156.5068	20.7914	12:29:00	66.8	0	2	0	0	23.2	1	0	6	0	1
536	-156.5067	20.7912	12:31:00	83	0	5.4	1.6	0	5	0	0	4.8	0	0.2
537	-156.5068	20.7910	12:33:00	22.4	0	7	11	7	2	0	0	50	0	0.6
538	-156.5068	20.7908	12:35:00	3	0	10	21.2	13.8	6.2	0	0	44.8	0	1
539	-156.5070	20.7908	12:36:59	32.2	0	14	6	0	9.8	0	0	35.8	0	2.2
540	-156.5070	20.7910	12:38:59	70	0	10	1	0	12	0	0	6	0	1
541	-156.5070	20.7913	12:42:00	56.7	0	28.8	0	0	0	0	0	14.5	0	0
542	-156.5069	20.7913	12:42:59	61.6	0	12	0	0	26	0	0	0	0	0.4
543	-156.5069	20.7914	12:45:00	22	0	42.8	17.5	0	6.2	1.2	0	10	0	0.2
544	-156.5071	20.7922	13:03:00	0.3	68	18.3	13.3	0	0	0	0	0	0	0
545	-156.5071	20.7920	13:05:59	2.3	64.3	18.3	15	0	0	0	0	0	0	0
546	-156.5070	20.7919	13:07:00	16.8	23	37.8	3	5	0	0	0	11.2	0	3.2
547	-156.5070	20.7917	13:09:59	21.2	32	38.2	0	1	0	0	0	7	0	0.6
548	-156.5069	20.7915	13:11:00	29.8	0	16	2	0	18.4	0	0	33.8	0	0
549	-156.5068	20.7913	13:12:59	85.4	0	9	0	0	5.4	0	0	0	0	0.2
550	-156.5067	20.7911	13:14:59	54.2	0	5.4	3.4	0	7.6	0	0	29	0	0.4
551	-156.5068	20.7909	13:16:59	5.4	0.4	10	12	2	6	0	0	62.8	0	1.4
552	-156.5070	20.7910	13:18:59	64.8	0	7	1	0	13.2	0	0	13.2	0	0.8
553	-156.5071	20.7912	13:21:00	53.8	0	27.6	2.4	0	5.6	0	0	10.4	0	0.2
554	-156.5071	20.7914	13:23:00	9.8	16.2	39.4	8	1	2	0	0	23.6	0	0
555	-156.5073	20.7914	13:25:00	2.2	3	74.2	11	0	0	0	0	0	0	9.6
556	-156.5076	20.7912	13:27:59	16.8	2	53.6	13	0	5	0	0	6	0	3.6
557	-156.5077	20.7909	13:30:00	29.5	0.5	22.5	0	15	2.5	0	0	28.2	0	1.8
558	-156.5078	20.7906	13:32:00	17.4	0	22	5	3	4	0	0	48.4	0	0.2

TABLE 1-5. Locations (site # and longitude/latitude) and benthic cover estimates of calibration/validation points for Maalaea Bay reef mapping collected on December 1, 2010. Abbreviations are: LS=limestone; CCA=crustose coralline algae; TBS= turf-bound sediment; INV=invetebrates such as sponges; DEAD=dead coral.

1-Dec-10

SITE	LONGITUDE	LATITUDE	TIME	CORAL	ALGAE	TURF	SAND	LS	DEAD	CCA	RUBBLE	TBS	MUD	INVERT
655	-156.5048	20.7941	7:43:02	31.4	0	5	9.4	0	19.6	0	0	31.6	0	3
656	-156.5048	20.7944	7:45:10	2	0	0	38	0.4	4	0	0	55.2	0	0.4
657	-156.5049	20.7946	7:46:54	0	7	18	44	0	0	0	0	31	0	0
658	-156.5049	20.7950	7:49:09	0	22.2	6.8	63	0	0	0	0	8	0	0
659	-156.5050	20.7951	7:51:30	0	21.2	8.8	60	0	0	0	0	10	0	0
660	-156.5054	20.7948	7:54:52	0	11	65.6	7	0	0	0	0	16	0	0.4
661	-156.5056	20.7945	7:57:08	0	13	20.6	34	0	0	0	0	32	0	0.4
662	-156.5059	20.7944	7:59:05	0	30	22	33	0	0	0	0	15	0	0
663	-156.5061	20.7941	8:01:16	0	17	51.8	14	0	0	0	0	17	0	0.2
664	-156.5062	20.7938	8:03:51	0.2	47	38.2	9.4	0	0	0	0	4	0	1.2
665	-156.5064	20.7934	8:06:30	0	54	13	27	0	0	0	0	4	0	0
666	-156.5064	20.7932	8:08:36	16.6	0	33	15	0	10	0	0	25	0	0.4
667	-156.5064	20.7930	8:10:20	46	0	10	3.6	0	17	0	0	22.2	0	1.2
668	-156.5062	20.7929	8:12:52	42.2	0	14	0	0	31.6	0	0	11.2	0	1
669	-156.5061	20.7930	8:14:15	55.8	0	2.4	0	0	32	0	0	8.6	0	1.2
670	-156.5059	20.7927	8:16:59	49.2	2	1	0	0	39.6	0	0	7.8	0	0.4
671	-156.5060	20.7926	8:18:50	61.8	0	9	0	0	22.4	0	0	6.4	0	0.4
672	-156.5059	20.7923	8:20:26	73.2	0	0	0	0	20.2	0	0	5.6	0	1
673	-156.5057	20.7923	8:22:28	78.4	0	0	0	0	8	0	0	12.6	0	1
674	-156.5058	20.7921	8:23:30	0	0	0	81.6	0	0.8	0	0	17.6	0	0
675	-156.5061	20.7922	8:26:07	0	0	0	100	0	0	0	0	0	0	0
676	-156.5063	20.7923	8:27:25	77.6	0	0	2	0	5.8	0	0	14.4	0	0.2
677	-156.5065	20.7925	8:29:43	35.2	0	29.4	0	0	32.4	0	0	3	0	0
678	-156.5067	20.7927	8:32:27	4.4	0.6	64.8	12	2	0	0	0	14	0	2.2
679	-156.5068	20.7928	8:34:35	0.8	45.4	35	11.8	5.8	0	0	0	1	0	0.2
681	-156.5072	20.7917	8:42:37	0.4	7	56	15	0	0	0	0	11	0	10.6
682	-156.5072	20.7914	8:44:51	14.8	33	23	2	2	3	0	0	20.6	0	1.6
683	-156.5071	20.7912	8:46:35	44	0	15	1	0	26.8	0	0	12	0	1.2
684	-156.5070	20.7909	8:48:28	80.4	0	2	4.2	0	6	0	0	7.4	0	0
685	-156.5069	20.7908	8:49:48	0.4	0	8	12	5	0	0	0	73	0	1.6
686	-156.5073	20.7909	8:52:05	50.2	0	21	0	0	26.4	0	0	2	0	0.4
687	-156.5075	20.7911	8:54:16	12.8	0	57.6	8	0	2	0	0	12	0	7.6
688	-156.5076	20.7904	9:11:13	0.6	0	2	19.4	17	0	0	0	60.2	0	0.8
689	-156.5076	20.7907	9:13:45	12.2	0	38.6	8.6	2	7.8	0	0	30.2	0	0.6
690	-156.5077	20.7910	9:15:52	13.4	0	68.4	8	1	0	0	0	8	0	1.2
691	-156.5078	20.7912	9:17:55	4.6	0	68.6	7	1.4	0	0	0	15	0	3.4
692	-156.5081	20.7911	9:20:40	2.6	2	68.8	13	0	1	0	0	8	0	4.6
693	-156.5082	20.7907	9:22:27	15.6	0	43	1	0	0	0	0	39.8	0	0.6
694	-156.5082	20.7904	9:24:45	33.8	0	16.6	3	0	9	0	0	37.6	0	0
695	-156.5082	20.7902	9:27:21	1	0	3	17	6.2	8	0	0	63.8	0	1
696	-156.5082	20.7900	9:28:45	0	0	2	62	3	0	0	0	33	0	0
697	-156.5084	20.7903	9:31:47	5.6	0	26	16	2	3.2	0	0	46.8	0	0.4
698	-156.5086	20.7905	9:33:59	1.6	1.6	69.2	7.6	0	0	0	0	10	0	10
699	-156.5089	20.7906	9:36:08	0.6	0	82.8	6	0	0	0	0	5	0	5.6
700	-156.5091	20.7905	9:38:08	1.2	34	49.4	7	1	0	0	0	6	0	1.4
701	-156.5093	20.7903	9:40:24	17.8	23	41.4	3.2	0	2	0	0	12.6	0	0
702	-156.5093	20.7900	9:42:33	18.6	22	39.2	10.2	0	7	0	0	3	0	0
703	-156.5093	20.7897	9:45:01	30.8	0	8	1	10	22.2	0	0	25.4	0	2.6
704	-156.5092	20.7895	9:46:35	1	0	22	22.4	8	0	0	0	45.8	0	0.8
705	-156.5095	20.7898	9:48:50	9	37	27.6	20	0	2.4	0	0	4	0	0
706	-156.5097	20.7900	9:50:48	7.2	37	40.2	3	0	1.6	0	0	11	0	0
707	-156.5098	20.7902	9:52:31	4.4	28	59.8	0	3	0	0	0	4	0	0.8
708	-156.5100	20.7901	9:54:56	7	12.4	39	0	10	6	0	0	25.6	0	0
709	-156.5100	20.7898	9:57:30	16.8	11.8	40	1	0	17.2	0	0	13.2	0	0
710	-156.5100	20.7895	9:59:47	7.8	14.2	38.2	1.5	8.2	0	0	0	30	0	0
711	-156.5099	20.7896	10:01:11	0.2	0	55.6	12	10.8	0	0	0	21.2	0	0.2
712	-156.5102	20.7907	10:10:00	71.5	0	6.2	0	0	3.8	0	0	17.8	0	0.8
713	-156.5102	20.7906	10:11:10	69.8	0	0	0	0	14	0	0	16	0	0.2
714	-156.5102	20.7904	10:12:57	78	0	0	0	0	10	1.5	0	10.5	0	0
715	-156.5101	20.7906	10:14:45	47.6	0	13	2	0	0	0	0	23	14.4	0
716	-156.5066	20.7946	10:31:02	0	90	0	5	0	0	0	5	0	0	0
717	-156.5066	20.7943	10:33:10	0	0	10	40	0	0	0	50	0	0	0
718	-156.5067	20.7940	10:34:25	0	85	0	10	0	0	0	5	0	0	0
719	-156.5070	20.7937	10:35:53	0	95	0	0	0	0	0	5	0	0	0
720	-156.5074	20.7934	10:38:08	0	20	10	20	0	0	0	50	0	0	0
721	-156.5075	20.7932	10:40:21	0	80	0	10	0	0	0	10	0	0	0
722	-156.5077	20.7927	10:43:33	0	95	0	5	0	0	0	0	0	0	0
723	-156.5080	20.7925	10:47:15	0	5	10	85	0	0	0	0	0	0	0
724	-156.5083	20.7924	10:50:35	0	95	0	5	0	0	0	0	0	0	0
725	-156.5087	20.7924	10:52:59	0	95	0	5	0	0	0	0	0	0	0
726	-156.5090	20.7922	10:56:20	0	80	0	10	0	0	0	10	0	0	0
727	-156.5091	20.7919	11:00:09	0	95	0	5	0	0	0	0	0	0	0
728	-156.5090	20.7916	11:03:24	0	5	25	20	0	0	0	50	0	0	0
729	-156.5087	20.7913	11:06:55	0	20	50	0	0	0	0	30	0	0	0
730	-156.5086	20.7911	11:10:17	0	10	50	0	0	0	10	30	0	0	0
731	-156.5082	20.7913	11:13:08	0	25	40	5	0	0	5	25	0	0	0
732	-156.5079	20.7916	11:16:17	0	15	35	5	0	0	5	40	0	0	0
733	-156.5074	20.7916	11:18:53	0	50	20	5	0	0	5	20	0	0	0
734	-156.5075	20.7919	11:22:20	0	10	50	10	0	0	0	30	0	0	0
735	-156.5078	20.7921	11:24:45	0	10	30	20	0	0	5	35	0	0	0
736	-156.5074	20.7923	11:27:13	0	20	30	15	0	0	0	35	0	0	0
737	-156.5073	20.7923	11:29:49	0	0	0	100	0	0	0	0	0	0	0
738	-156.5070	20.7927	11:31:21	0	10	40	10	0	0	5	35	0	0	0
739	-156.5070	20.7932	11:35:04	0	25	20	15	0	0	0	40	0	0	0
740	-156.5072	20.7939	11:38:13	0	90	0	10	0	0	0	0	0	0	0
741	-156.5070	20.7943	11:40:51	0	80	0	10	0	0	0	10	0	0	0

TABLE 2-1 . Locations and concentrations of all nutrients and salinity collected in Maalaea Bay and groundwater wells on August 24, 2010. All nutrient concentrations are micromolar (µM). Salinity is parts per thousand (‰). S/B indicates surface or bottom sample.

24-Aug-2010

Sample ID	Longitude	Latitude	SALINITY	PO4	NH4	NO2	NO3	SiO3	S/B
Well 4927-01	-156.45222	20.81389	1.10	3.73	nd	nd	333.36	986.86	
m1	-156.46770	20.78488	34.53	0.21	nd	nd	2.41	17.78	S
m10	-156.48797	20.79568	34.88	0.43	nd	nd	0.14	10.43	S
m11	-156.49140	20.79613	34.97	0.18	nd	nd	0.13	8.30	S
m12	-156.49405	20.79695	34.89	0.11	nd	nd	0.22	10.51	S
m13	-156.49762	20.79718	34.74	0.16	nd	nd	0.16	11.30	S
m14	-156.50260	20.79660	34.56	0.20	nd	nd	1.41	13.78	S
m15	-156.50428	20.79608	33.92	0.41	nd	nd	7.76	24.90	S
m16	-156.50537	20.79562	33.08	0.17	nd	nd	14.78	38.08	S
m17	-156.50552	20.79548	33.32	0.16	nd	nd	13.01	35.28	S
m18	-156.50673	20.79487	33.28	0.23	nd	nd	11.93	36.23	S
m19	-156.50728	20.79458	30.93	1.31	nd	nd	26.26	73.30	S
m2	-156.46862	20.78587	34.20	0.15	nd	nd	0.86	15.56	S
m20	-156.50818	20.79360	30.29	0.55	nd	nd	22.84	69.82	S
m21	-156.50872	20.79298	32.79	0.59	nd	nd	10.43	38.98	S
m22	-156.50963	20.79238	34.06	0.55	nd	nd	4.95	21.65	S
m23	-156.50963	20.79238	33.64	0.42	nd	nd	8.85	33.90	S
m24	-156.51385	20.79075	27.08	0.77	nd	nd	29.53	178.67	S
m25	-156.51418	20.78973	34.21	0.21	nd	nd	1.39	21.07	S
m3	-156.47040	20.78740	34.43	0.13	nd	nd	1.35	11.72	S
m4	-156.47245	20.78898	34.74	0.13	nd	nd	0.24	10.64	S
m5	-156.47532	20.79010	34.81	0.10	nd	nd	0.12	13.32	S
m6	-156.47807	20.79138	34.93	0.09	nd	nd	0.10	7.56	S
m7	-156.48033	20.79267	35.00	0.14	nd	nd	0.09	7.45	S
m8	-156.48275	20.79390	35.09	0.15	nd	nd	0.13	7.22	S
m9	-156.48567	20.79507	35.03	0.10	nd	nd	0.10	7.15	S

TABLE 2-2. Locations and concentrations of all nutrients and salinity collected in Maalaea Bay on October 23, 2010. All nutrient concentrations are micromolar (µM). Salinity is parts per thousand (‰). S/B indicates surface or bottom sample.

23-Oct-2010

Sample ID	Longitude	Latitude	SALINITY	PO4	NH4	NO2	NO3	SiO3	S/B
1	-156.51003	20.79222	32.74	0.48	2.43	0.17	15.73	26.79	S
2	-156.51003	20.79222	33.51	0.43	2.47	0.14	10.74	22.38	S
3	-156.51012	20.79225	34.01	0.35	1.40	0.09	7.70	16.89	S
4	-156.51042	20.79147	34.26	0.33	1.12	0.08	5.77	15.65	S
5	-156.51042	20.79147	34.82	0.14	1.43	0.06	2.46	9.97	B
6	-156.51053	20.79040	34.40	0.22	1.41	0.09	3.99	15.83	S
8	-156.51053	20.78980	34.67	0.21	1.58	0.06	2.86	12.54	S
9	-156.51053	20.78980	35.06	0.09	0.65	0.02	0.49	3.88	B
10	-156.51057	20.78862	35.05	0.07	0.74	0.01	0.39	3.78	S
11	-156.51057	20.78862	35.07	0.04	0.45	0.01	0.29	2.98	B
12	-156.50615	20.78755	35.04	0.05	0.45	0.01	0.45	4.34	S
13	-156.50615	20.78755	35.09	0.05	0.56	0.00	0.10	3.14	B
14	-156.50615	20.79333	31.99	0.58	4.38	1.23	22.58	26.80	S
15	nd	nd	32.76	0.32	1.67	0.22	16.81	25.59	S
16	nd	nd	33.77	0.21	1.64	0.13	6.02	21.19	S
17	nd	nd	33.27	0.28	1.34	0.15	12.87	23.49	S
18	-156.50580	20.79333	34.18	0.16	0.95	0.12	3.97	17.51	S
19	-156.50580	20.79333	34.97	0.09	0.69	0.09	1.17	5.15	B
20	-156.50600	20.79400	33.74	0.17	0.54	0.11	7.95	20.37	S
21	-156.50600	20.79400	35.00	0.08	0.86	0.05	1.05	5.11	B
22	-156.50528	20.79282	34.11	0.16	1.19	0.15	5.74	15.64	S
23	-156.50528	20.79282	35.08	0.05	0.59	0.02	0.36	2.98	B
24	-156.50522	20.79087	34.63	0.13	1.26	0.08	1.98	10.91	S
25	-156.50522	20.79087	35.11	0.09	0.54	0.00	0.09	2.30	B
26	nd	nd	35.17	0.08	0.68	0.01	0.04	2.52	S
27	nd	nd	35.16	0.06	0.60	0.01	0.04	1.72	S
28	-156.48822	20.79513	35.17	0.06	0.78	0.01	0.03	1.81	S
29	-156.48822	20.79513	35.16	0.05	0.52	0.01	0.02	1.58	B
30	-156.48823	20.79455	35.17	0.05	0.69	0.01	0.02	1.92	S
31	-156.48823	20.79455	35.16	0.05	0.80	0.00	0.01	1.61	B
32	-156.48817	20.79358	35.15	0.05	0.56	0.00	0.00	1.83	S
33	-156.48817	20.79358	35.14	0.05	0.64	0.00	0.00	1.96	B
34	-156.48798	20.79142	35.14	0.05	0.85	0.00	0.00	3.08	S
35	-156.48798	20.79142	35.14	0.04	0.52	0.00	0.00	1.76	B
36	nd	nd	34.84	0.13	0.87	0.07	0.70	8.25	S
37	-156.47173	20.78815	34.86	0.11	1.04	0.05	0.53	6.88	S
38	-156.47172	20.78775	34.94	0.14	0.90	0.05	0.34	6.23	S
39	-156.47172	20.78775	34.94	0.12	0.22	0.03	0.25	5.79	B
40	-156.47183	20.78748	35.00	0.12	0.52	0.02	0.16	4.85	S
41	-156.47183	20.78748	35.09	0.06	0.41	0.00	0.05	2.69	B
42	-156.47287	20.78677	35.09	0.06	0.56	0.00	0.03	2.94	S
43	-156.47287	20.78677	35.13	0.07	0.68	0.00	0.01	2.11	B
44	-156.47457	20.78557	35.11	0.05	0.53	0.00	0.01	3.17	S
45	-156.47457	20.78557	35.14	0.05	0.71	0.00	0.00	1.96	B
46	-156.51383	20.78898	34.32	0.10	1.38	0.04	0.17	15.12	S
47	-156.51383	20.78898	34.67	0.10	1.39	0.02	0.33	11.74	B
48	-156.50477	20.78852	34.23	0.12	0.28	0.04	0.64	16.20	S
49	-156.50477	20.78852	35.02	0.10	0.67	0.04	0.36	4.02	B
50	-156.51238	20.78787	34.68	0.07	0.74	0.02	0.33	10.00	S
51	-156.51238	20.78787	35.07	0.06	0.50	0.01	0.21	2.95	B
52	-156.51042	20.78590	35.07	0.07	0.54	0.00	0.06	3.07	S
53	-156.51042	20.78590	35.10	0.07	0.50	0.00	0.18	2.20	B
54	-156.51415	20.78955	33.92	0.14	0.83	0.03	1.10	20.70	S
55	-156.51415	20.78955	33.94	0.11	0.19	0.03	0.71	20.79	S

TABLE 2-3. Locations and concentrations of all nutrients and salinity collected in Maalaea Bay on December 10, 2010. All nutrient concentrations are micromolar (μM). Salinity is parts per thousand (‰). S/B indicates surface or bottom sample.

10-Dec-2010

Sample	Longitude	Latitude	SALINITY	PO4	NH4	NO2	NO3	SiO3	S/B
1	-156.51342	20.79073	30.49	0.90	3.18	0.23	9.63	29.95	S
2	-156.51394	20.78953	33.98	0.05	1.97	0.03	0.25	9.97	S
3	-156.51389	20.78953	33.97	0.03	2.31	0.04	0.33	11.54	S
4	-156.50996	20.79230	31.97	0.69	1.90	0.32	9.83	23.64	S
5	-156.51000	20.79226	32.37	0.81	3.49	0.34	9.92	19.43	S
6	-156.50946	20.79223	33.67	0.20	4.65	0.22	3.72	10.82	S
7	-156.50830	20.79329	33.84	0.28	3.03	0.18	3.95	12.78	S
8	-156.50838	20.79305	33.79	0.27	3.51	0.17	4.98	14.44	S
9	-156.50803	20.79358	33.22	0.73	5.60	0.34	9.24	6.61	S
10	-156.50746	20.79408	33.25	0.75	11.16	1.12	9.24	4.24	S
11	-156.50421	20.79594	33.86	0.21	2.95	0.18	7.80	12.19	S
12	-156.50557	20.79541	33.88	0.20	3.28	0.20	8.32	12.29	S
13	-156.50190	20.79640	34.30	0.09	2.30	0.23	3.78	11.82	S
14	-156.48576	20.79489	34.64	0.15	1.72	0.11	1.46	8.67	S
15	-156.47478	20.78972	34.44	0.18	1.63	0.12	1.25	8.15	S
16	-156.47060	20.78752	34.68	0.20	1.35	0.09	0.86	8.64	S
17	-156.49300	20.79155	34.69	0.16	1.93	0.04	1.10	6.95	S
18	-156.49300	20.79155	34.97	0.09	1.00	0.01	0.60	4.81	B
19	-156.50642	20.79453	33.51	0.46	2.22	0.35	5.30	16.66	S
20	-156.50629	20.79417	33.37	0.44	1.60	0.32	5.07	10.19	S
21	-156.50629	20.79417	33.69	0.41	1.81	0.24	3.97	14.66	B
22	-156.50591	20.79357	33.91	0.20	1.56	0.22	3.67	10.70	S
23	-156.50591	20.79357	34.72	0.08	0.92	0.07	0.01	6.15	B
24	-156.50545	20.79221	34.13	0.18	1.76	0.14	2.49	10.24	S
25	-156.50545	20.79221	34.70	0.11	1.02	0.04	0.87	8.07	B
26	-156.50518	20.79060	34.23	0.12	1.22	0.13	2.09	8.41	S
27	-156.50518	20.79060	34.76	0.04	0.87	0.04	0.86	7.31	B
28	-156.50544	20.78884	34.56	0.03	1.43	0.06	1.29	6.25	S
29	-156.50544	20.78884	34.86	0.14	1.23	0.02	0.72	5.50	B
30	-156.49226	20.79586	34.62	0.20	2.07	0.12	1.36	7.40	S
31	-156.49233	20.79547	34.60	0.14	1.36	0.11	1.45	7.86	S
32	-156.49265	20.79477	34.76	0.08	1.18	0.06	1.15	6.65	S
33	-156.49265	20.79477	34.91	0.09	0.94	0.06	0.92	5.62	B
34	-156.49283	20.79331	34.70	0.09	1.08	0.05	1.32	6.43	S
35	-156.49283	20.79331	34.96	0.06	1.48	0.02	0.60	3.89	B
36	-156.50175	20.79574	34.46	0.14	1.73	0.17	2.23	9.51	S
37	-156.50183	20.79508	34.65	0.21	1.74	0.06	1.89	19.33	S
38	-156.50173	20.79452	34.67	0.10	0.93	0.09	1.47	6.25	S
39	-156.50154	20.79368	34.71	0.09	1.14	0.04	1.10	5.66	S
40	-156.50987	20.79207	32.12	1.13	2.68	0.20	7.65	23.85	S
41	-156.51010	20.79137	33.06	0.58	1.59	0.14	5.62	12.29	S
42	-156.51053	20.79015	32.67	0.54	1.62	0.18	5.51	8.08	S
43	-156.51053	20.79015	34.81	0.11	0.95	0.04	0.05	5.08	B
44	-156.51029	20.78929	33.33	0.42	1.47	0.14	3.27	17.83	S
45	-156.51029	20.78929	34.83	0.13	0.87	0.04	0.11	4.81	B
46	-156.51023	20.78779	34.54	0.08	1.59	0.06	0.55	7.05	S
47	-156.51023	20.78779	34.76	0.12	0.84	0.03	0.14	5.51	B
48	-156.51370	20.78926	34.16	0.14	0.97	0.05	0.00	11.86	S
49	-156.51347	20.78877	34.36	0.12	1.13	0.07	0.22	8.65	S
50	-156.51347	20.78877	34.78	0.18	1.05	0.07	0.80	6.67	B
51	-156.51311	20.78794	34.46	0.15	1.28	0.07	1.03	6.69	S
52	-156.51311	20.78794	34.80	0.02	1.47	0.05	0.60	5.93	B
53	-156.51266	20.78627	33.96	0.24	0.99	0.08	2.23	10.72	S
54	-156.51266	20.78627	34.75	0.06	1.01	0.04	0.63	5.67	B

TABLE 2-4. Locations and concentrations of all nutrients and salinity collected in Maalaea Bay on February 11, 2011. All nutrient concentrations are micromolar (µM). Salinity is parts per thousand (‰). S/B indicates surface or bottom sample.

11-Feb-2011

Sample ID	Longitude	Latitude	SALINITY	PO4	NH4	NO2	NO3	SiO3	S/B
1	-156.50948	20.79221	32.64	0.40	0.88	0.18	7.50	29.69	S
2	-156.50942	20.79207	34.74	0.11	0.46	0.13	1.52	9.98	S
3	-156.50935	20.79193	34.07	0.13	0.54	0.16	1.36	21.68	S
4	-156.50926	20.79171	NaN	0.12	0.50	0.11	1.17	9.11	S
5	-156.50909	20.79137	34.81	0.13	0.51	0.12	1.27	8.64	S
6	-156.50897	20.79259	32.76	0.43	0.93	0.16	10.11	46.21	S
7	-156.50891	20.79249	33.22	0.47	0.45	0.18	7.22	36.31	S
8	-156.50884	20.79241	34.56	0.13	0.60	0.13	2.02	12.52	B
9	-156.50884	20.79241	34.29	0.16	0.72	0.18	2.42	16.35	S
10	-156.50870	20.79220	34.82	0.01	0.75	0.14	1.17	8.22	S
11	-156.50848	20.79295	32.16	0.84	0.94	0.18	14.31	59.52	S
12	-156.50844	20.79291	33.62	0.47	0.47	0.15	6.89	30.66	B
13	-156.50836	20.79283	34.31	0.14	1.01	0.15	3.59	18.20	S
14	-156.50827	20.79276	34.57	0.06	0.27	0.08	1.41	12.24	S
15	-156.50827	20.79276	34.63	0.08	0.39	0.10	1.79	11.28	B
16	-156.50807	20.79356	31.84	0.64	0.70	0.23	16.67	61.05	S
17	-156.50802	20.79350	32.26	0.49	0.51	0.23	14.14	54.30	S
18	-156.50789	20.79334	33.47	0.35	0.33	0.14	8.29	33.50	S
19	-156.50783	20.79318	34.15	0.24	0.42	0.11	4.64	20.88	S
20	-156.50783	20.79318	34.76	0.15	0.29	0.10	1.43	9.40	B
21	-156.50749	20.79410	33.44	0.21	0.66	0.19	7.62	33.78	S
22	-156.50743	20.79403	33.59	0.30	0.52	0.20	7.11	33.52	S
23	-156.50729	20.79388	33.44	0.32	0.22	0.17	6.40	31.58	S
24	-156.50717	20.79376	33.32	0.36	0.42	0.17	8.40	35.46	S
25	-156.50717	20.79376	34.43	0.11	0.34	0.11	3.20	15.73	B
26	-156.50518	20.79558	32.24	0.50	0.84	0.27	20.73	62.02	S
27	-156.50515	20.79552	32.34	0.42	0.93	0.28	20.34	60.66	S
28	-156.50510	20.79545	32.61	0.49	0.88	0.27	18.88	52.12	S
29	-156.50494	20.79521	32.63	0.45	0.54	0.27	18.73	54.32	S
30	-156.50494	20.79521	32.94	0.41	1.09	0.28	16.26	46.98	B
31	-156.50402	20.79338	34.46	0.04	0.35	0.12	3.80	18.12	S
32	-156.50540	20.79277	34.47	0.04	0.28	0.11	3.41	17.99	S
33	-156.50655	20.79155	34.50	0.03	0.35	0.10	3.28	17.59	S
34	-156.50805	20.79060	34.55	0.03	0.28	0.09	3.05	16.11	S
35	-156.50988	20.78918	34.62	0.04	0.45	0.08	2.28	13.80	S

TABLE 2-5. Locations and concentrations of all nutrients and salinity collected in Maalaea Bay on March 8, 2011. All nutrient concentrations are micromolar (µM). Salinity is parts per thousand (‰). S/B indicates surface or bottom sample.

8-Mar-2011

Sample ID	Longitude	Latitude	SALINITY	PO4	NH4	NO2	NO3	SiO3	S/B
1 s	-156.52016	20.78077	33.46	0.09	2.06	0.07	1.03	31.26	S
2 s	-156.51408	20.78932	33.17	0.44	0.64	0.12	4.65	44.86	S
3 s	-156.51401	20.78929	33.59	0.39	0.77	0.10	3.29	35.47	S
4 s	-156.51391	20.78924	33.85	0.11	1.33	0.11	2.37	28.45	S
5 s	-156.50998	20.79233	33.54	0.36	0.97	0.14	8.19	33.67	S
6 s	-156.51004	20.79226	33.97	0.45	1.07	0.13	11.53	46.39	S
7 s	-156.51004	20.79226	34.26	0.24	1.01	0.11	4.62	20.41	S
8 s	-156.50946	20.79225	30.42	0.62	1.45	0.39	23.73	65.11	S
9 s	-156.50944	20.79214	30.17	0.78	3.56	0.38	24.66	71.34	S
10 s	-156.50936	20.79179	31.30	0.61	1.58	0.32	20.61	60.22	S
11 s	-156.50831	20.79327	30.13	1.04	2.27	0.29	38.58	97.13	S
12 s	-156.50836	20.79306	30.83	0.91	2.56	0.32	33.41	85.65	S
13 s	-156.50808	20.79354	31.42	0.57	1.46	0.28	28.72	75.66	S
14 s	-156.50796	20.79339	29.32	0.83	1.67	0.38	42.12	109.30	S
15 s	-156.50796	20.79339	28.83	1.16	1.52	0.25	45.62	120.12	S
16 s	-156.50552	20.79545	34.19	0.33	0.56	0.13	7.99	21.78	S
17 s	-156.50541	20.79529	34.17	0.20	1.67	0.11	3.55	22.39	S
18 s	-156.50541	20.79529	34.14	0.23	1.49	0.12	8.63	22.93	S
19 s	-156.50187	20.79643	34.45	0.13	0.36	0.14	3.34	14.43	S
20 s	-156.50181	20.79617	34.41	0.15	0.49	0.13	4.86	16.31	S
21 s	-156.50181	20.79617	34.44	0.17	1.54	0.13	4.92	15.70	S
22 s	-156.48613	20.79501	35.13	0.08	0.92	0.02	0.15	2.98	S
23 s	-156.48619	20.79483	35.12	0.04	0.54	0.00	0.01	2.47	S
24 s	-156.48619	20.79483	35.12	0.05	0.72	0.01	0.02	2.31	S
25 s	-156.47000	20.78707	34.63	0.12	0.91	0.05	0.18	6.50	S
26 s	-156.47012	20.78691	34.69	0.08	0.89	0.05	0.10	5.64	S
27 s	-156.47012	20.78691	34.77	0.08	0.87	0.00	0.00	2.51	S
28 s	-156.46862	20.78585	34.33	0.18	1.06	0.05	0.35	7.89	S
29 s	-156.46875	20.78573	34.43	0.20	0.58	0.03	0.14	7.53	S
30 s	-156.46875	20.78573	34.85	0.13	1.44	0.01	0.02	4.10	S
31 s	-156.51643	20.78461	27.90	0.23	1.08	0.19	7.59	120.04	S
32 s	-156.51630	20.78462	30.94	0.11	0.96	0.09	1.48	70.39	S
33 s	-156.52085	20.78041	33.29	0.13	0.79	0.06	1.38	34.66	S
34 s	-156.52085	20.78041	33.29	0.18	0.76	0.06	1.33	34.36	S
35 s	-156.52085	20.78041	33.29	0.16	0.67	0.06	1.43	34.83	S
1 b	-156.52016	20.78077	34.83	0.07	1.25	0.10	1.25	8.29	B
2 b	-156.51408	20.78932	35.02	0.05	3.13	0.02	0.82	3.87	B
3 b	-156.51401	20.78929	35.03	0.06	1.04	0.01	0.59	3.55	B
4 b	-156.51391	20.78924	34.95	0.09	1.12	0.04	1.00	5.31	B
5 b	-156.50998	20.79233	34.99	0.04	1.05	0.02	0.76	4.14	B
6 b	-156.51004	20.79226	35.07	0.02	0.97	0.00	0.17	2.64	B
7 b	-156.51004	20.79226	34.58	0.13	1.70	0.08	nd	14.11	B
8 b	-156.50946	20.79225	35.01	0.18	1.43	0.04	0.79	4.34	B
9 b	-156.50944	20.79214	35.07	0.10	1.24	0.01	0.17	2.71	B
10 b	-156.50936	20.79179	35.02	0.09	1.28	0.05	0.81	3.87	B
11 b	-156.50831	20.79327	35.06	0.05	0.92	0.01	0.42	3.12	B
12 b	-156.50836	20.79306	35.09	0.06	1.44	0.00	0.02	2.32	B
13 b	-156.50808	20.79354	35.09	0.07	0.93	0.00	0.05	2.29	B
14 b	-156.50796	20.79339	35.09	0.06	0.95	0.00	0.06	2.35	B
15 b	-156.50796	20.79339	35.10	0.08	1.34	0.02	0.15	2.18	B
16 b	-156.50552	20.79545	35.11	0.08	1.04	0.00	0.02	1.94	B
17 b	-156.50541	20.79529	35.01	0.10	1.36	0.00	0.07	2.25	B
18 b	-156.50541	20.79529	35.08	0.11	1.07	0.00	0.05	2.33	B
50	-156.51608	20.78511	33.53	0.06	1.32	0.10	2.32	24.92	S
51	-156.51593	20.78496	34.09	0.20	0.88	0.09	2.14	23.92	S
52	-156.51585	20.78465	34.22	0.22	1.09	0.10	2.00	19.82	S
53	-156.51562	20.78487	34.35	0.20	0.90	0.09	1.70	17.29	S
54	-156.51510	20.78460	34.81	0.16	2.99	0.06	1.55	7.85	S
55	-156.51444	20.78422	34.91	0.13	1.06	0.03	0.87	4.60	S
56	-156.51381	20.78394	34.99	0.12	0.89	0.02	0.42	3.23	S
57	-156.51307	20.78306	34.97	0.11	0.73	0.03	0.63	3.80	S
58	-156.51375	20.78969	34.57	0.25	1.36	0.11	2.17	14.95	S
59	-156.51345	20.78936	34.87	0.17	1.15	0.05	1.04	6.07	S
60	-156.51315	20.78880	34.88	0.13	0.96	0.04	1.02	5.81	S
61	-156.51293	20.78797	34.88	0.12	1.14	0.04	1.15	5.90	S
62	-156.51246	20.78738	34.88	0.12	1.01	0.03	1.07	4.93	S
63	-156.51233	20.78683	34.92	0.12	0.74	0.03	0.94	4.70	S
64	-156.51216	20.78598	34.94	0.12	0.97	0.02	0.86	4.38	S
65	-156.51010	20.79176	34.31	0.25	1.75	0.10	4.28	19.82	S
66	-156.51049	20.79038	34.35	0.28	1.68	0.10	3.74	18.07	S
67	-156.51024	20.78953	34.36	0.25	1.29	0.11	4.59	15.44	S
68	-156.50978	20.78830	34.56	0.22	0.88	0.09	3.55	12.61	S
69	nd	nd	35.05	0.12	0.80	0.01	0.18	2.48	S
70	-156.50935	20.79141	33.04	0.21	1.27	0.12	2.89	12.17	S
71	-156.50906	20.78999	33.04	0.14	0.86	0.09	2.29	8.55	S
72	-156.50850	20.78799	35.05	0.10	0.54	0.01	0.13	2.33	S
73	-156.50824	20.79269	31.08	0.54	1.67	0.22	21.34	59.06	S
74	-156.50748	20.79249	34.31	0.21	0.84	0.13	3.71	15.17	S
75	-156.50617	20.79460	33.37	0.32	1.27	0.16	13.26	34.32	S
76	-156.50560	20.79384	34.86	0.14	0.41	0.05	2.17	6.99	S
77	-156.50514	20.79326	34.94	0.12	0.59	0.02	0.90	4.29	S
78	-156.50406	20.79175	34.99	0.12	0.59	0.02	0.10	2.29	S
79	-156.50148	20.79576	34.50	0.18	1.62	0.11	3.57	12.76	S
80	-156.50111	20.79483	34.91	0.14	0.91	0.07	1.15	4.65	S
81	-156.50063	20.79347	35.04	0.08	1.20	0.01	0.10	2.41	S
82	-156.50027	20.79327	35.04	0.07	0.71	0.00	0.01	2.21	S
83	-156.49962	20.79154	35.06	0.09	0.63	0.00	0.00	1.86	S
84	-156.49125	20.79563	35.03	0.11	1.00	0.03	0.09	2.17	S
85	-156.49140	20.79465	35.05	0.09	0.76	0.02	0.06	2.21	S
86	-156.49198	20.79245	35.07	0.08	0.59	0.00	0.00	1.78	S
87	-156.47037	20.78699	34.64	0.14	0.88	0.11	0.97	6.47	S
88	-156.47033	20.78686	34.84	0.09	0.84	0.02	0.04	3.73	S
89	-156.47061	20.78649	34.89	0.11	1.18	0.01	0.05	3.65	S
90	-156.47104	20.78573	34.92	0.10	0.83	0.00	0.02	3.24	S
91	-156.47157	20.78495	34.95	0.11	0.92	0.00	0.01	3.37	S
92	-156.47213	20.78410	34.97	0.10	0.64	0.02	0.01	3.15	S
53B	-156.51562	20.78487	34.83	0.07	1.25	0.10	1.25	8.29	B
55B	-156.51444	20.78422	35.02	0.05	3.13	0.02	0.82	3.87	B
57B	-156.51307	20.78306	35.03	0.06	1.04	0.01	0.59	3.55	B
60B	-156.51315	20.78880	34.95	0.09	1.12	0.04	1.00	5.31	B
62B	-156.51246	20.78738	34.99	0.04	1.05	0.02	0.76	4.14	B
64B	-156.51216	20.78598	35.07	0.02	0.97	0.00	0.17	2.64	B
65B	-156.51010	20.79176	34.58	0.13	1.70	0.08	nd	14.11	B
66B	-156.51049	20.79038	35.01	0.18	1.43	0.04	0.79	4.34	B
68B	-156.50978	20.78830	35.07	0.10	1.24	0.01	0.17	2.71	B
72B	-156.50850	20.78799	35.02	0.09	1.28	0.05	0.81	3.87	B
77B	-156.50514	20.79326	35.06	0.05	0.92	0.01	0.42	3.12	B
78B	-156.50406	20.79175	35.09	0.06	1.44	0.00	0.02	2.32	B
80B	-156.50111	20.79483	35.09	0.07	0.93	0.00	0.05	2.29	B
83B	-156.49962	20.79154	35.09	0.06	0.95	0.00	0.06	2.35	B
85B	-156.49140	20.79465	35.10	0.08	1.34	0.02	0.15	2.18	B
86B	-156.49198	20.79245	35.11	0.08	1.04	0.00	0.02	1.94	B
89B	-156.47061	20.78649	35.01	0.10	1.36	0.00	0.07	2.25	B
91B	-156.47157	20.78495	35.08	0.11	1.07	0.00	0.05	2.33	B

TABLE 2-6. Locations and concentrations of all nutrients and salinity collected in Maalaea Bay, groundwater wells and injection wells on May 1, 2011. All nutrient concentrations are micromolar (µM). Salinity is parts per thousand (‰). S/B indicates surface or bottom sample.MT indicates Maalaea Triangle.

1-May-2011

Sample	Longitude	Latitude	SALINITY	PO4	NH4	NO2	NO3	SiO3	S/B
S1	-156.52085	20.78042	34.12	0.07	0.59	0.04	0.17	16.31	S
S2	-156.52015	20.78078	33.72	0.06	0.95	0.03	-0.05	22.90	S
S3	-156.51665	20.78411	31.53	0.08	0.86	0.07	1.72	73.55	S
S4	-156.51639	20.78462	30.89	0.06	0.68	0.04	0.00	86.02	S
S5	-156.51393	20.78952	34.05	0.07	0.55	0.05	0.96	16.30	S
S6	-156.51150	20.79043	33.43	0.10	0.93	0.17	7.18	37.01	S
S7	-156.51366	20.79074	27.11	0.23	1.09	0.20	34.91	214.90	S
S8	-156.50961	20.79153	33.89	0.22	1.14	0.21	4.52	21.95	S
S9	-156.50999	20.79229	31.87	0.50	0.71	0.12	16.44	61.27	S
S10	-156.50949	20.79221	31.94	0.10	0.65	0.11	4.31	53.10	S
S11	-156.50949	20.79221	31.98	0.06	0.57	0.12	3.53	49.76	S
S12	-156.50858	20.79286	31.42	0.17	2.08	0.22	13.79	63.68	S
S13	-156.50832	20.79328	29.95	0.34	0.99	0.40	26.03	85.82	S
S14	-156.50802	20.79359	31.01	0.34	1.21	0.35	14.84	60.68	S
S15	-156.50779	20.79386	32.33	0.15	1.09	0.24	9.28	39.10	S
S16	-156.50523	20.79557	32.23	0.15	0.50	0.29	18.00	50.39	S
S17	-156.50420	20.79596	33.48	0.18	0.61	0.21	9.40	27.34	S
S18	-156.50191	20.79646	34.54	0.07	1.76	0.08	0.72	7.36	S
S19	-156.50191	20.79646	34.54	0.07	0.53	0.08	0.64	7.45	S
S20	-156.50324	20.79635	34.82	0.07	0.56	0.01	0.09	2.65	S
S21	-156.46998	20.78705	34.58	0.16	1.20	0.02	0.09	7.31	S
1	-156.51358	20.78862	34.41	0.16	0.89	0.05	0.64	6.49	S
2	-156.51358	20.78862	34.42	0.15	0.63	0.04	0.53	7.78	S
3	-156.51345	20.78828	34.66	0.14	1.17	0.06	0.82	6.05	S
4	-156.51345	20.78828	34.66	0.15	3.25	0.06	0.87	5.94	B
5	-156.51298	20.78819	34.59	0.16	0.85	0.05	0.87	5.92	S
6	-156.51298	20.78819	34.59	0.13	1.74	0.04	0.85	5.74	S
7	-156.51262	20.78770	34.69	0.14	0.67	0.03	0.84	5.73	S
8	-156.51262	20.78770	34.72	0.11	0.92	0.04	0.70	5.03	B
9	-156.51232	20.78643	34.78	0.08	0.72	0.03	0.13	3.66	S
10	-156.51232	20.78643	34.83	0.11	1.02	0.02	0.11	4.08	B
11	-156.51007	20.79210	33.51	0.22	0.85	0.08	4.95	22.30	S
12	-156.51007	20.79210	33.46	0.29	1.14	0.07	4.78	19.24	S
13	-156.51020	20.79151	33.96	0.30	1.33	0.08	4.87	21.18	S
14	-156.51020	20.79151	34.17	0.25	2.68	0.07	2.70	12.16	B
15	-156.51051	20.79060	34.08	0.25	1.01	0.07	3.09	15.96	S
16	-156.51051	20.79060	34.67	0.19	1.30	0.05	1.35	7.79	B
17	-156.51058	20.78973	34.43	0.14	1.32	0.04	1.11	5.65	S
18	-156.51058	20.78973	34.69	0.18	0.71	0.06	1.70	10.14	B
19	-156.51038	20.78876	34.65	0.15	0.50	0.03	0.85	4.56	S
20	-156.51038	20.78876	34.75	0.15	0.84	0.02	0.66	5.61	B
21	-156.51021	20.78761	34.79	0.11	0.57	0.02	0.50	4.35	S
22	-156.51021	20.78761	34.81	0.16	1.26	0.02	0.41	4.25	B
23	-156.50998	20.78569	34.77	0.10	0.42	0.00	0.00	2.30	S
24	-156.50998	20.78569	34.87	0.14	0.68	0.01	0.02	2.33	B
27	-156.50924	20.79175	34.56	0.13	0.88	0.05	0.43	5.25	S
28	-156.50924	20.79175	34.56	0.14	0.49	0.05	0.41	5.86	S
29	-156.50882	20.79198	34.53	0.10	0.74	0.05	0.51	6.60	S
30	-156.50831	20.79230	34.52	0.15	1.30	0.05	0.63	6.46	S
31	-156.50809	20.79306	34.46	0.16	1.20	0.04	0.98	9.53	S
32	-156.50774	20.79339	34.04	0.17	0.84	0.05	1.69	11.55	S
33	-156.50749	20.79379	34.14	0.19	0.66	0.05	2.42	15.28	S
34	-156.50702	20.79419	33.80	0.20	0.72	0.06	3.38	22.77	S
35	-156.50641	20.79445	32.55	0.23	0.98	0.05	5.66	22.69	S
36	-156.50596	20.79480	31.87	0.41	0.82	0.16	21.32	52.64	S
51	-156.50570	20.79501	32.09	0.39	0.69	0.15	16.57	47.74	S
52	-156.50525	20.79514	32.25	0.35	0.78	0.10	11.58	40.80	S
53	-156.50464	20.79540	33.17	0.27	0.92	0.10	5.78	18.79	S
54	-156.50416	20.79555	33.19	0.33	0.85	0.14	11.62	33.21	S
55	-156.50376	20.79565	33.19	0.27	1.01	0.12	8.33	22.57	S
56	-156.50307	20.79587	33.63	0.29	1.39	0.10	3.06	13.37	S
57	-156.50239	20.79583	33.72	0.23	0.98	0.08	5.26	14.66	S
58	-156.50179	20.79603	34.33	0.21	0.57	0.05	2.44	5.36	S
59	-156.50119	20.79598	34.54	0.11	0.67	0.04	1.83	4.01	S
60	-156.50053	20.79599	34.56	0.15	0.41	0.08	0.93	2.97	S
61	-156.50096	20.79552	34.59	0.12	0.63	0.04	0.85	4.02	S
62	-156.50156	20.79519	34.64	0.12	0.45	0.04	1.18	4.28	S
63	-156.50239	20.79546	34.23	0.20	0.73	0.08	3.44	14.35	S
64	-156.50319	20.79513	33.93	0.20	0.66	0.11	7.34	21.34	S
65	-156.50512	20.79448	33.09	0.27	0.81	0.10	11.07	34.95	S
66	-156.50427	20.79473	33.83	0.25	0.55	0.08	7.32	21.17	S
67	-156.50612	20.79367	33.50	0.14	0.63	0.05	1.08	8.44	S
68	-156.50666	20.79322	34.51	0.17	0.66	0.09	0.91	6.59	S
69	-156.50731	20.79258	34.49	0.13	1.15	0.06	0.51	5.02	S
70	-156.50807	20.79230	34.64	0.06	0.98	0.04	0.27	6.03	S
71	-156.50885	20.79177	34.63	0.13	0.74	0.04	0.45	4.94	S
72	-156.50869	20.79080	34.55	0.21	0.74	0.04	0.55	3.73	S
73	-156.50783	20.79127	34.71	0.18	0.82	0.06	0.68	4.56	S
74	-156.50783	20.79127	34.76	0.16	0.81	0.06	0.59	4.31	B
75	-156.50685	20.79183	34.67	0.15	0.62	0.08	0.73	4.39	S
76	-156.50685	20.79183	34.69	0.15	0.85	0.07	0.82	6.05	B
77	-156.50570	20.79334	34.61	0.16	0.86	0.09	0.79	5.91	S
78	-156.50570	20.79334	34.81	0.17	0.66	0.06	0.42	3.59	B
79	-156.50485	20.79393	33.76	0.22	0.74	0.10	6.75	22.59	S
80	-156.50485	20.79393	34.78	0.19	0.69	0.04	0.42	2.43	B
81	-156.50312	20.79404	34.36	0.19	0.69	0.07	3.31	14.19	S
82	-156.50312	20.79404	34.75	0.38	0.56	0.03	0.32	2.28	B
83	-156.50076	20.79397	34.76	0.14	0.67	0.03	0.75	4.68	S
84	-156.50076	20.79397	34.85	0.12	0.60	0.02	0.03	3.04	B
85	-156.47037	20.78710	34.54	0.22	0.51	0.03	0.02	7.15	S
86	-156.47047	20.78687	34.55	0.16	0.62	0.03	0.04	5.66	S
87	-156.47139	20.78579	34.70	0.15	0.51	0.06	0.24	6.99	S
88	-156.47139	20.78579	34.75	0.22	0.51	0.00	0.00	5.12	B
89	-156.47247	20.78479	34.58	0.17	0.76	0.04	0.33	8.39	S
90	-156.47247	20.78479	34.89	0.17	0.55	0.01	0.00	2.93	B
91	-156.47250	20.78478	34.68	0.12	0.69	0.04	0.91	8.69	S
92	-156.47250	20.78478	34.89	0.11	0.45	0.00	0.00	2.37	B
93	-156.49899	20.79134	34.77	0.10	2.59	0.03	0.24	4.01	S
94	-156.49899	20.79134	34.87	0.11	0.45	0.00	0.00	2.83	B
95	-156.50163	20.79017	34.58	0.12	1.69	0.05	2.18	8.57	S
96	-156.50163	20.79017	34.88	0.17	0.74	0.01	0.02	2.48	B
97	-156.50474	20.78952	34.70	0.13	1.52	0.04	0.43	5.50	S
98	-156.50474	20.78952	34.84	0.17	0.85	0.01	0.00	3.41	B
99	-156.50742	20.78873	34.78	0.15	0.88	0.02	0.23	3.65	S
100	-156.50742	20.78873	34.85	0.25	0.68	0.01	0.00	2.64	B
MT EFF #1			0.65	177.00	7.38	3.91	1667.94	970.28	
MT EFF #2			0.65	192.61	7.53	2.72	1693.02	997.71	
Well 4830-01	-156.51028	20.79694	0.94	8.50	0.23	1.63	190.60	858.56	
Mermaid #1			0.28	100.38	315.86	18.10	128.64	1025.52	
Mermaid #2			0.27	101.85	282.75	2.03	118.06	1042.14	
Isl. Sand #1			0.34	161.45	254.84	29.38	1691.98	557.94	
Isl. Sand #2			0.35	178.35	203.74	1.71	1714.96	546.43	
Well 4930-01	-156.51139	20.81611	0.43	5.52	3.63	1.14	152.44	1249.89	

TABLE 3. Boundaries of nutrient concentrations defining three "bins" representing ranges of oceanic, reef, and impact levels in Maalaea Bay. All values are in micromoles (µM).

ZONE	PO4	NH4	NO3+NO2	NO2	SIO3
OCEANIC	≤0.1	≤ 0.4	≤ 0.05	0	≤ 3
REEF	>0.1- <1.0	>0.4 - <5	>0.05-<30	<.4 - >0	>3-<100
IMPACT	≥ 1	≥ 5	≥30	≥0.4	≥100

TABLE 4. Values of stable isotopic ratios of $^{15}N/^{14}N$ and $^{13}C/^{12}C$, molar composition of C, N and P, as well as C:N, C:P and N:P ratios of algae collected along the shoreline of Maalaea Bay. See Figure x for collection locations.

SAMPLE ID	^{15}*N* o/oo	^{13}*C* o/oo	C mmol g^{-1}	N mmol g^{-1}	P μmole g^{-1}	C:N	C:P	N:P
1	*5.8*	*-13.9*	12.8	0.8	38.2	15.9	336	21.15
2	*6.4*	*-18.2*	22.4	2.0	57.0	11.1	394	35.49
3	*4.8*	*-13.7*	18.7	1.6	41.8	11.8	448	37.99
4	*5.8*	*-16.3*	24.8	2.1	54.3	11.7	457	39.22
5	*3.9*	*-14.7*	24.6	2.4	55.1	10.2	447	44.00
6	*3.3*	*-18.4*	23.9	2.3	68.7	10.6	349	32.85
7	*3.8*	*-16.6*	22.6	2.2	62.2	10.4	362	34.97
8	*3.3*	*-16.6*	26.0	2.5	52.3	10.4	498	48.09
9	*3.7*	*-17.3*	23.3	2.0	79.4	11.7	293	25.10
10	*4.7*	*-14.7*	23.3	2.1	65.2	11.2	357	31.82
11	*5.3*	*-16.8*	24.4	1.7	83.2	14.3	293	20.51
12	*3.5*	*-19.0*	15.6	2.0	70.2	7.8	222	28.42
13	*3.1*	*-14.9*	25.2	2.5	80.2	9.9	314	31.65
14	*2.8*	*-20.4*	20.0	2.7	79.8	7.5	251	33.51
15	*4.1*	*-13.6*	20.4	2.2	57.5	9.4	356	37.70
16	*4.2*	*-16.3*	20.0	1.9	55.1	10.7	363	33.80
17	*5.4*	*-18.7*	22.3	2.2	60.1	10.3	371	35.89

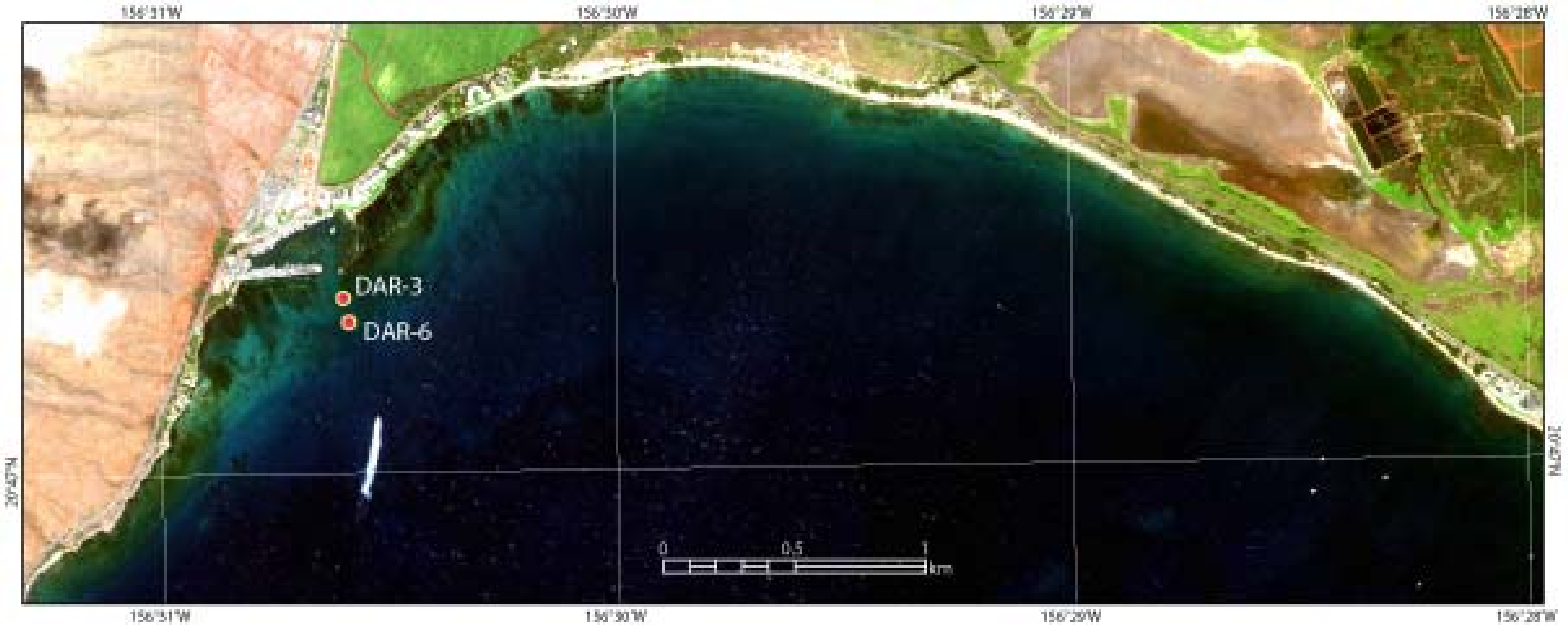


FIGURE 1. Aerial image of Maalaea Bay showing locations of two DAR coral reef survey sites.

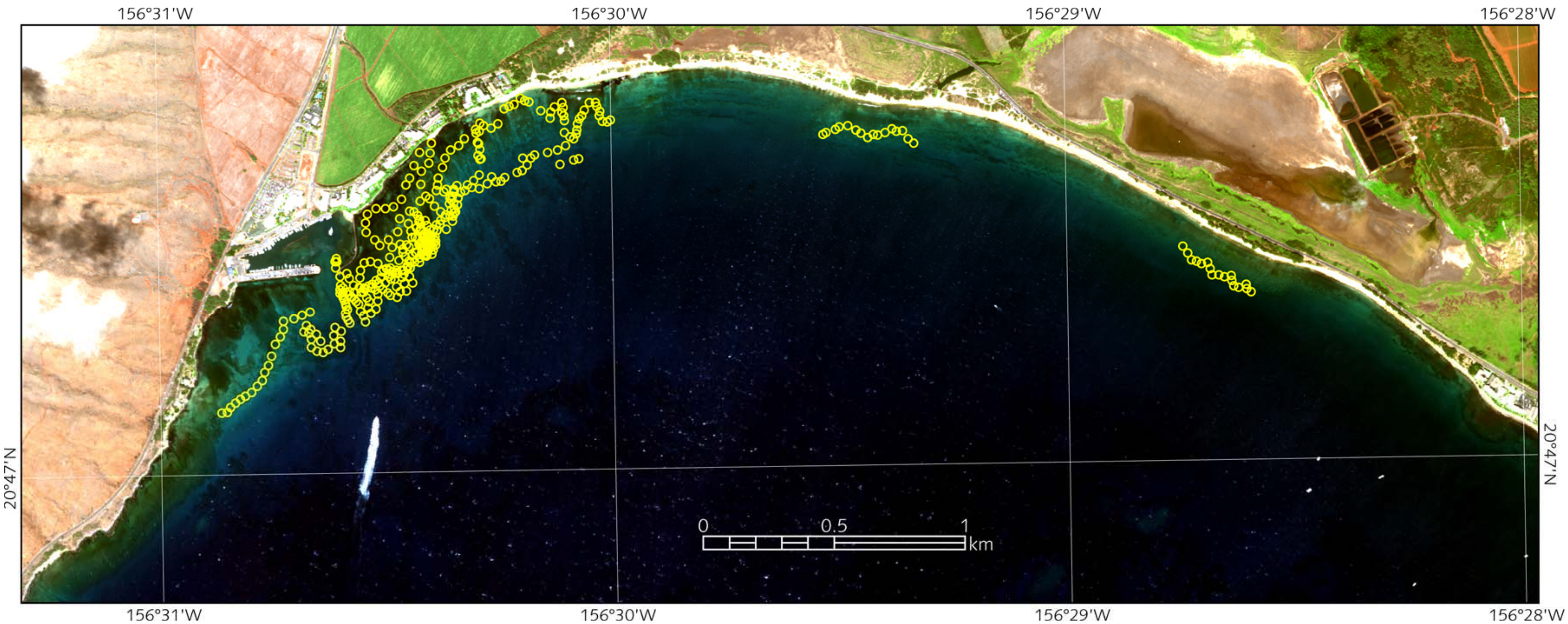


FIGURE 2. Maalaea Bay showing locations of 359 calibration/validation survey points used to create benthic habitat maps.

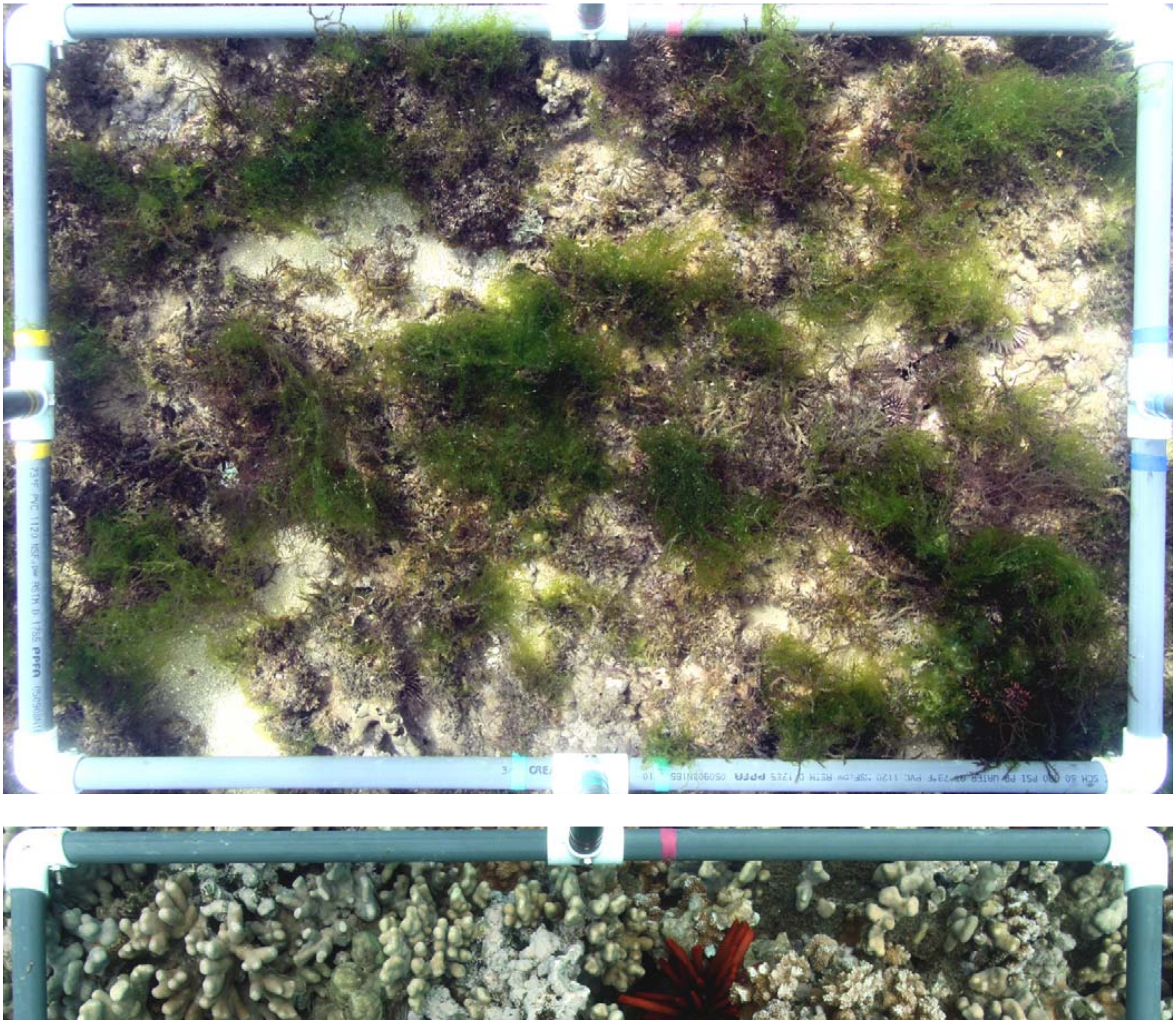


FIGURE 3. Typical photo-quadrats taken in Zones B (top) and C (bottom) in Maalaea Bay used for estimating benthic cover for preparation of benthic habitat maps.

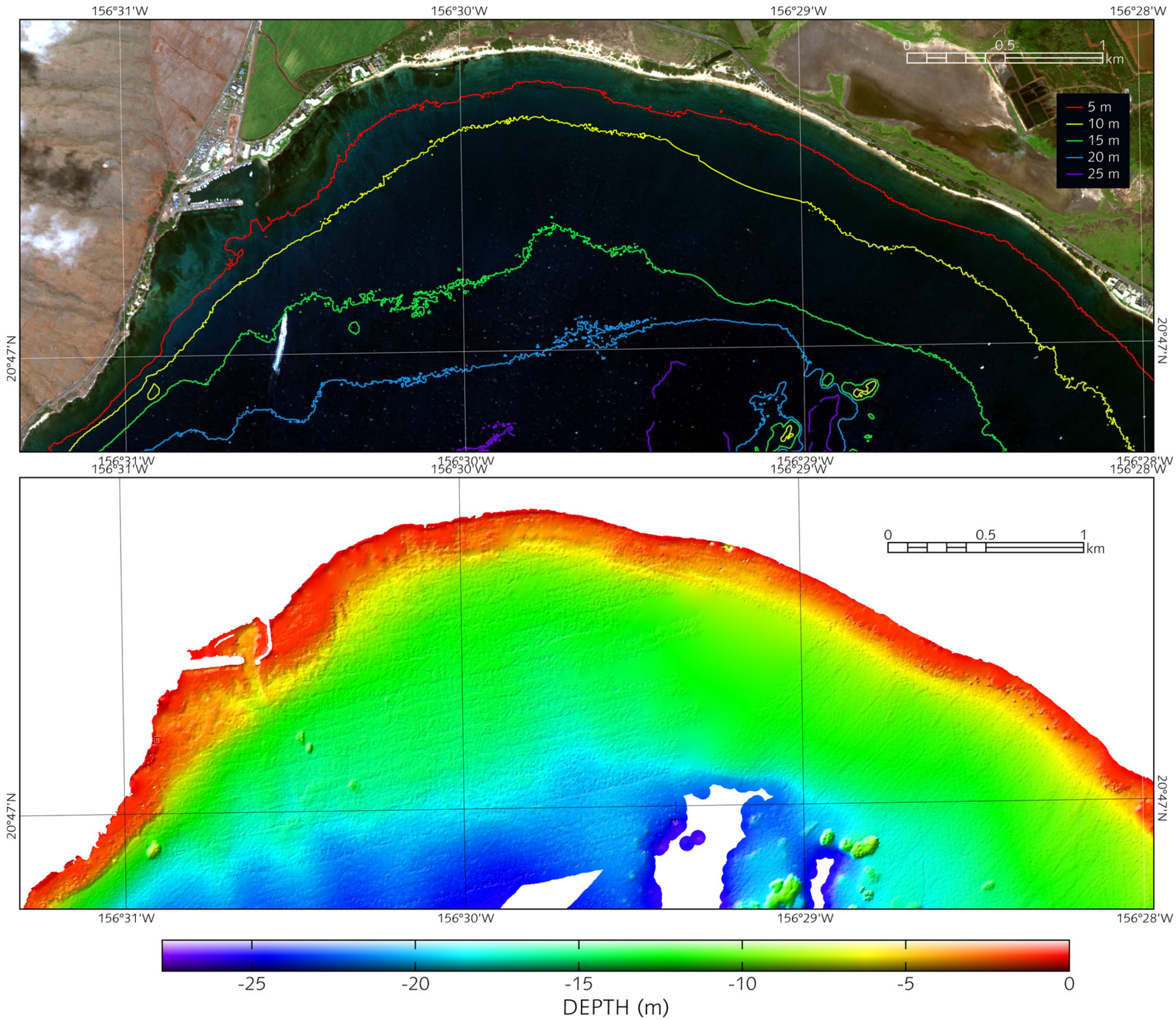


FIGURE 4. Bathymetry of Maalaea Bay.

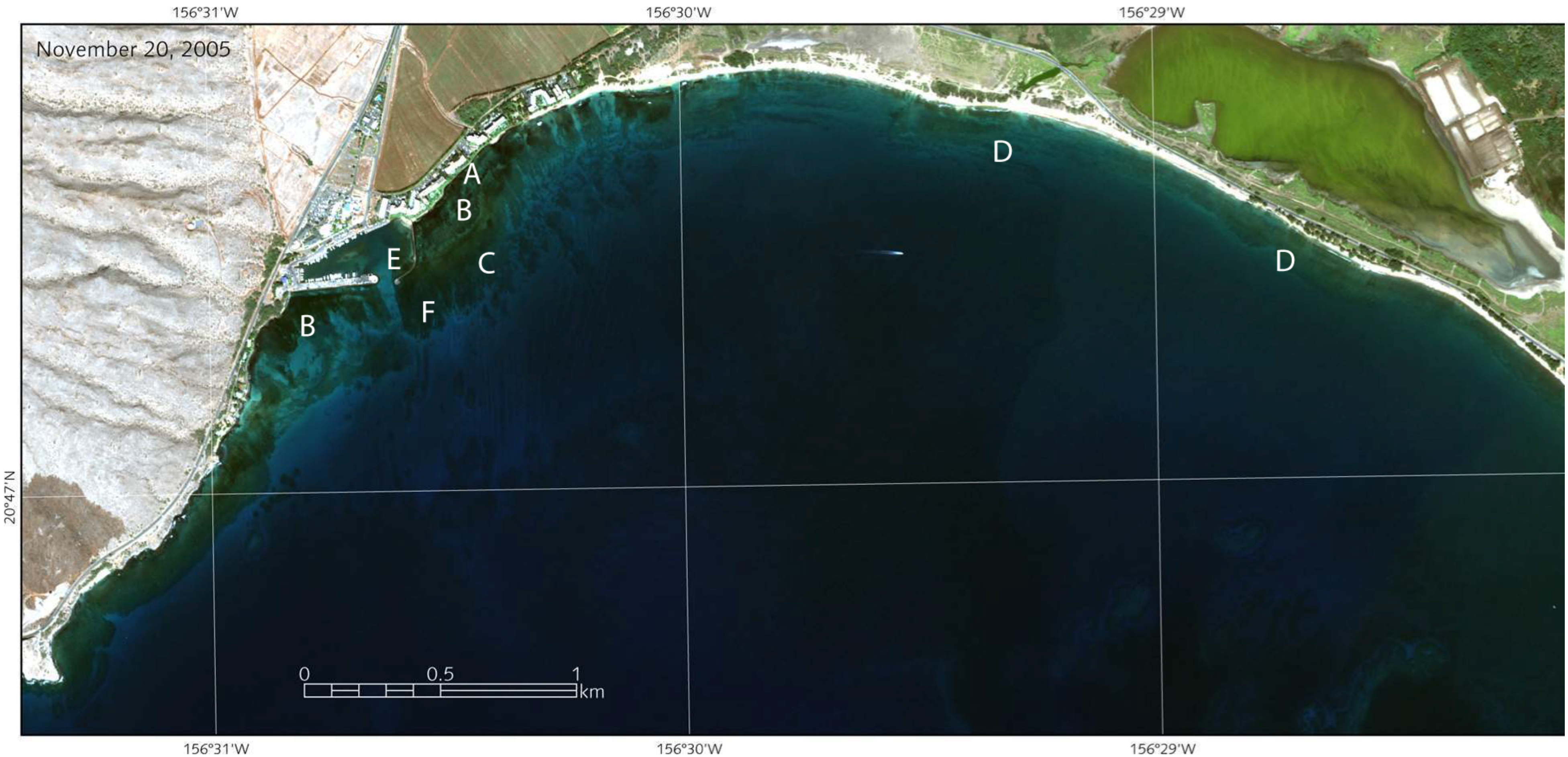


FIGURE 5. Aerial image of Maalaea Bay showing locations of reef zones A-F.

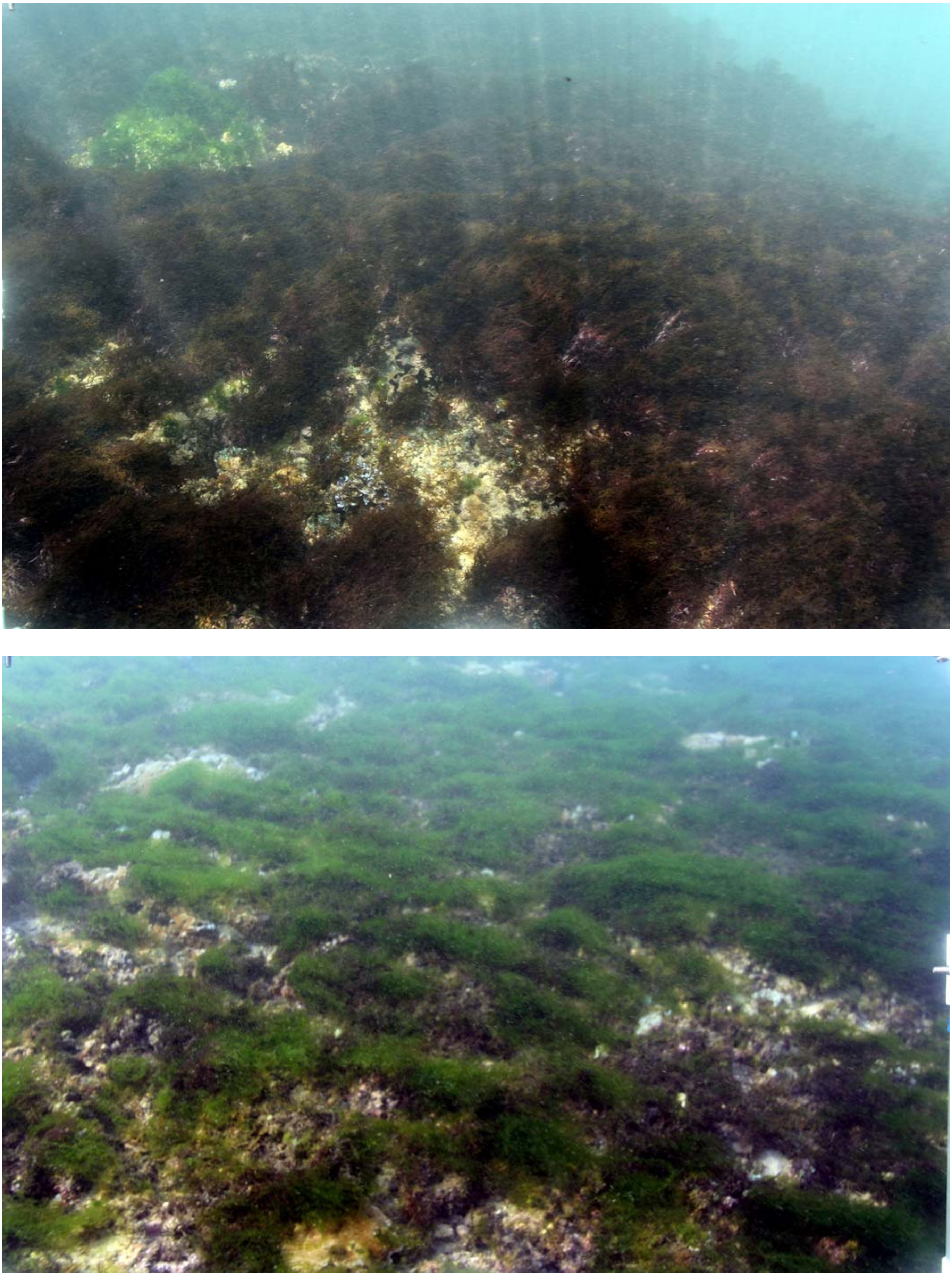


FIGURE 6. Nearshore algae covering bottom of Zone A (Figure 5) fronting the Condominium area of inner Maalaea Bay. Red algae is *Hypnea musciformis*; green algae is *Ulva* spp. Water depth is approximately 1-2 feet in both photos.

FIGURE 7. Sand and rubble covered areas of the outer reef flat in Zone B (Figure 5) in the central region of Maalaea Bay.

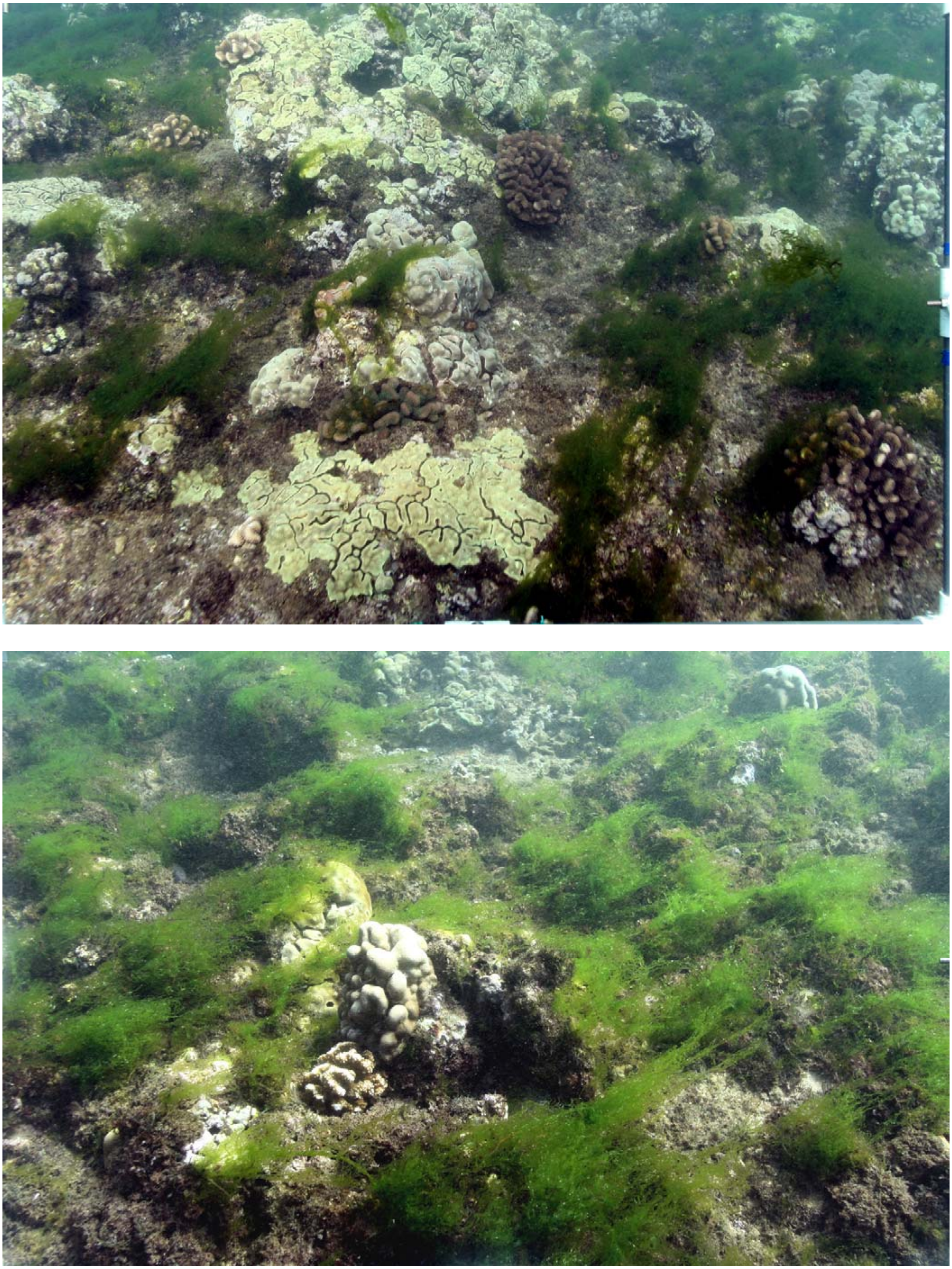


FIGURE 8. Surface of reef flat off central area of Maalaea Bay shown as Zone B on Figure 5. Green algae in both photos is *Ulva* spp. Corals in both photos are predominantly various growth forms of *Porites lobata*.

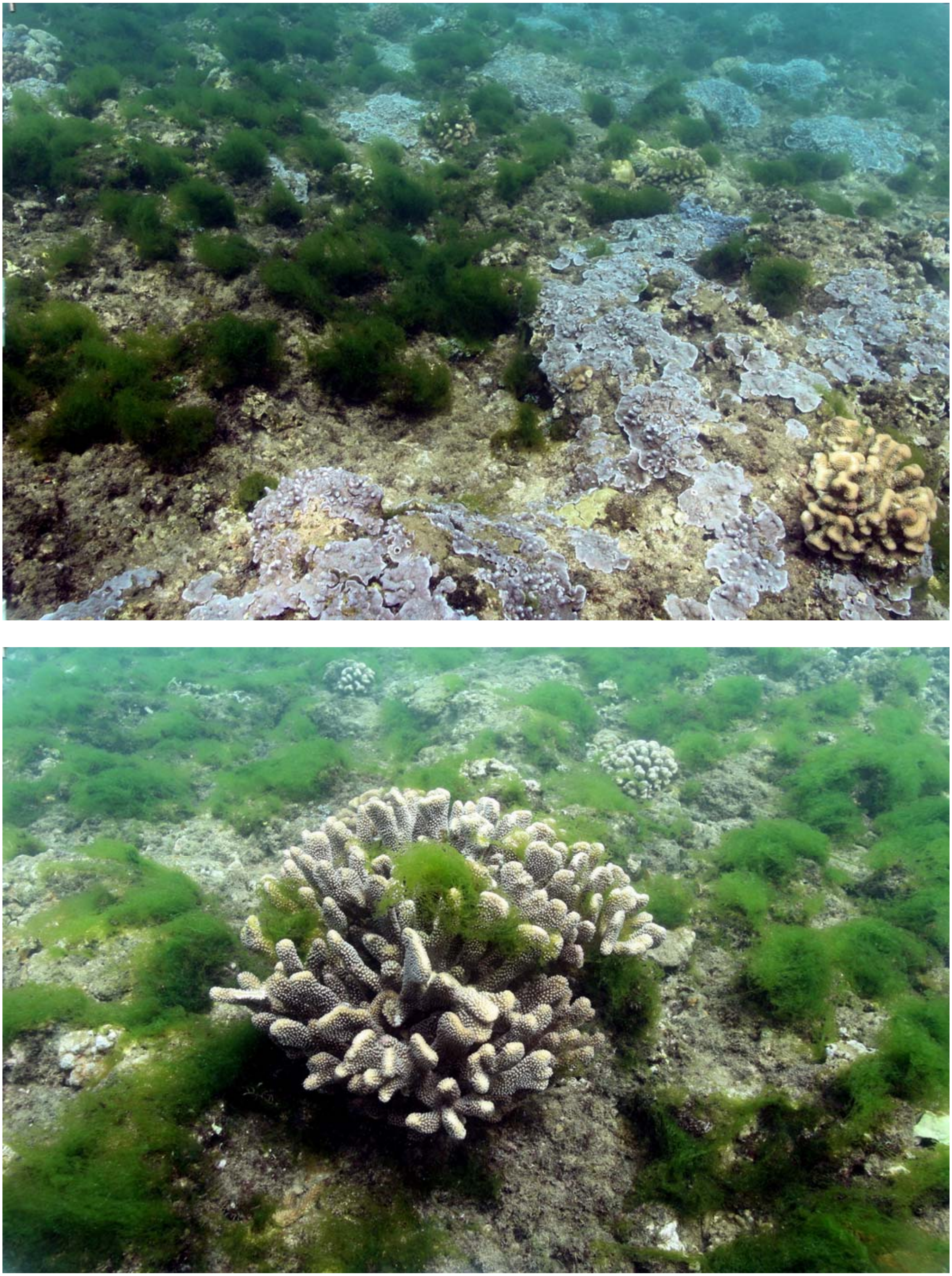


FIGURE 9. Shallow reef platform in Zone B (see Figure 5) showing expansive growth of green algae *Ulva* spp, along with corals *Montipora flabellata* (top) and *Pocillopora eydouxi* (bottom).

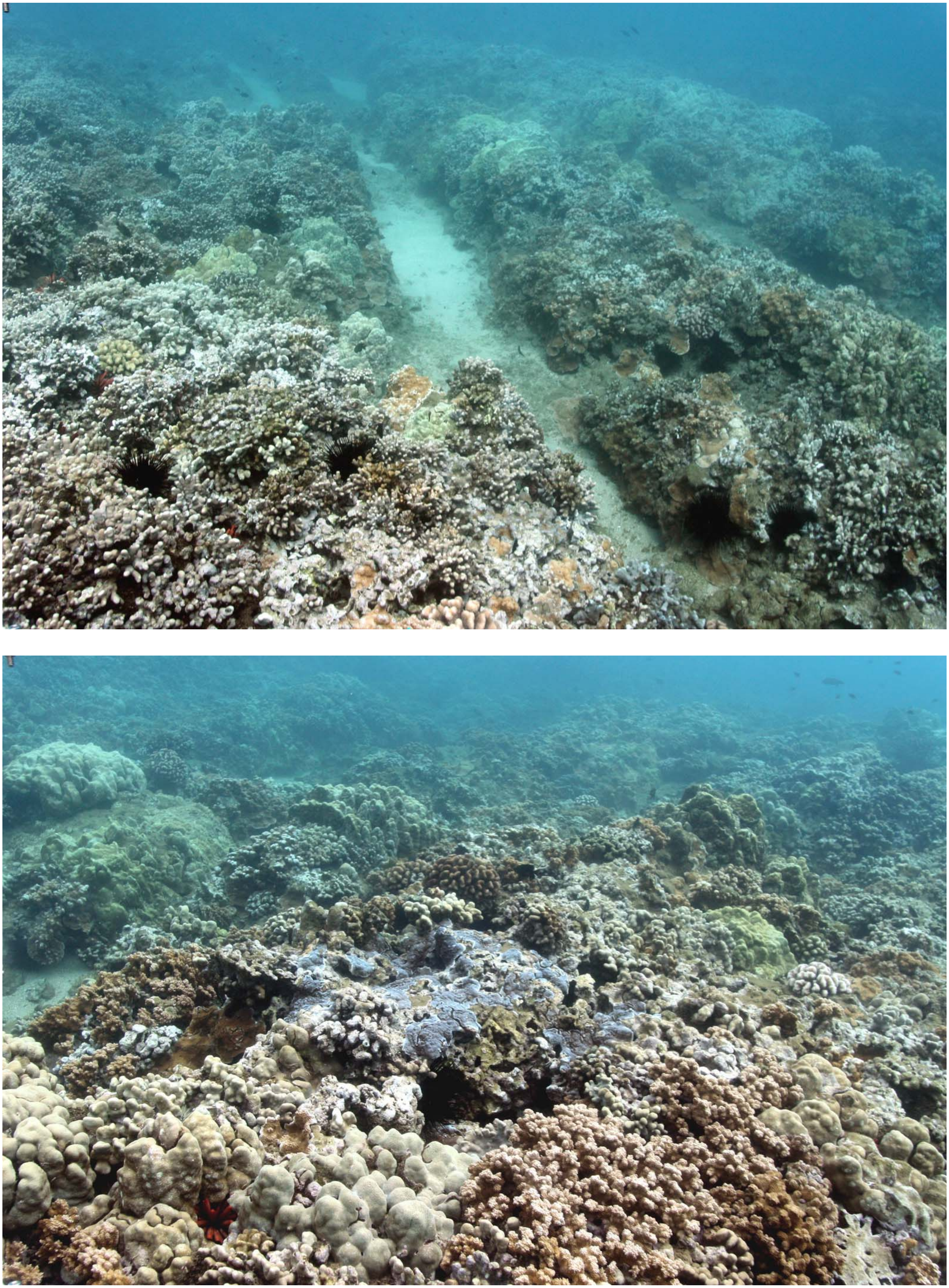


FIGURE 10. Extensive coral growth covering the bottom of Zone C (Figure 5) off the central portion of Maalaea Bay. The inshore edge of the reef occurs at the outer edge of the reef flat; the outer edge terminates in sand flats.

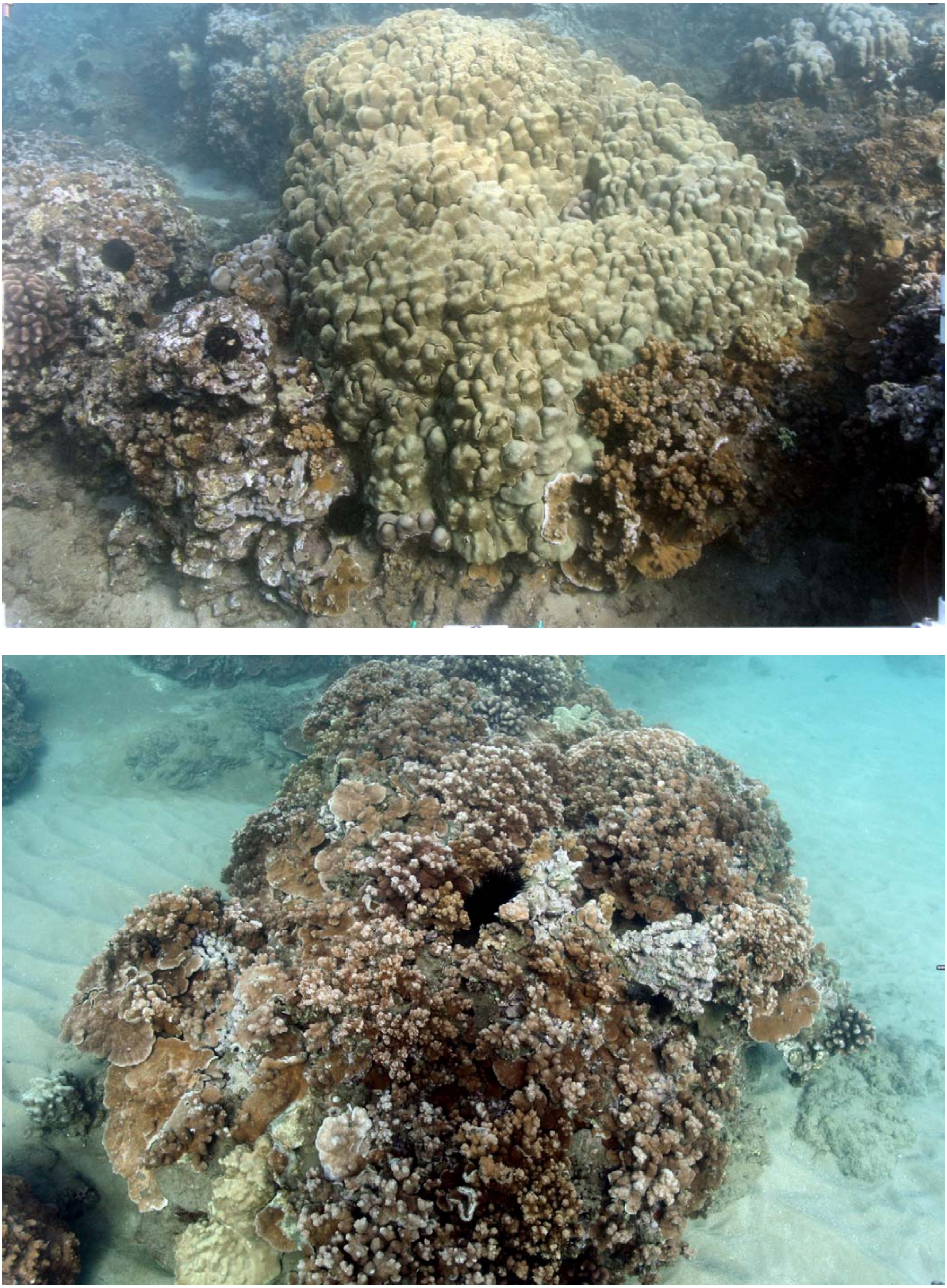


FIGURE 11. Large coral colonies occurring at the outer edge of the reef in the central region of Maalaea Bay (Zone C in Figure 5). The upper photo shows a large colony of *Porites lobata*; the lower photo shows an amalgamated colony composed primarily of various growth forms of *Montipora* spp.

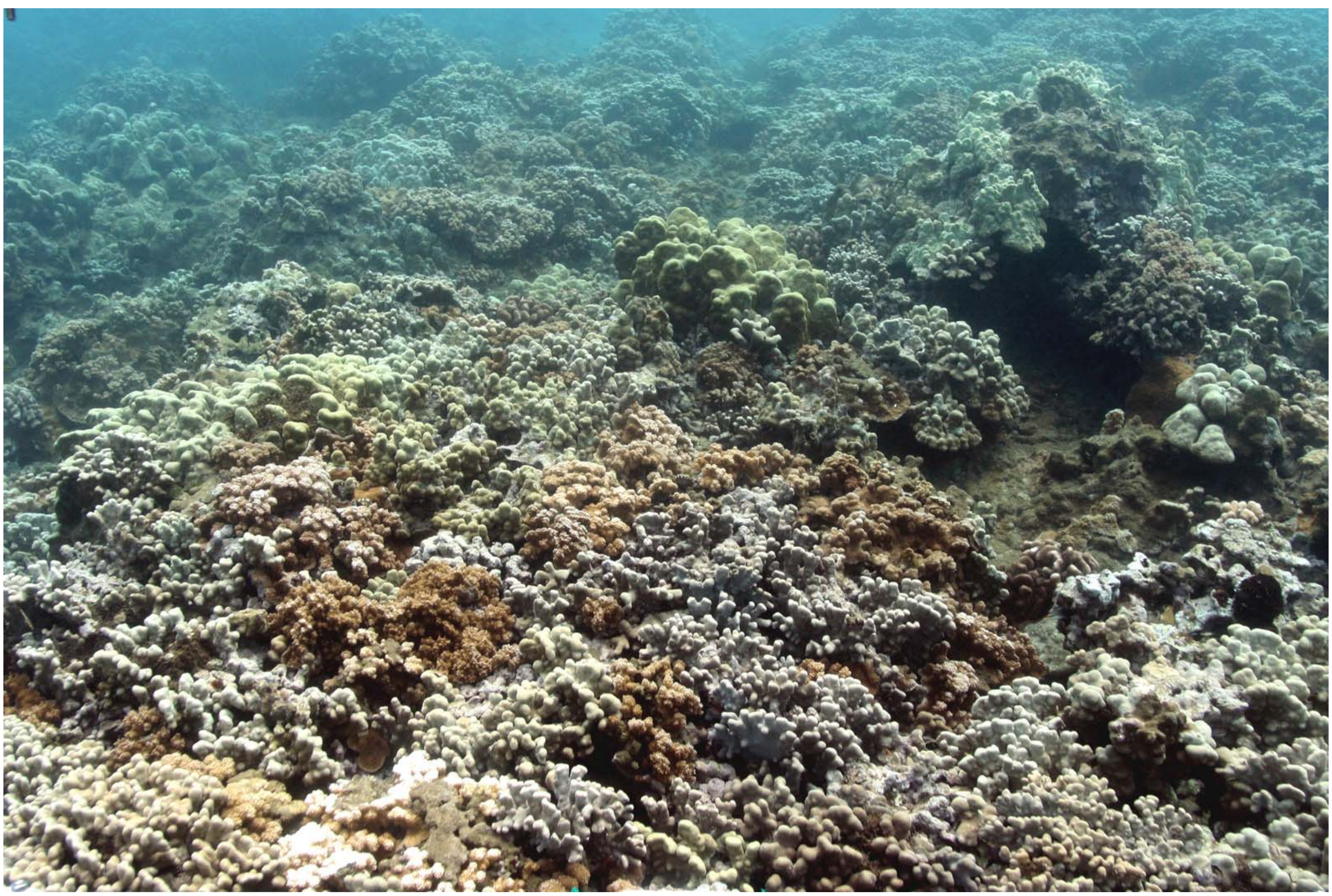


FIGURE 12. Large colonies of *Porites lobata* in upper photo and amalgamated coral platform consisting primarily of various species of *Porites* and *Montipora* in lower photo comprise the two major growth forms that form the accreting reefs of Zone C (see Figure 5).

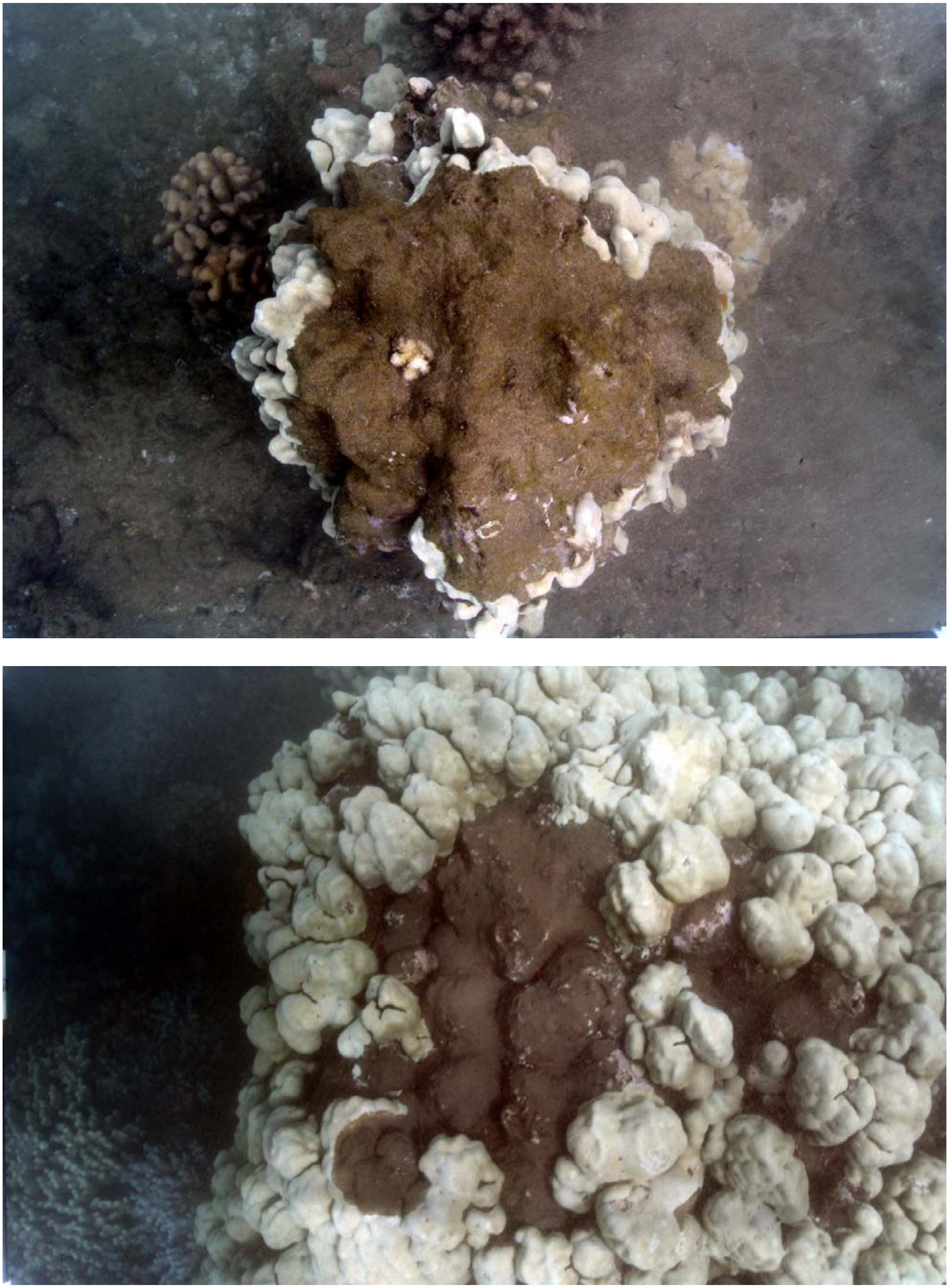


FIGURE 13. Partially mud covered colonies on finger reefs in Zone D (figure 5) along eastern shoreline of Maalaea Bay.

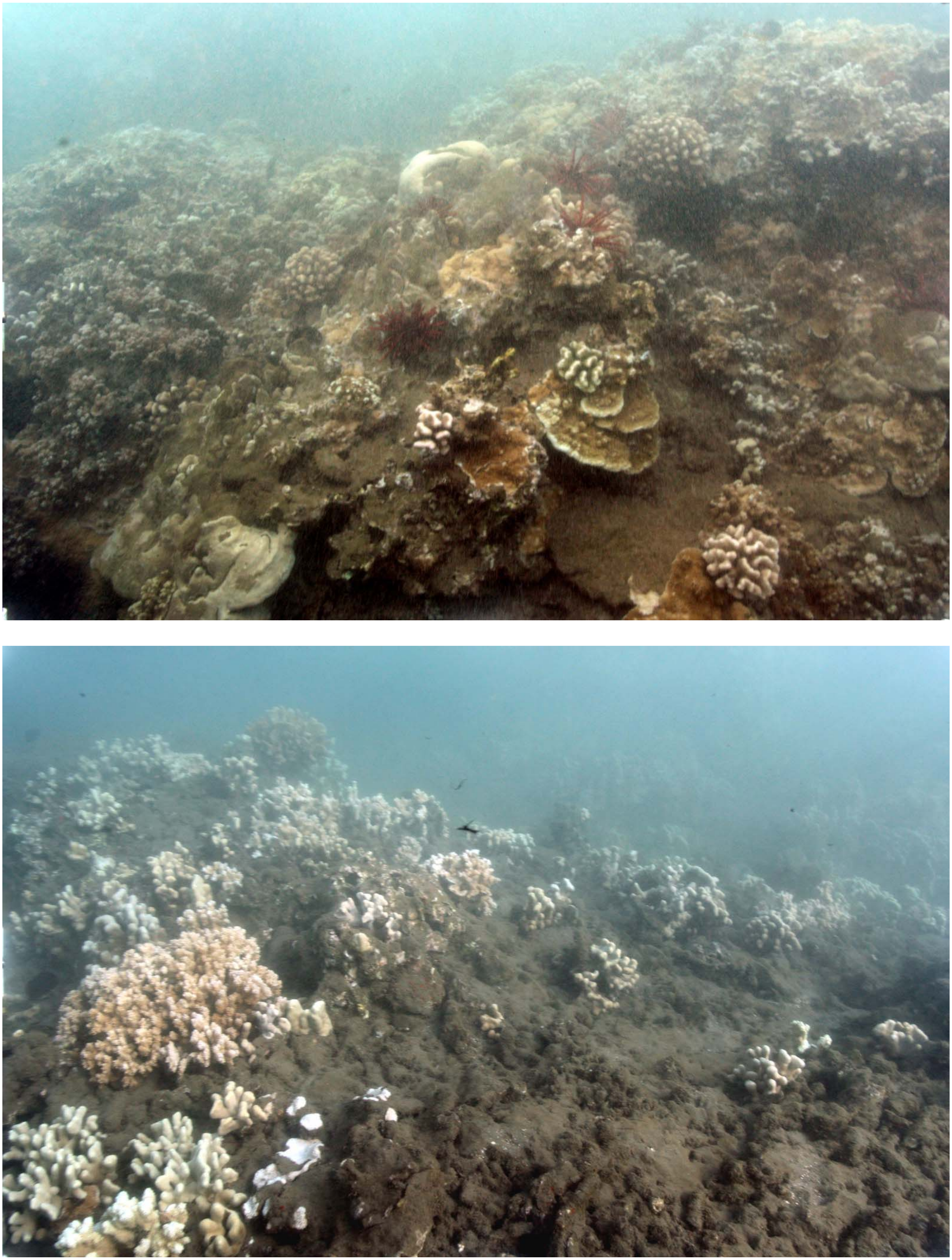


FIGURE 14. Two views of the finger reefs in Zone D (Figure 5) on east side of Maalaea Bay. Note deposition of red mud over much of the reef surface.

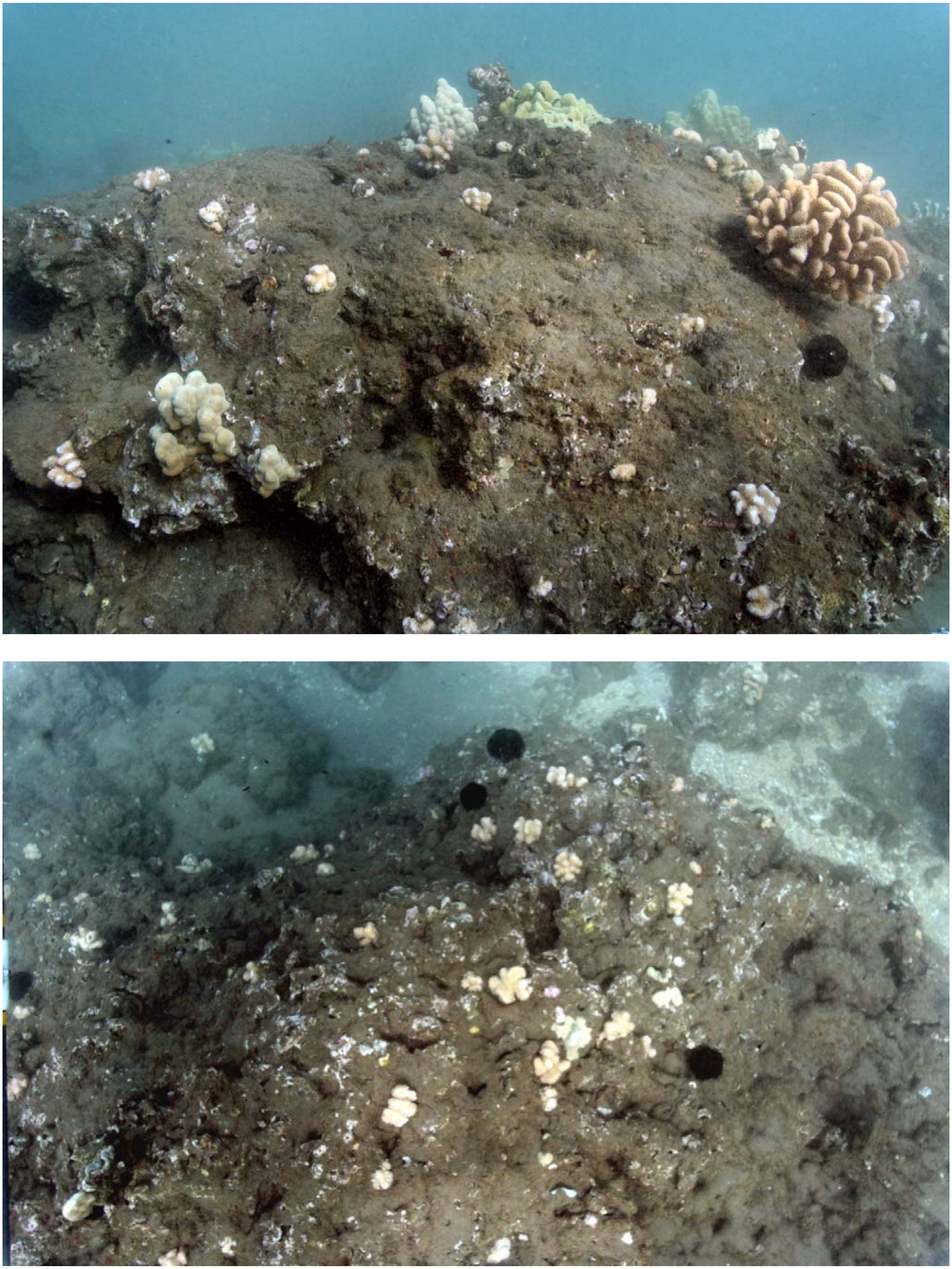


FIGURE 15. Sediment covered area of finger reef on East side of Maalaea Bay showing numerous recent recruits of small coral colonies, primarily of the species *Pocillopora meandrina*. The existence of such recent settlement, which is probably within the last 2-3 years suggests that the reef has the potential for recovery with the removal of continual sediment stress.

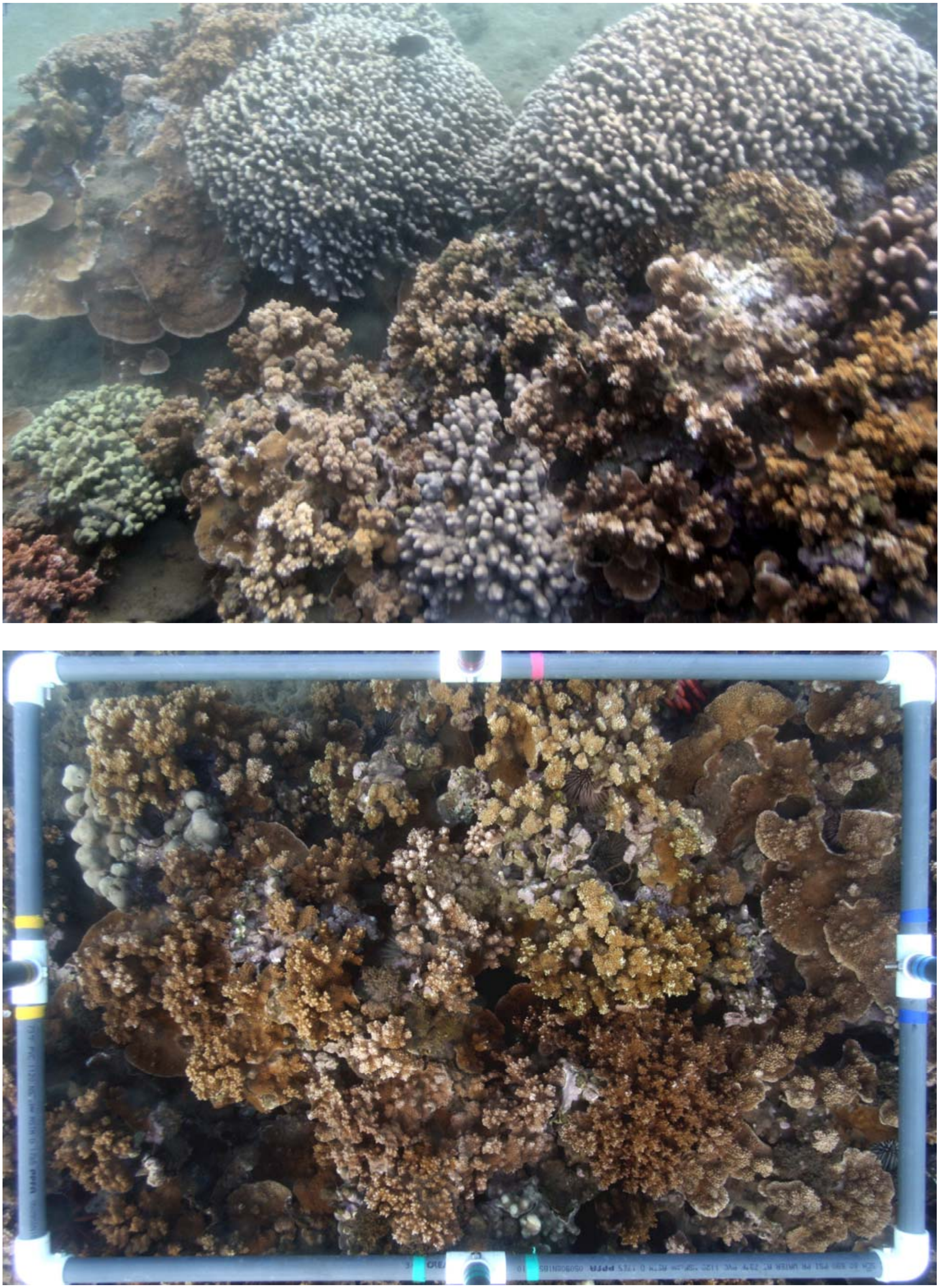


FIGURE 16. Coral community inside eastern breakwater of Maalaea Harbor (Zone E in Figure 5). Large hemispherical gray colonies in upper photo are a distinct growth form of *Porites compressa*. Brown colored corals in both photos are species of the genus *Montipora*.

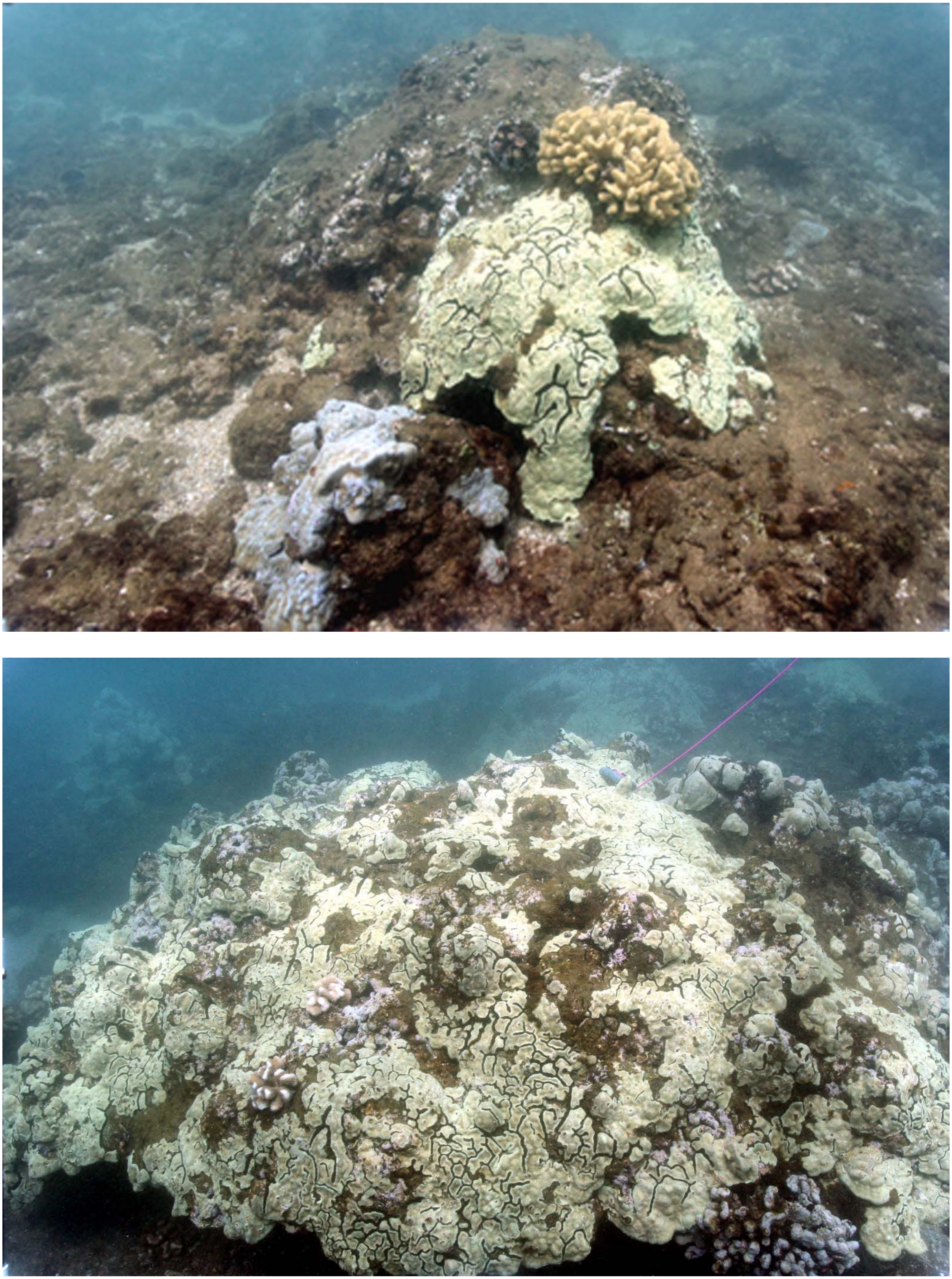


FIGURE 17. Coral colonies in Zone F (Figure 5) on the eastern side of the Harbor channel in Maalaea Bay. Portions of the colony of *Porites lobata* in lower photo show patches covered with sediment.

FIGURE 18. Stressed reef in Zone F (see Figure 5) off Maalaea Harbor. Upper photo shows extensive growth of alien algae *Acanthophora specifera* on reef surface. While live corals are evident in both photos, portions of colonies are dead and covered with sediment.

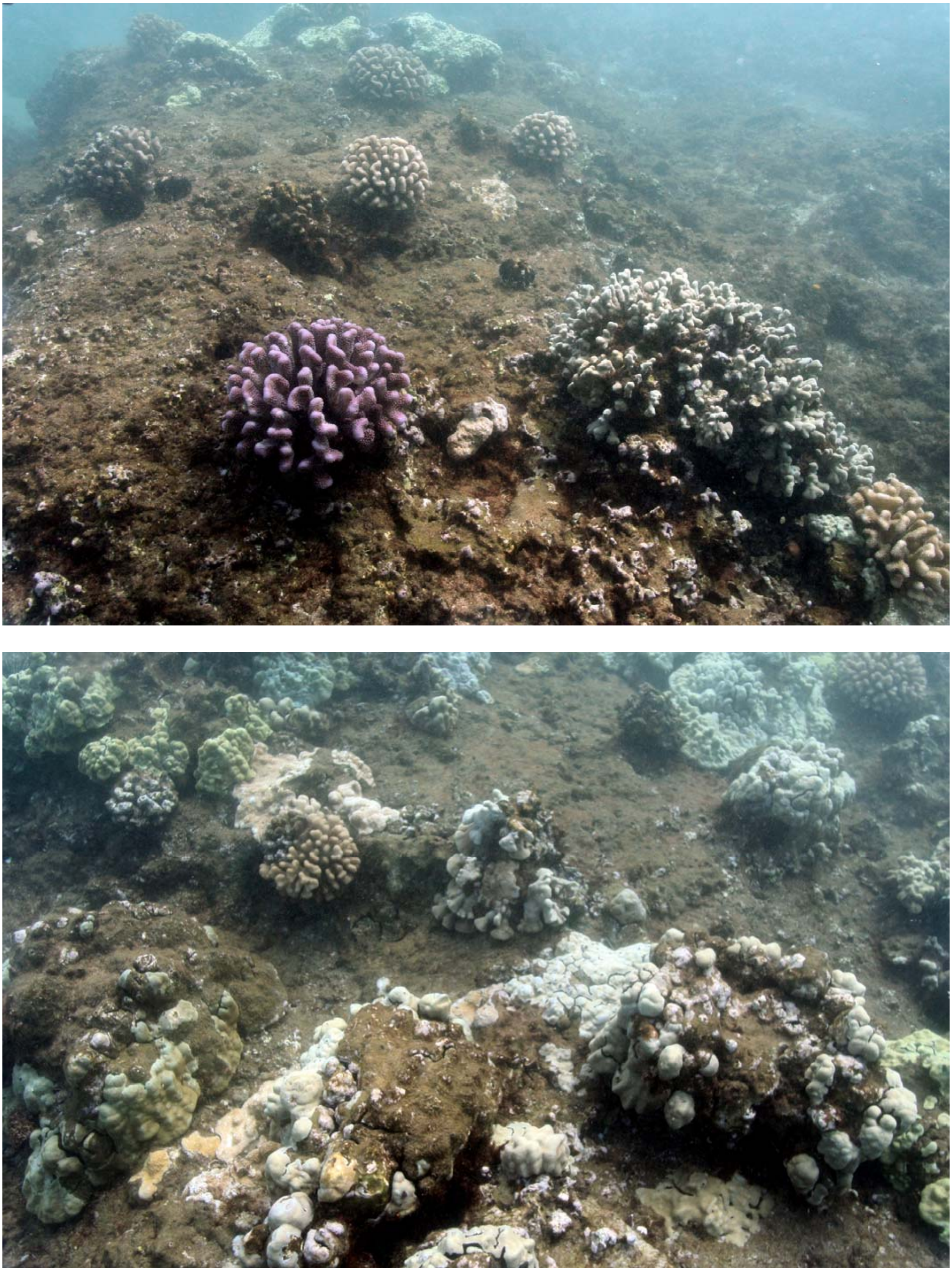


FIGURE 19. Sections of the reef platform in Zone F (Figure 5) of the outer reef platform in Maalaea Bay.

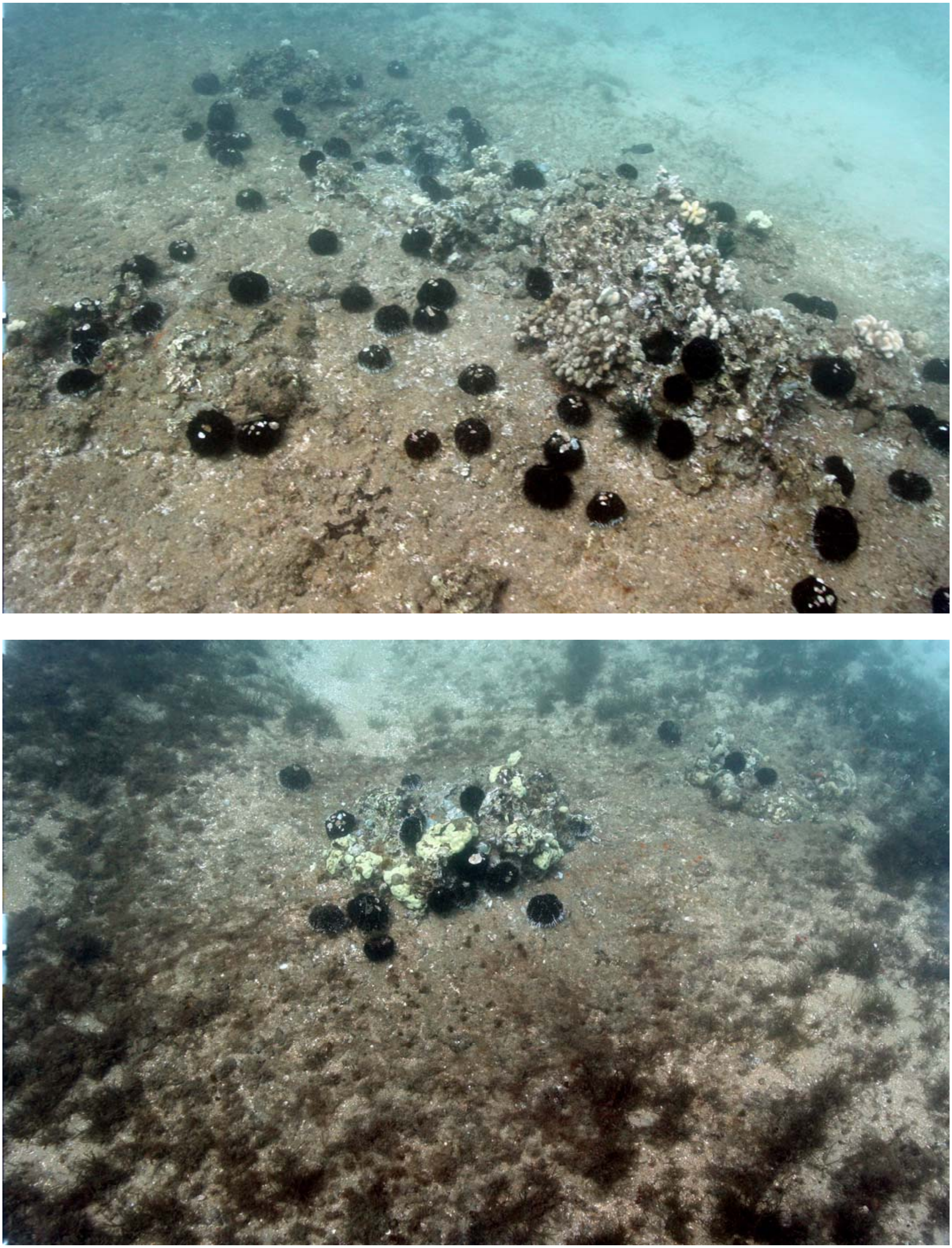


FIGURE 20. Aggregations of the sea urchin *Tripneustes gratilla* on the reef surface of Zone F (see Figure 5) off the east side of the Maalaea Harbor entrance channel. In the lower photo, a “halo” of bare bottom can be seen where urchins have grazed algae.

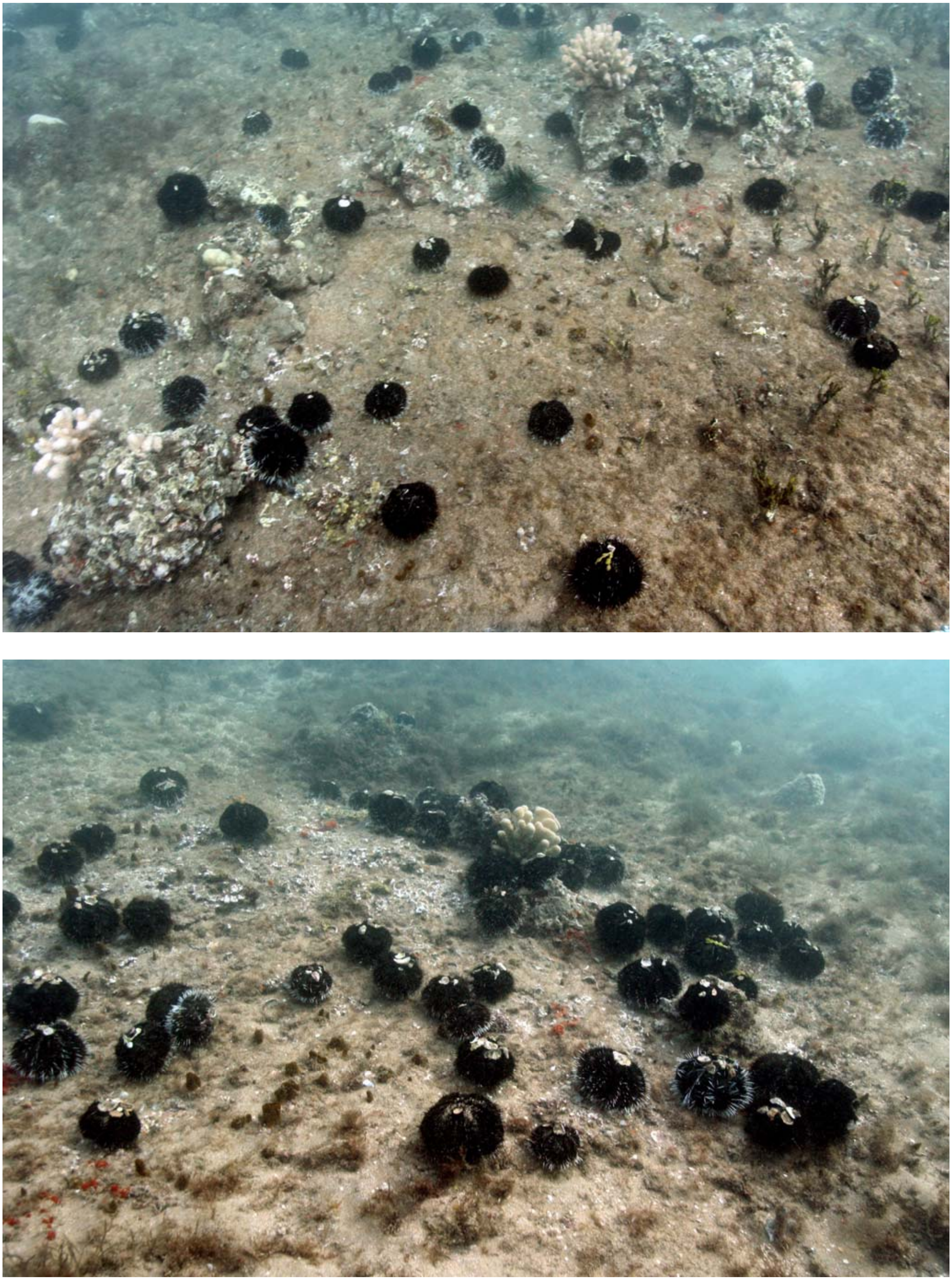


FIGURE 21. Aggregations of sea urchins *Tripneustes gratilla* on the reef surface of Zone F (Figure 5) on the eastern side of the Maalaea Harbor entrance channel.

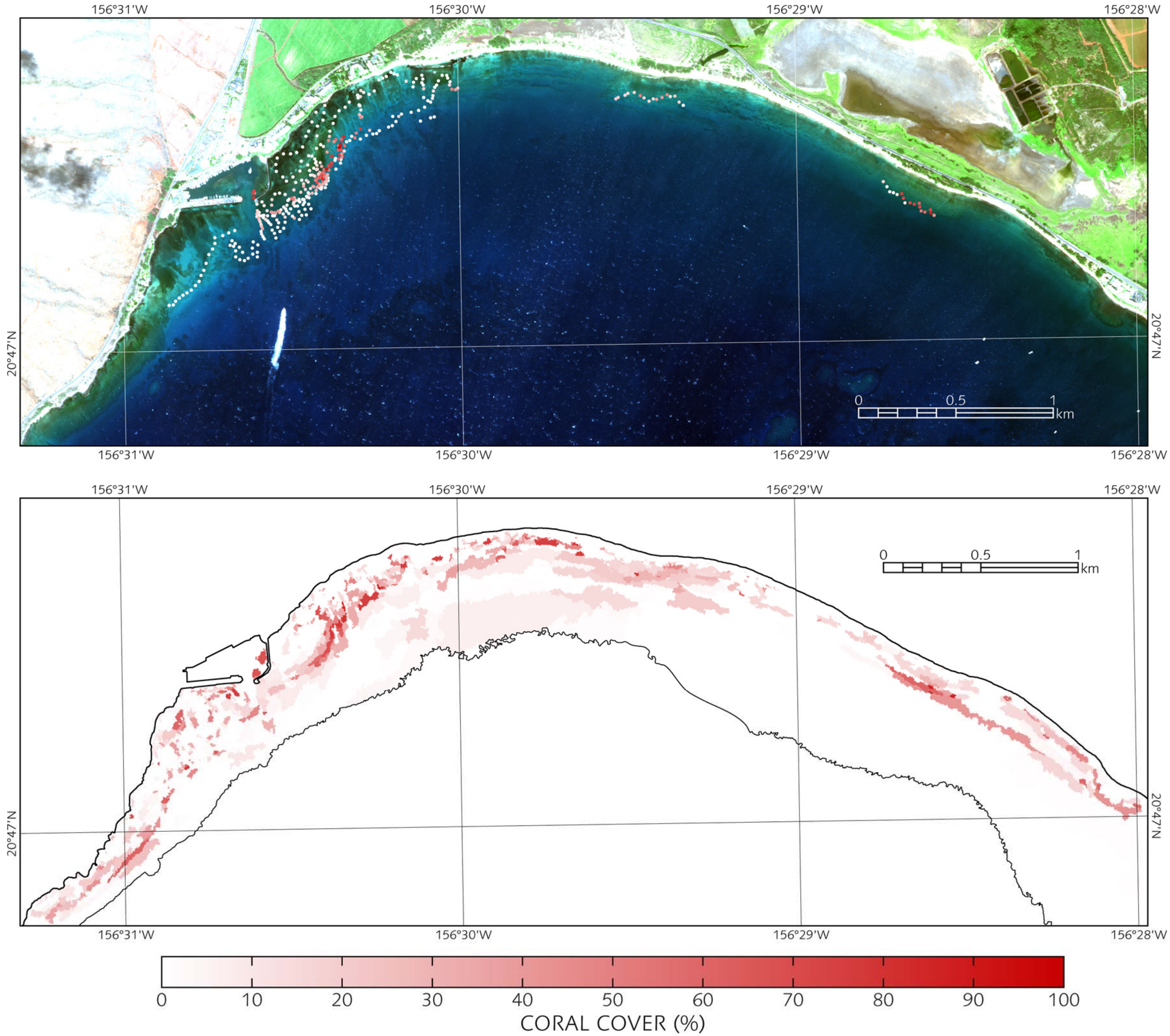


FIGURE 22. Upper image shows locations of ca/val sampling points in Maalaea Bay with intensity of color of circle representing percent coral cover. Bottom image shows map of coral cover created from cal/val data.

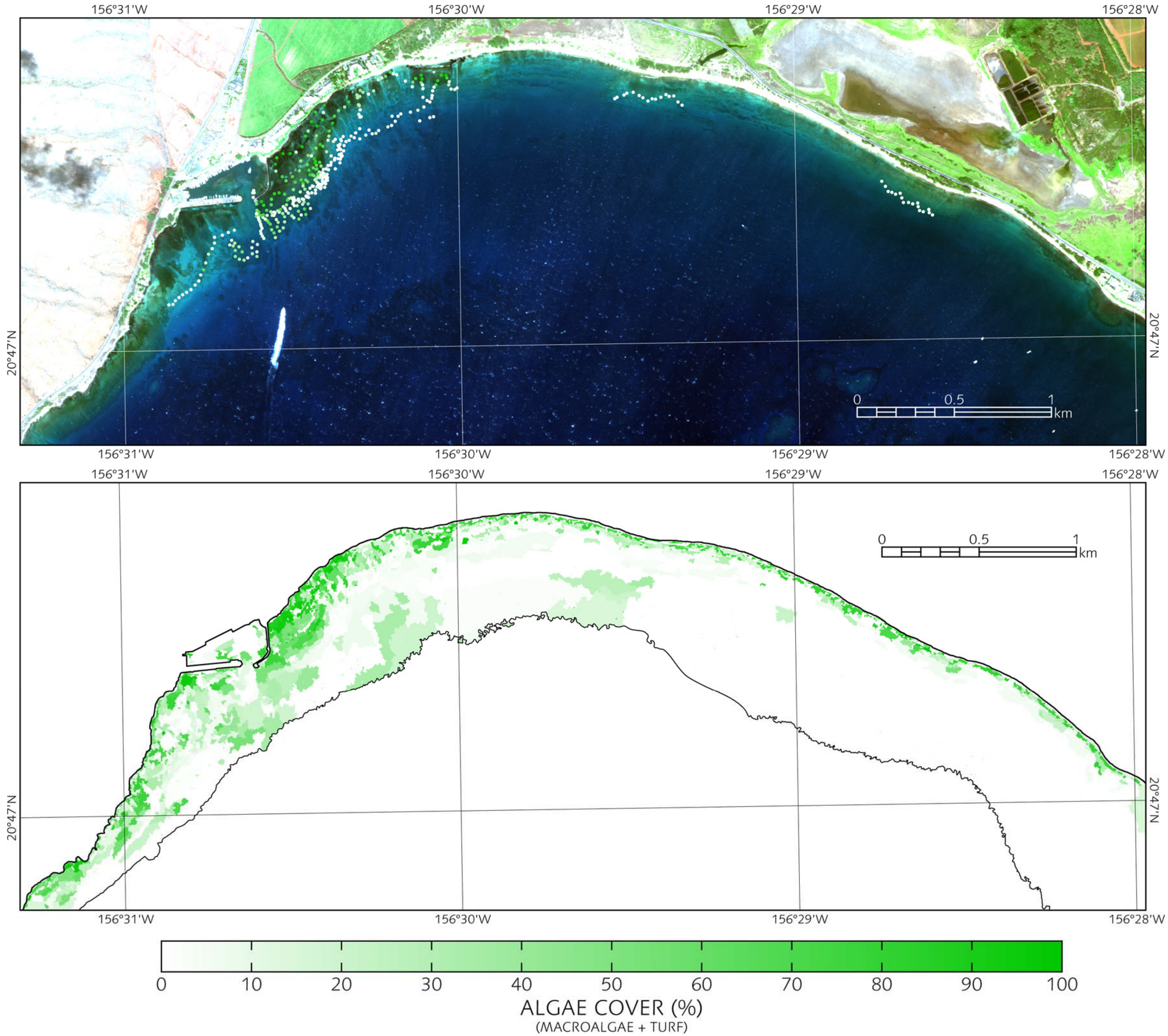


FIGURE 23. Upper image shows locations of ca/val sampling points in Maalaea Bay with intensity of color of circle representing percent algal cover. Bottom image shows map of algal cover created from cal/val data.

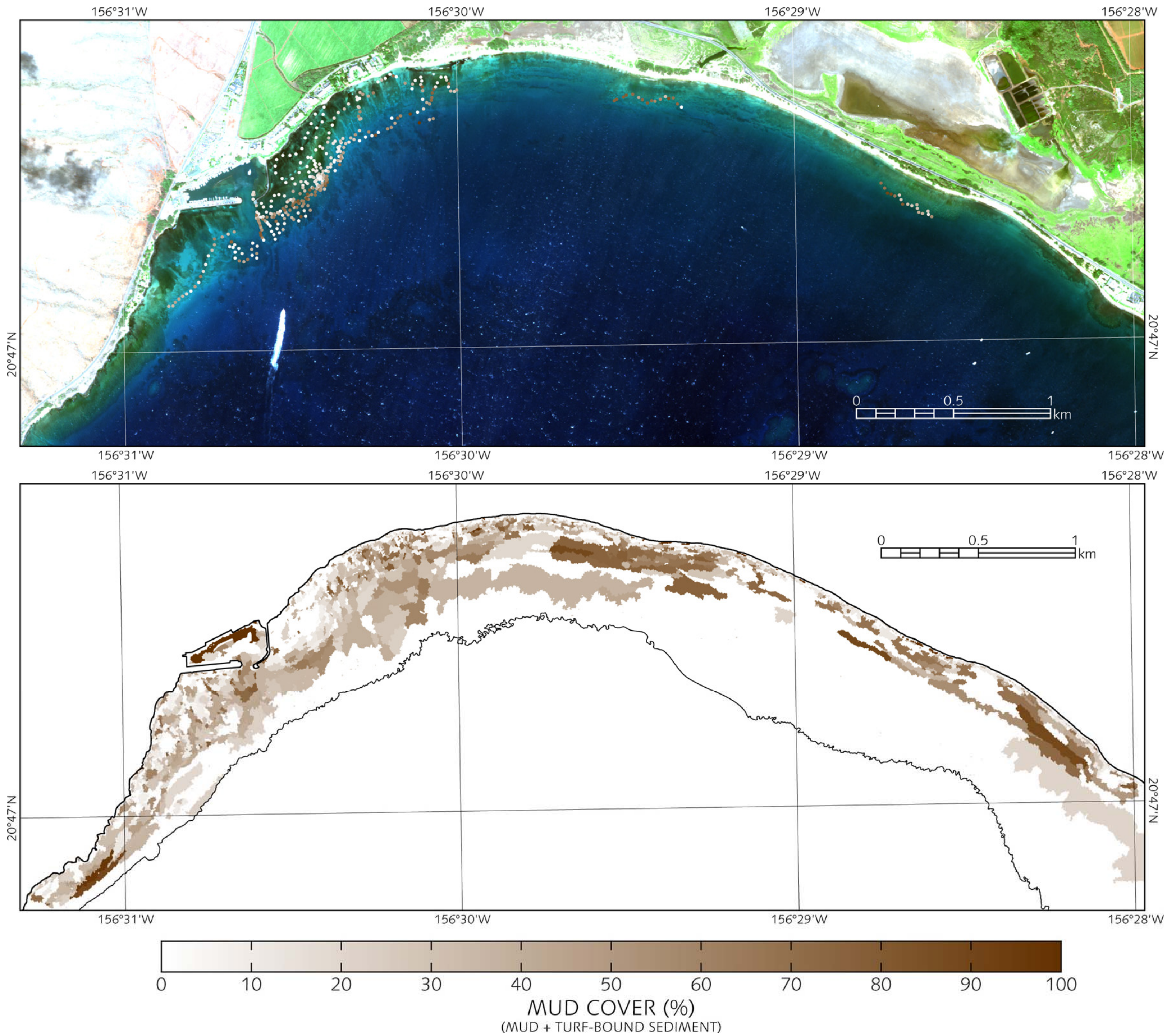


FIGURE 24. Upper image shows locations of ca/val sampling points in Maalaea Bay with intensity of color of circle representing percent bottom cover of mud and turf-bound sediment. Bottom image shows map of mud and sediment cover created from cal/val data.

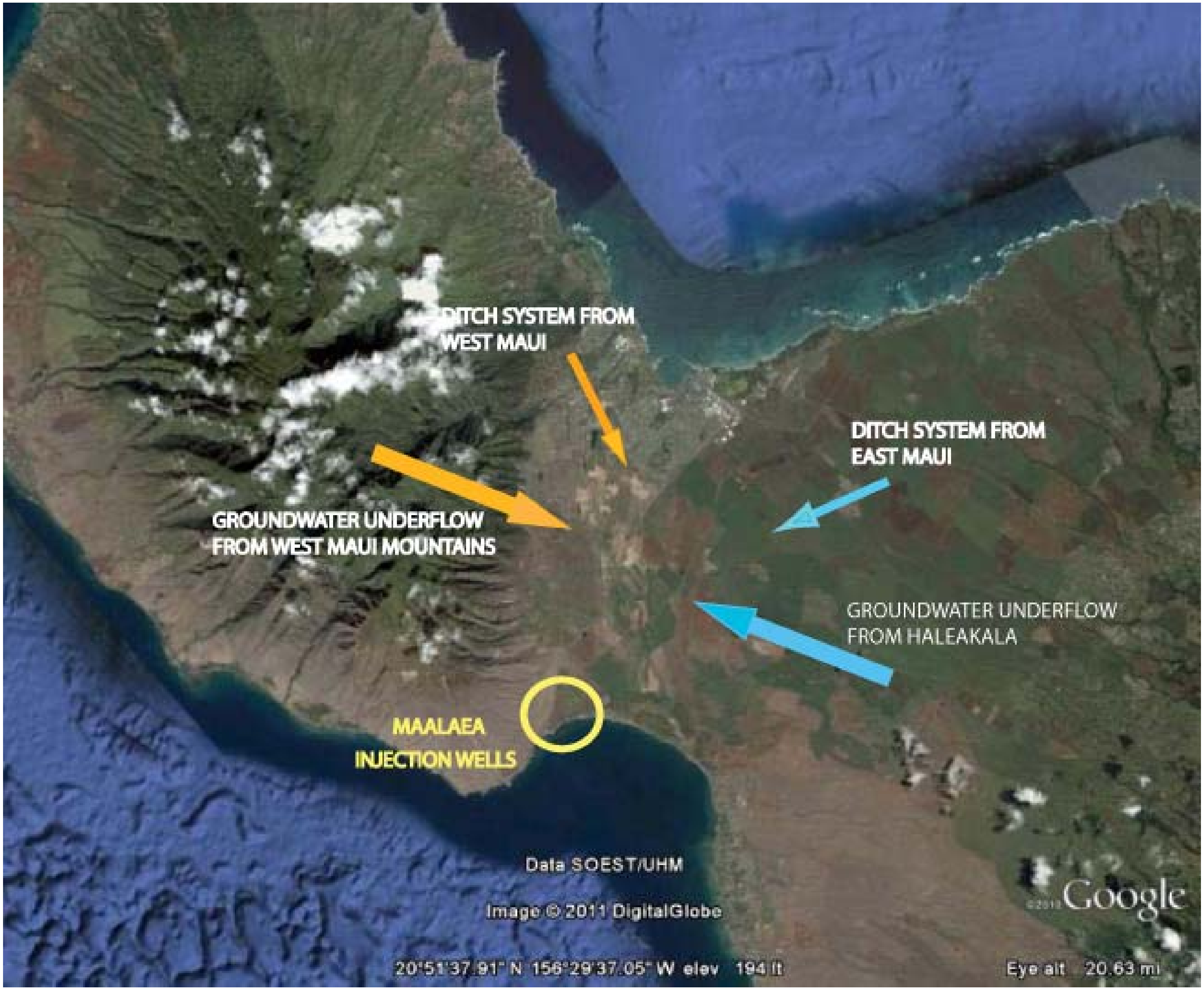


FIGURE 25. Schematic representation of additional sources contributing to basal groundwater lens that discharges to the ocean in central Maui.

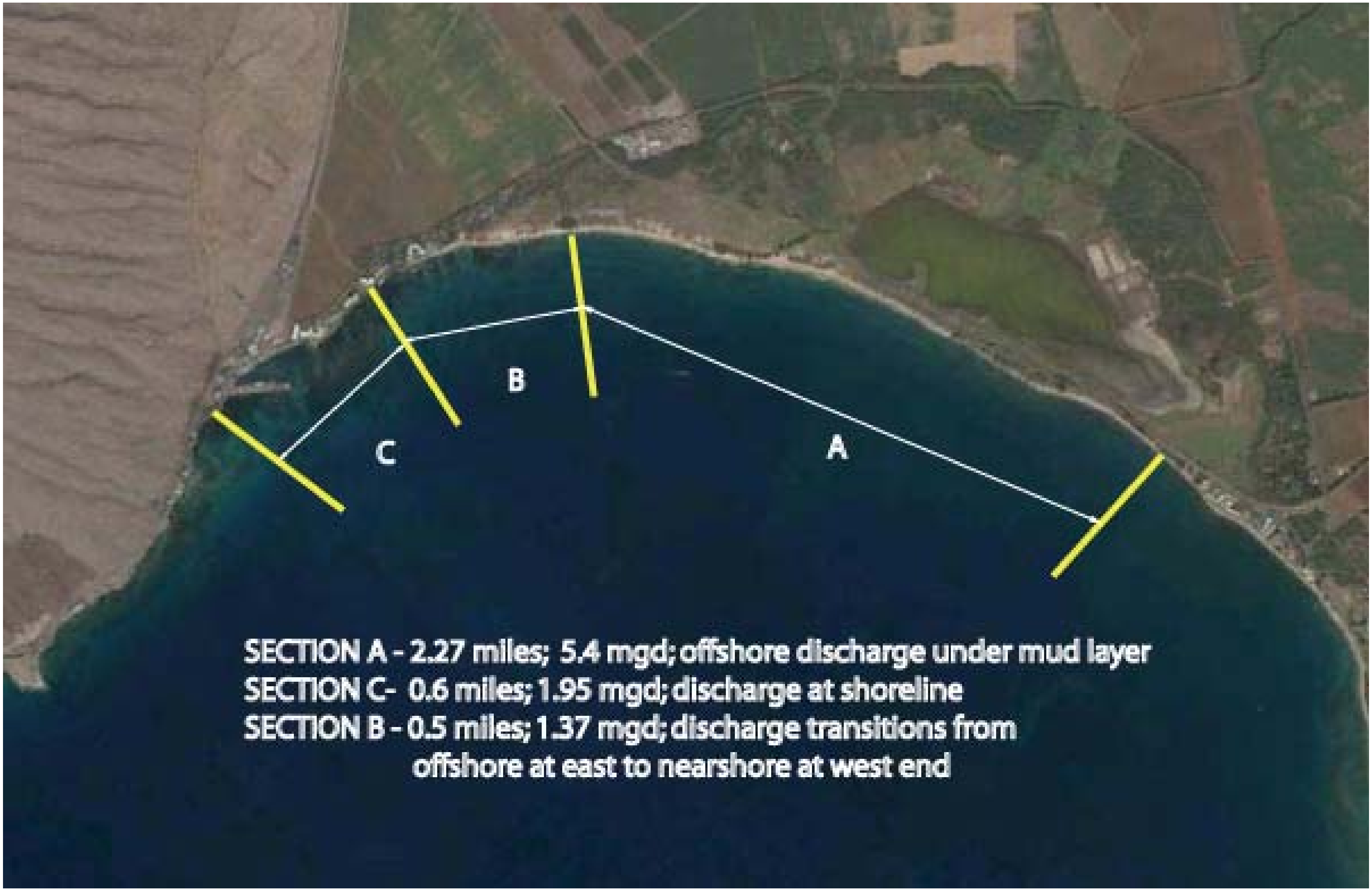
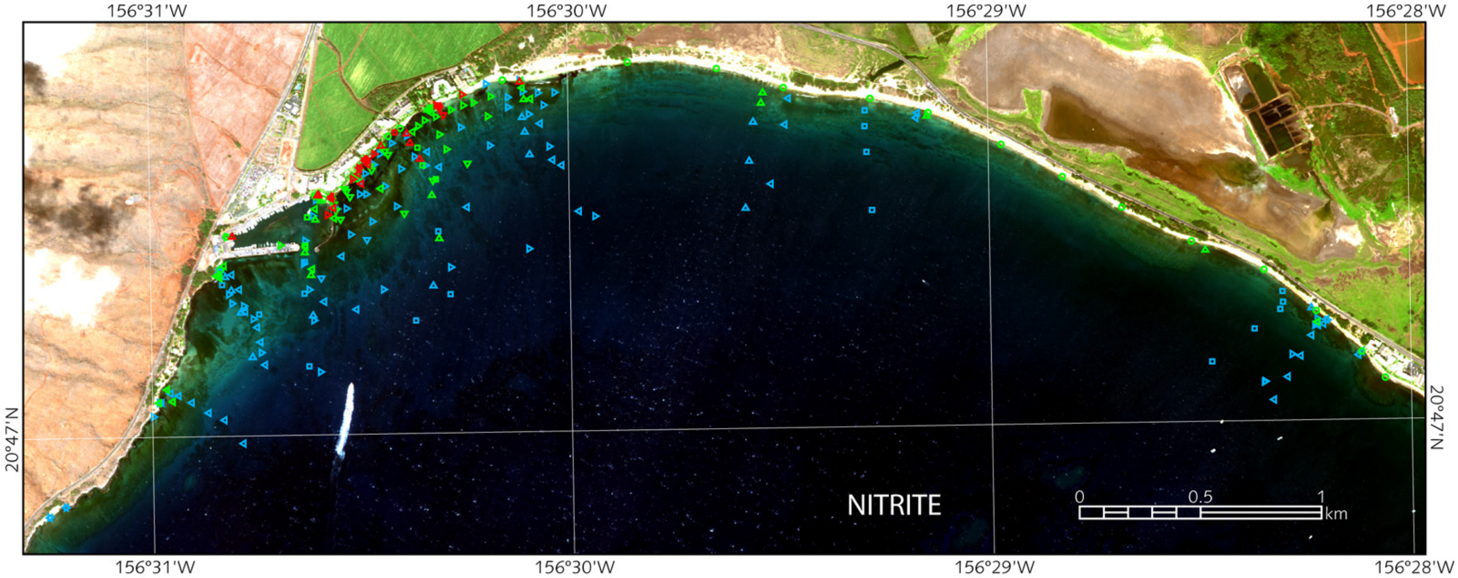


FIGURE 26. Approximate boundaries of sectors of different groundwater discharge into Maalaea Bay

FIGURE 27. Satellite images of Maalaea Bay showing water sampling locations with different symbols representing six sampling days. Color coding corresponds to three "bins" that represent concentrations of PO_4^{3-} typically found in the open coastal ocean (blue), typical concentrations found on nearshore coral reefs (green), and "impact" values (red) that represent input from land through groundwater discharge near the shoreline. Top image shows entire study area; bottom images shows area between Maalaea Harbor and Haycraft Beach Park.

FIGURE 28. Satellite images of Maalaea Bay showing water sampling locations with different symbols representing six sampling days. Color coding corresponds to three "bins" that represent concentrations of $NO_3^-+NO_2^-$ typically found in the open coastal ocean (blue), typical concentrations found on nearshore coral reefs (green), and "impact" values (red) that represent input from land through groundwater discharge near the shoreline. Top image shows entire study area; bottom images shows area between Maalaea Harbor and Haycraft Beach Park.

FIGURE 29. Satellite images of Maalaea Bay showing water sampling locations with different symbols representing six sampling days. Color coding corresponds to three "bins" that represent concentrations of NH_4^+ typically found in the open coastal ocean (blue), typical concentrations found on nearshore coral reefs (green), and "impact" values (red) that represent input from land through groundwater discharge near the shoreline. Top image shows entire study area; bottom images shows area between Maalaea Harbor and Haycraft Beach Park.



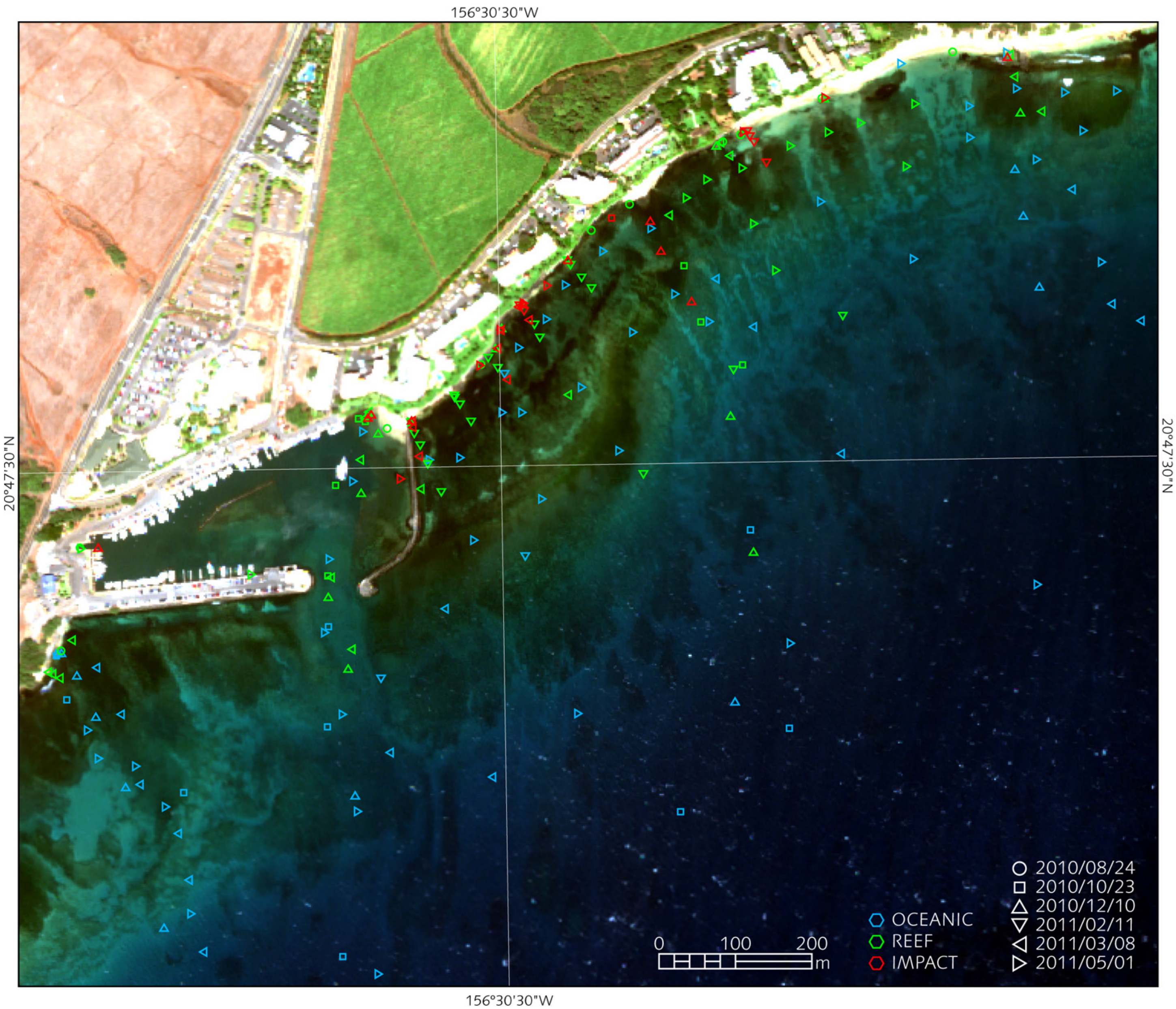


FIGURE 30. Satellite images of Maalaea Bay showing water sampling locations with different symbols representing six sampling days. Color coding corresponds to three "bins" that represent concentrations of NO_2^- typically found in the open coastal ocean (blue), typical concentrations found on nearshore coral reefs (green), and "impact" values (red) that represent input from land through groundwater discharge near the shoreline. Top image shows entire study area; bottom images shows area between Maalaea Harbor and Haycraft Beach Park.

FIGURE 31. Satellite images of Maalaea Bay showing water sampling locations with different symbols representing six sampling days. Color coding corresponds to three "bins" that represent concentrations of Si typically found in the open coastal ocean (blue), typical concentrations found in the transition zone where groundwater mixes with ocean water (green), and "impact" values (red) that represent input from land through groundwater discharge near the shoreline. Top image shows entire study area; bottom images shows area between Maalaea Harbor and Haycraft Beach Park.

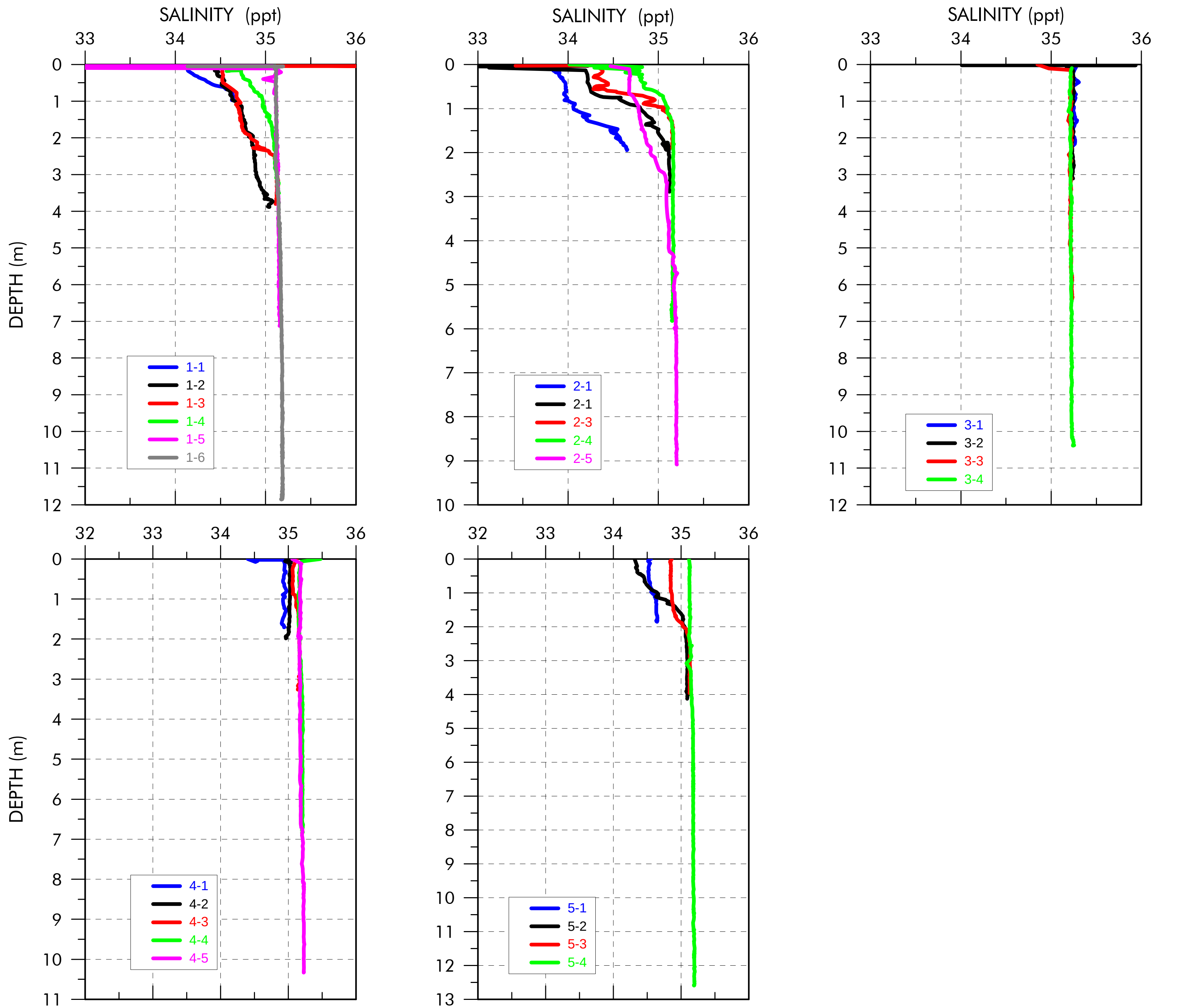


FIGURE 32. Vertical profiles of salinity at water sampling stations in Maalaea Bay sampled on October 23, 2010. Locations of sampling transects are shown on Figure 33.

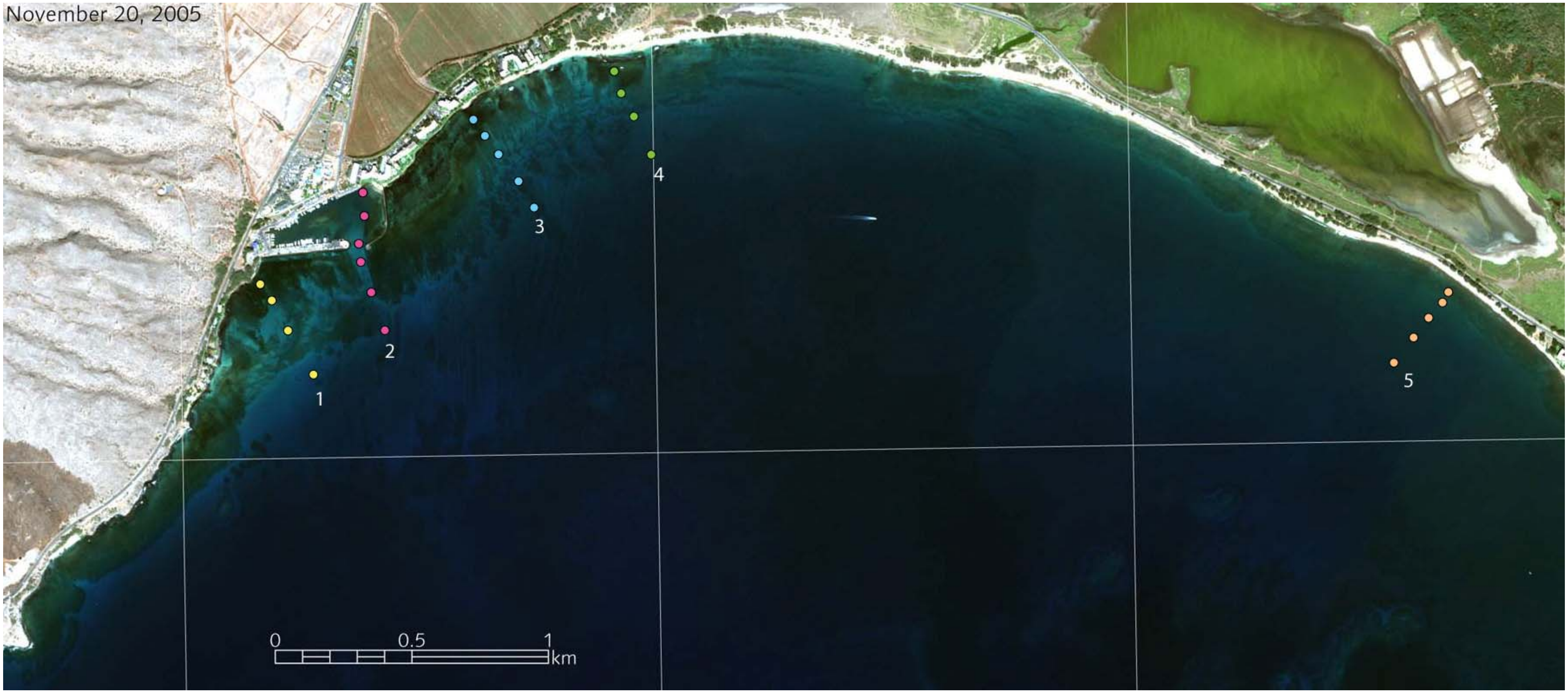


FIGURE 33. Aerial image of Maalaea Bay showing locations of vertical profiles shown in Figure 32 on 10-23-10.

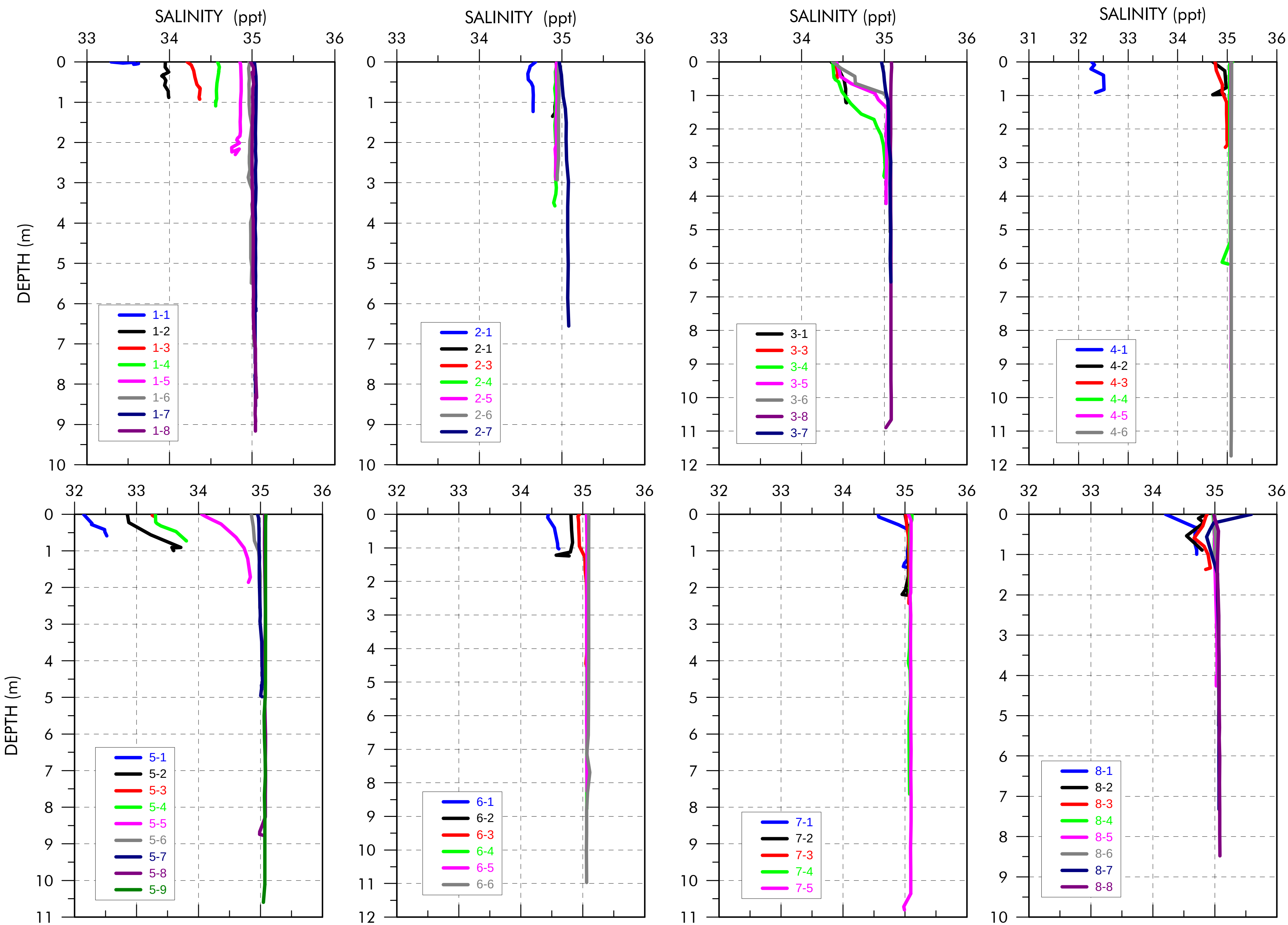


FIGURE 34. Vertical profiles of salinity at water sampling stations in Maalaea Bay sampled on March 8, 2011. Locations of sampling transects are shown on Figure 35.

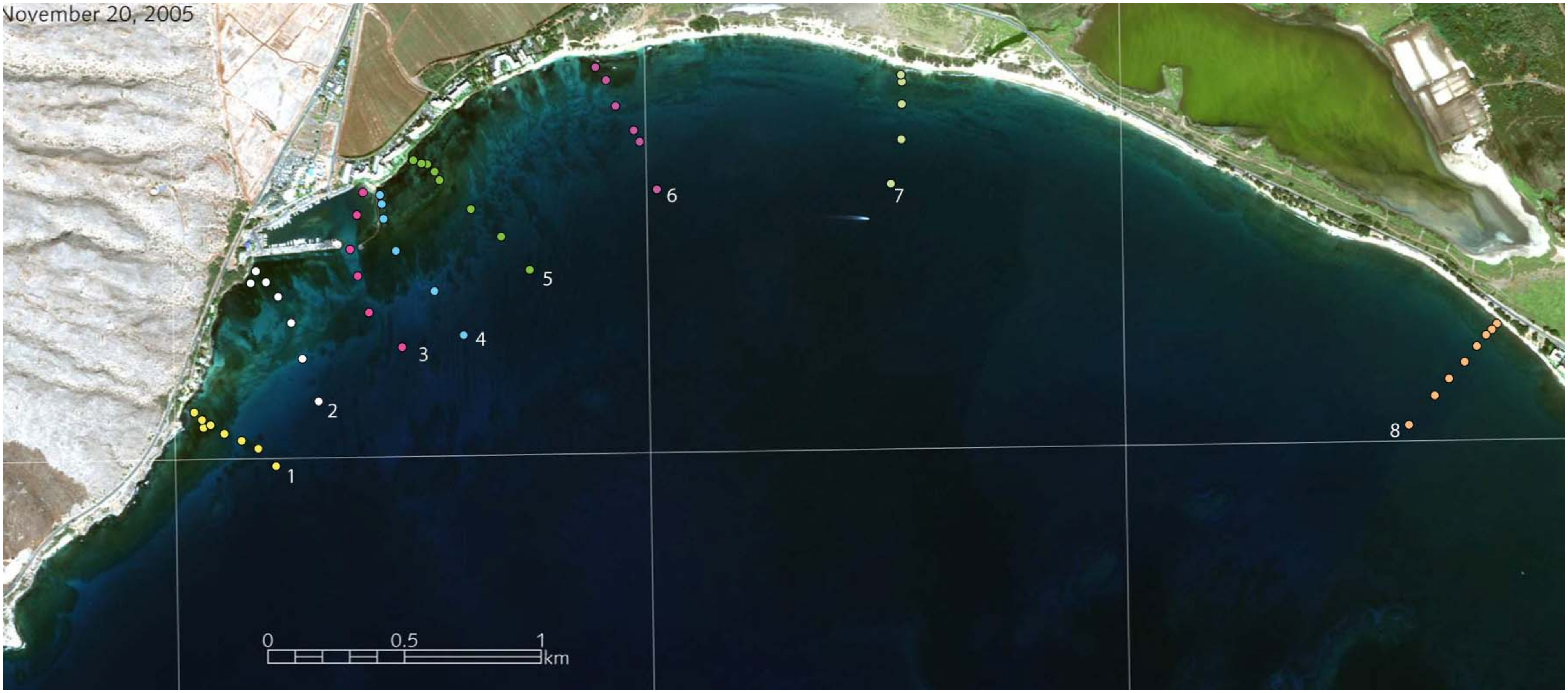


FIGURE 35. Aerial image of Maalaea Bay showing locations of vertical profiles shown in Figure 34 on 3-8-11.

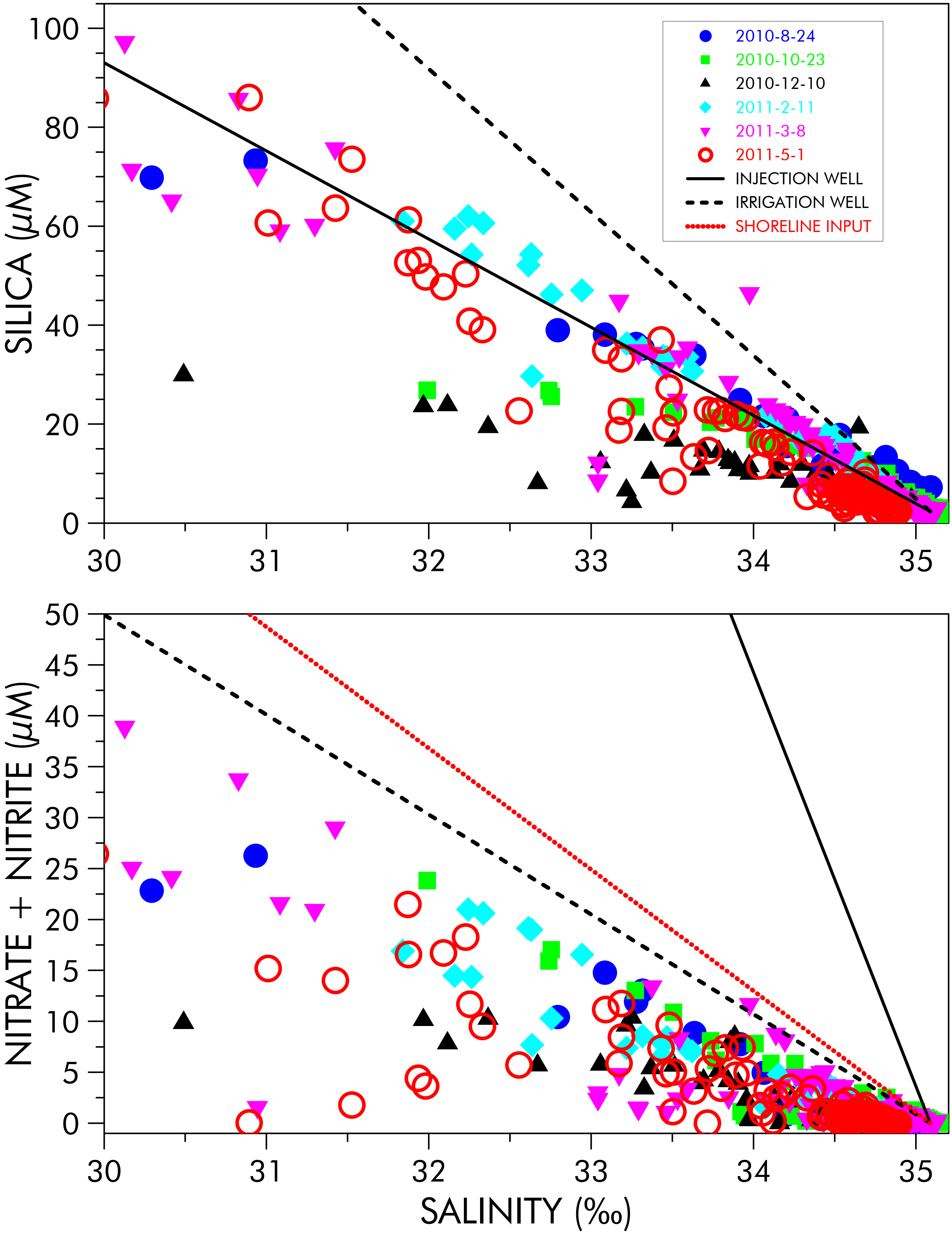


FIGURE 36. Mixing diagrams of concentrations of silica (top) and nitrate+nitrite (bottom) as functions of salinity for samples collected in Maalaea Bay during six increments of sampling in 2010-2011. Straight lines represent conservative mixing lines connecting endpoint concentrations of open coastal water and injection well effluent (solid black line), irrigation well water (dashed black line), and calculated value of groundwater entering the shoreline (dashed red line).

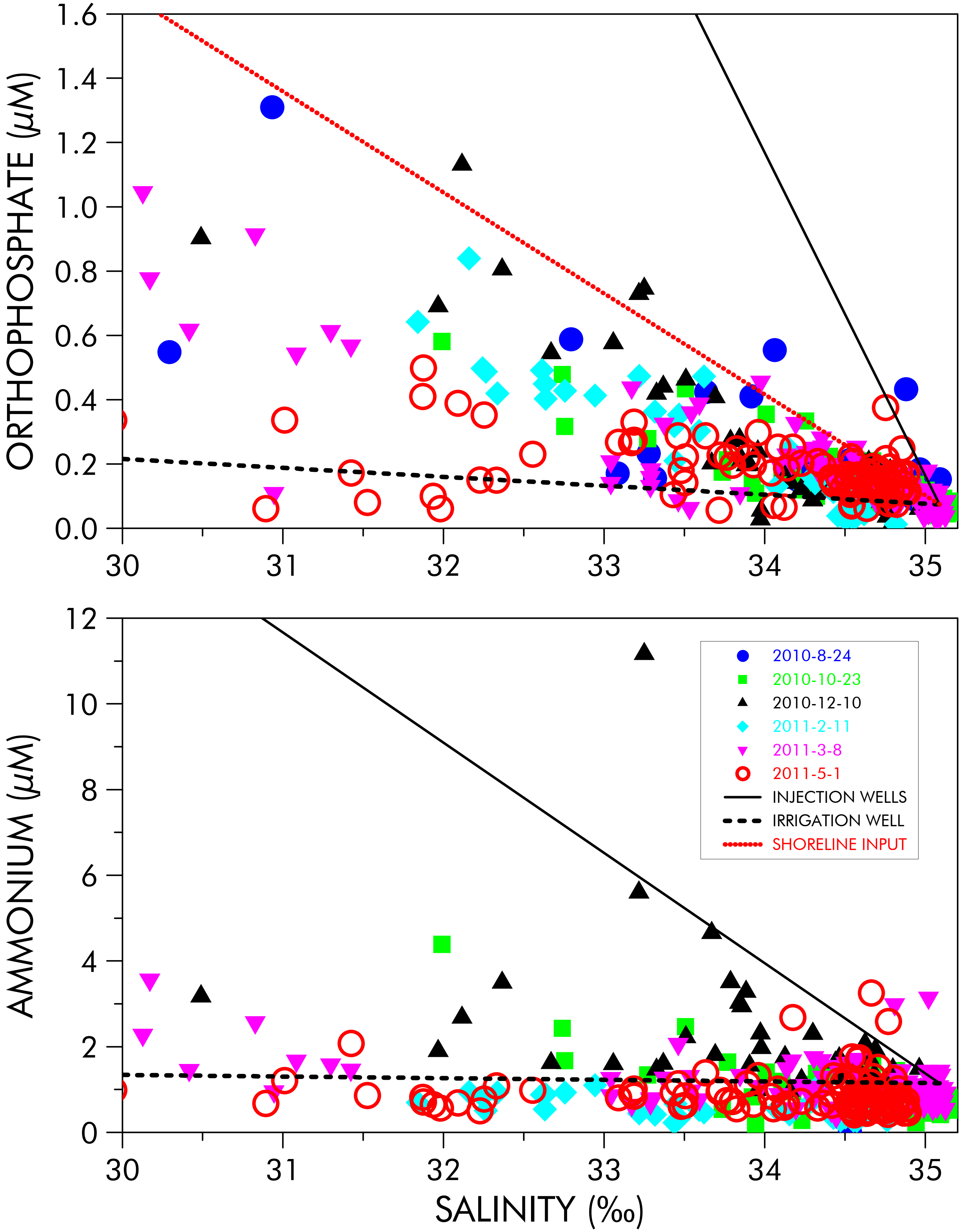


FIGURE 37. Mixing diagrams of concentrations of phosphate (top) and ammonium (bottom) as functions of salinity for samples collected in Maalaea Bay during six increments of sampling in 2010-2011. Straight lines represent conservative mixing lines connecting endpoint concentrations of open coastal water and injection well effluent (solid black line), irrigation well water (dashed black line), and calculated value of groundwater entering the shoreline (dashed red line).

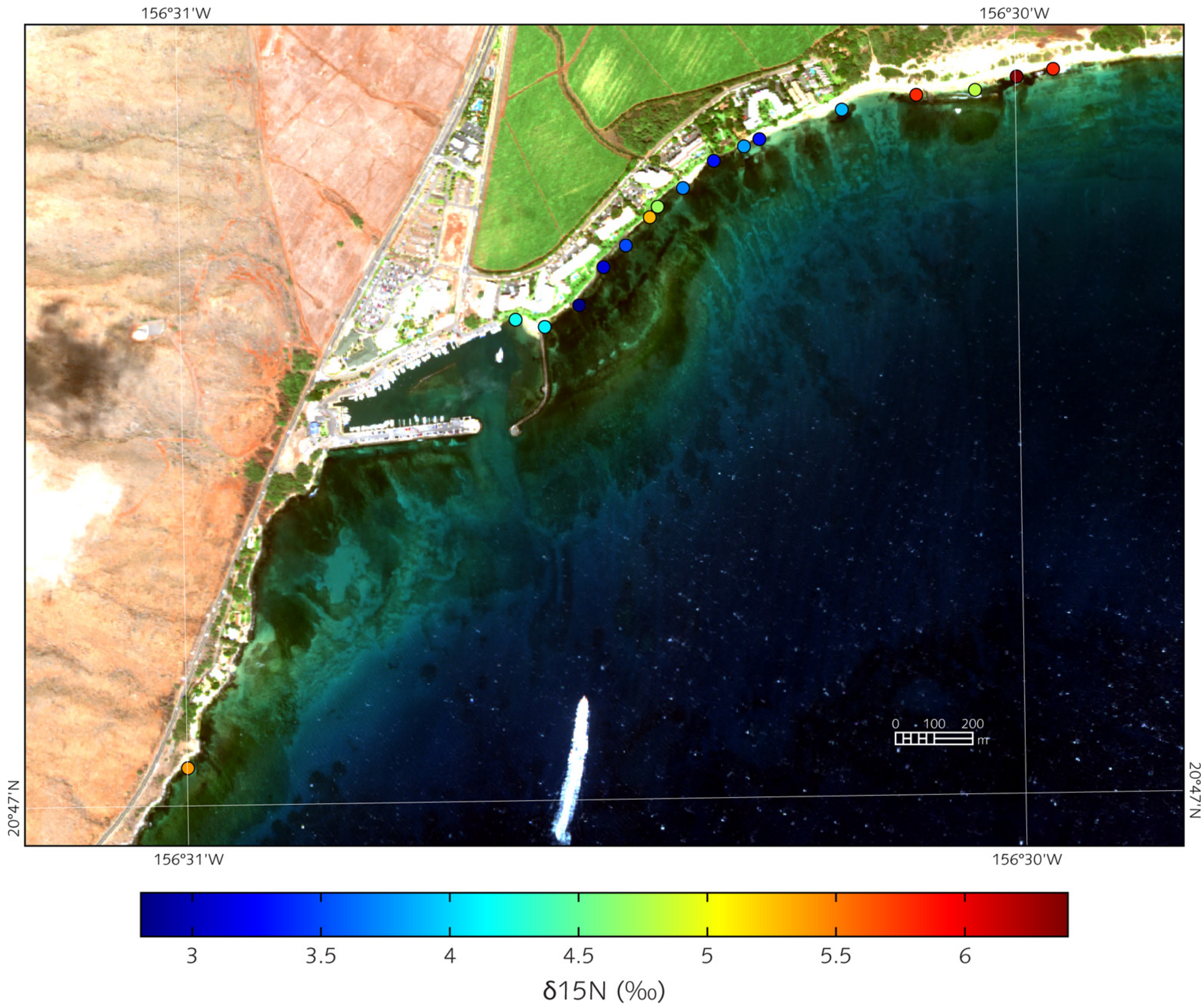


FIGURE 38. Locations and values of del 15N in algae sampled along the shoreline of Maalaea Bay.

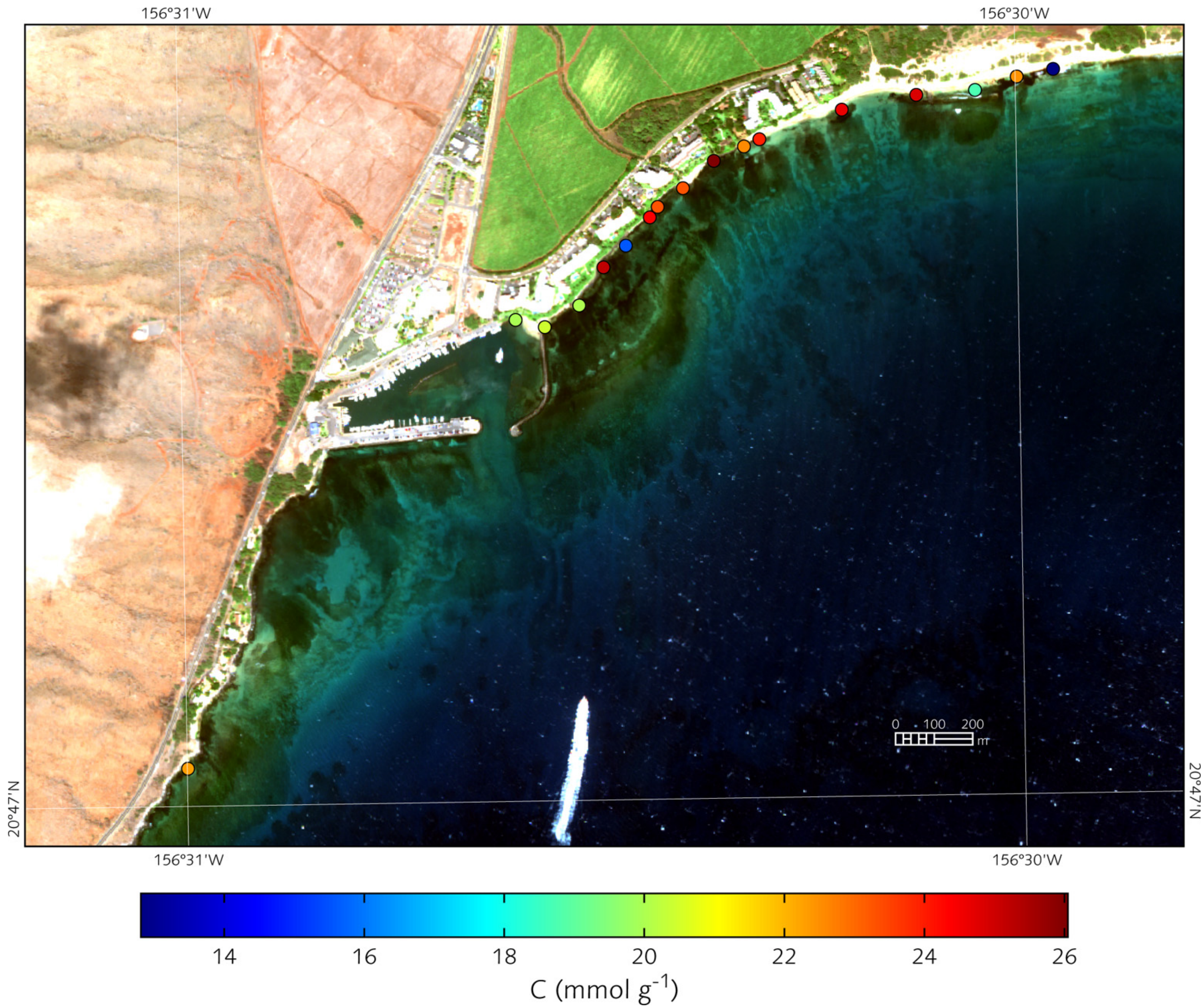


FIGURE 39. Locations and values of carbon (C) in algae sampled along the shoreline of Maalaea Bay.

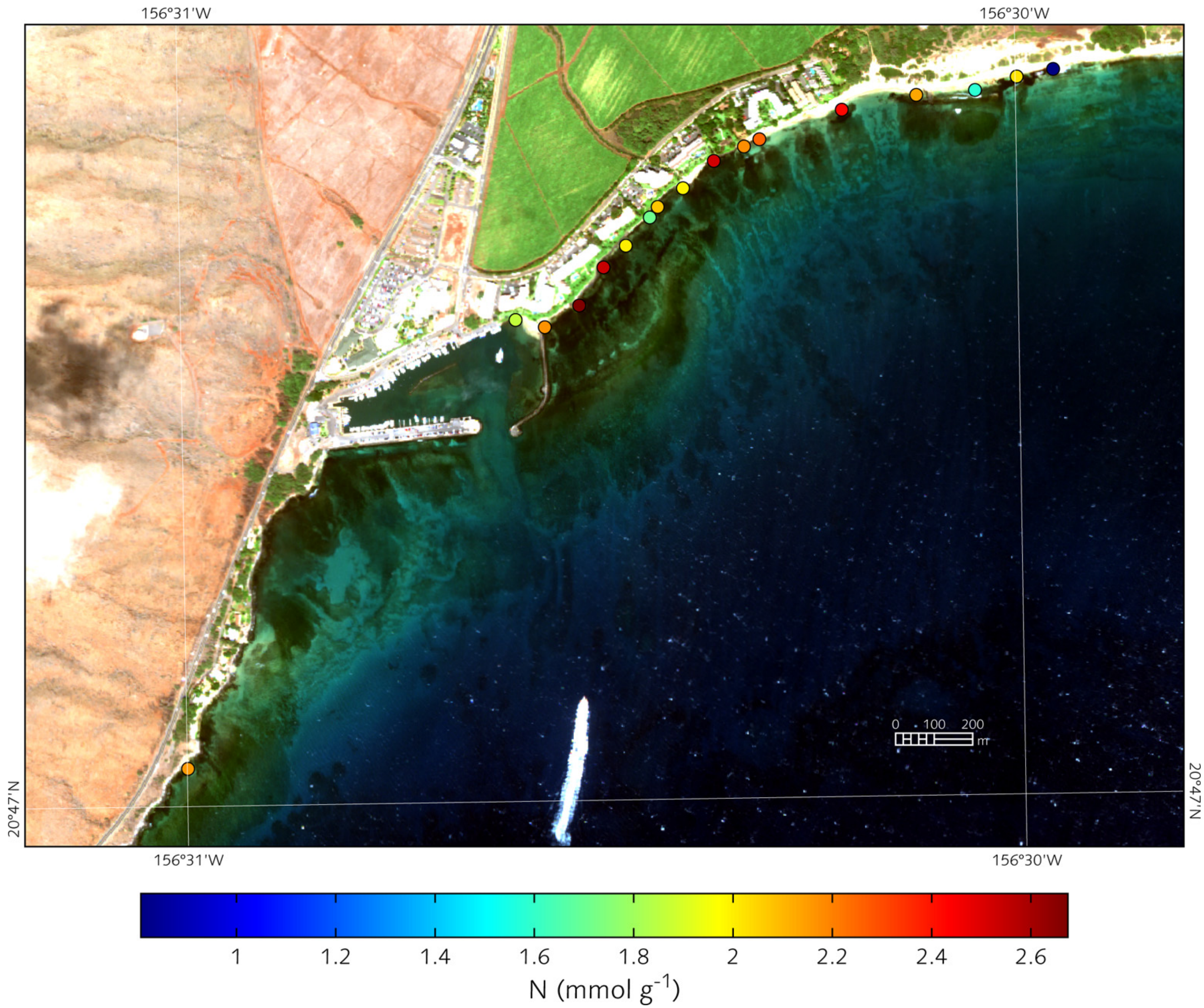


FIGURE 40. Locations and values of nitrogen (N) in algae sampled along the shoreline of Maalaea Bay.

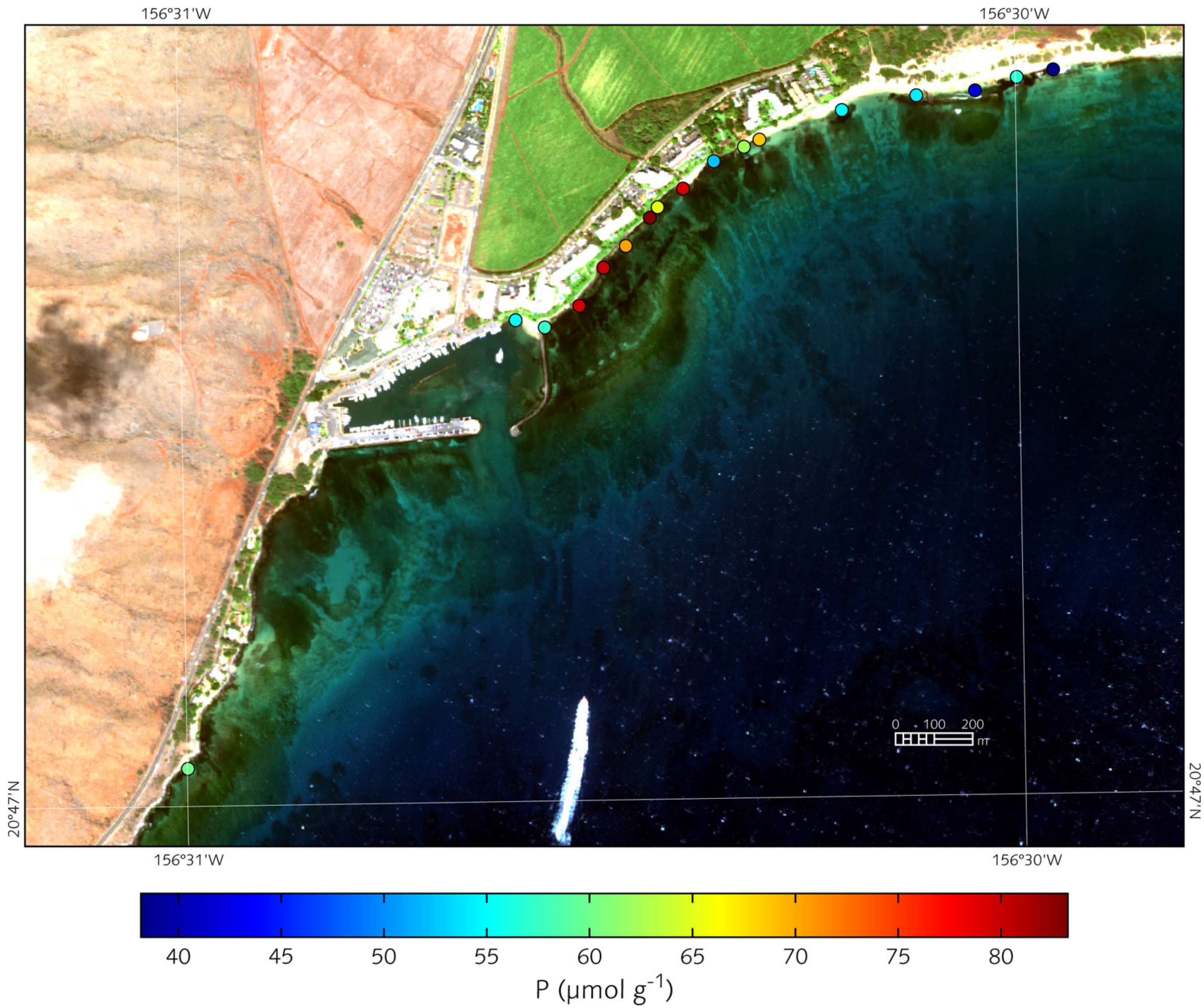


FIGURE 41. Locations and values of phosphorus (P) in algae sampled along the shoreline of Maalaea Bay.

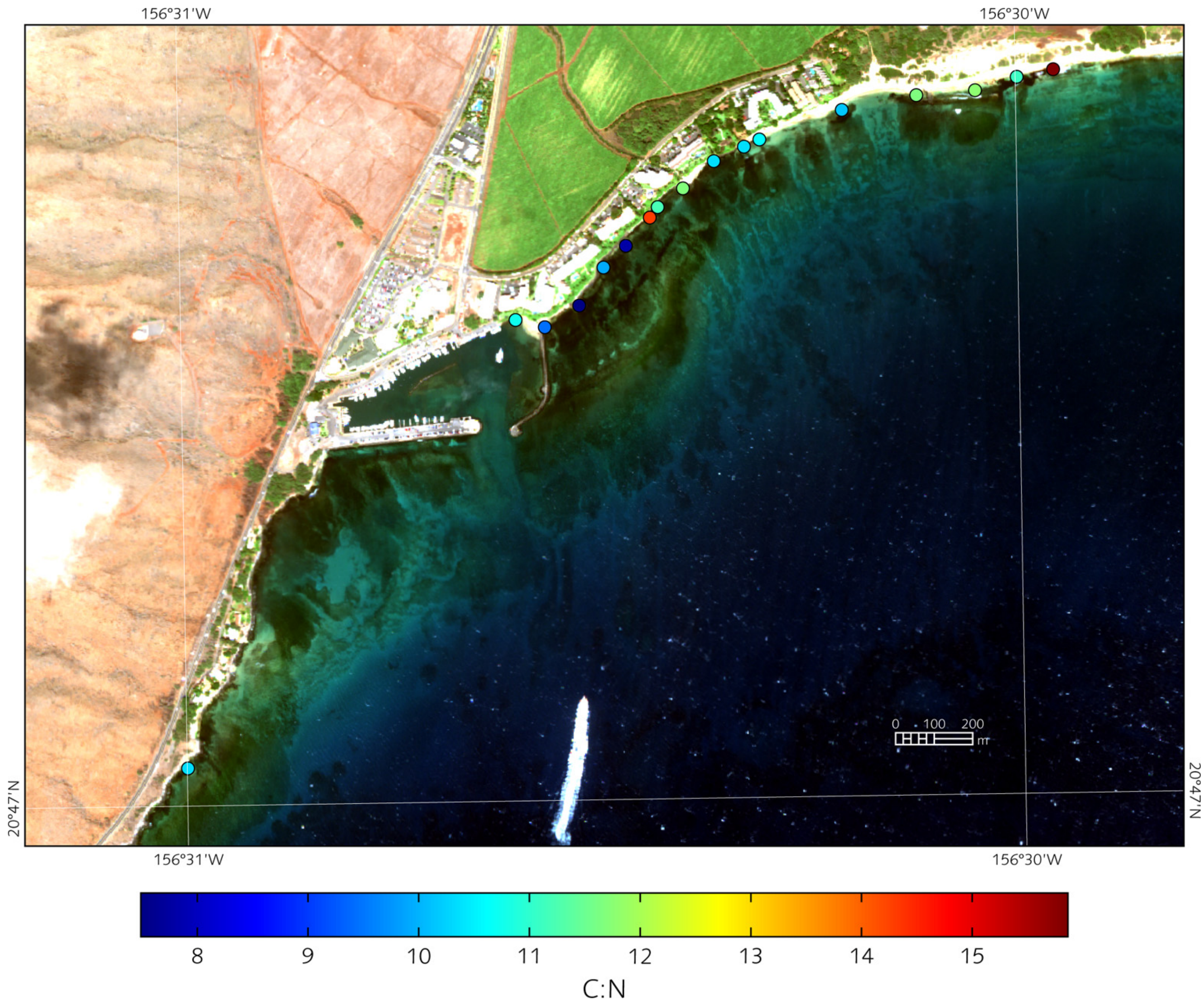


FIGURE 42. Locations and values of the ratio of carbon to nitrogen (C:N) in algae sampled along the shoreline of Maalaea Bay.

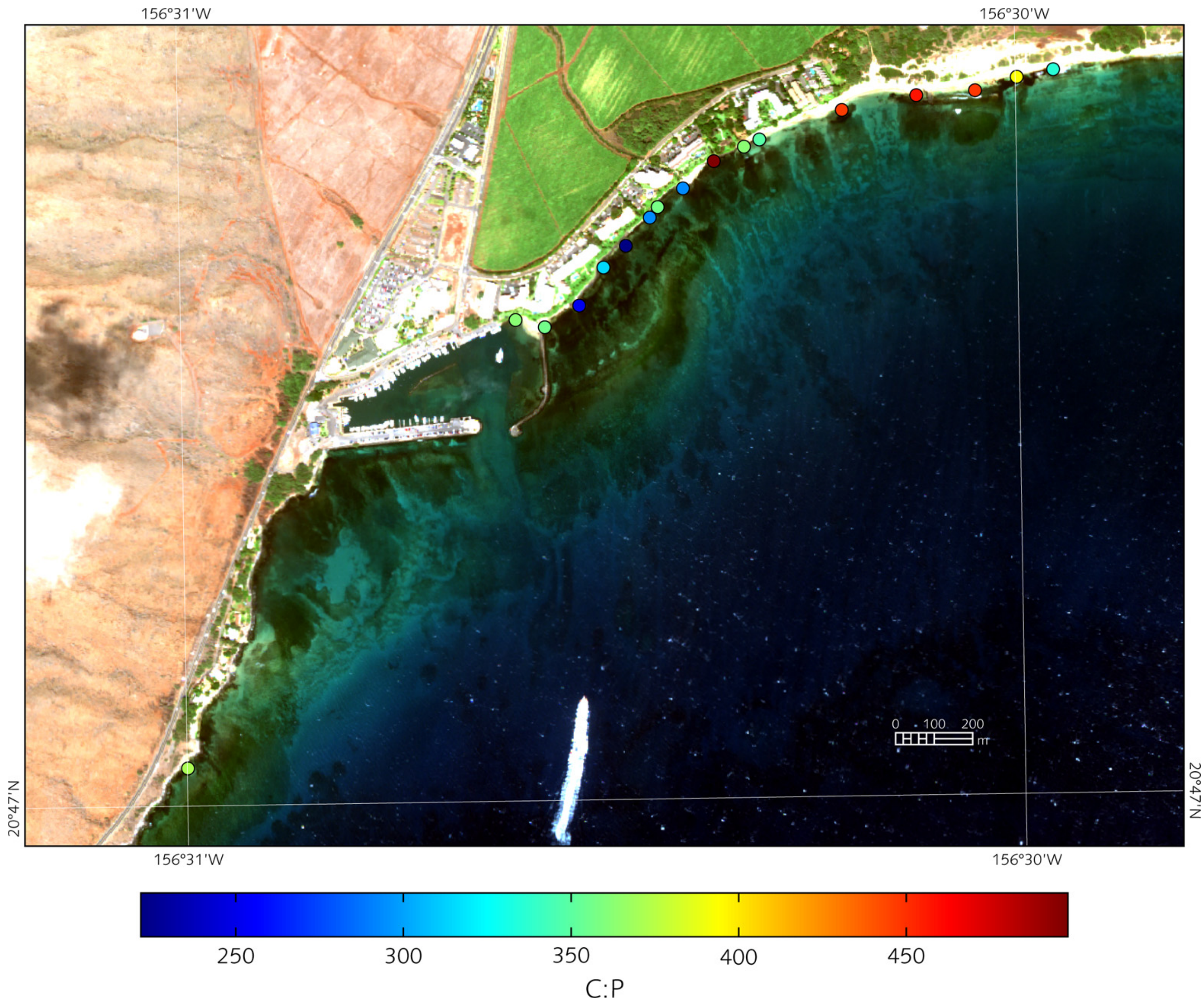


FIGURE 43. Locations and values of the ratio of carbon to phosphorus (C:P) in algae sampled along the shoreline of Maalaea Bay.

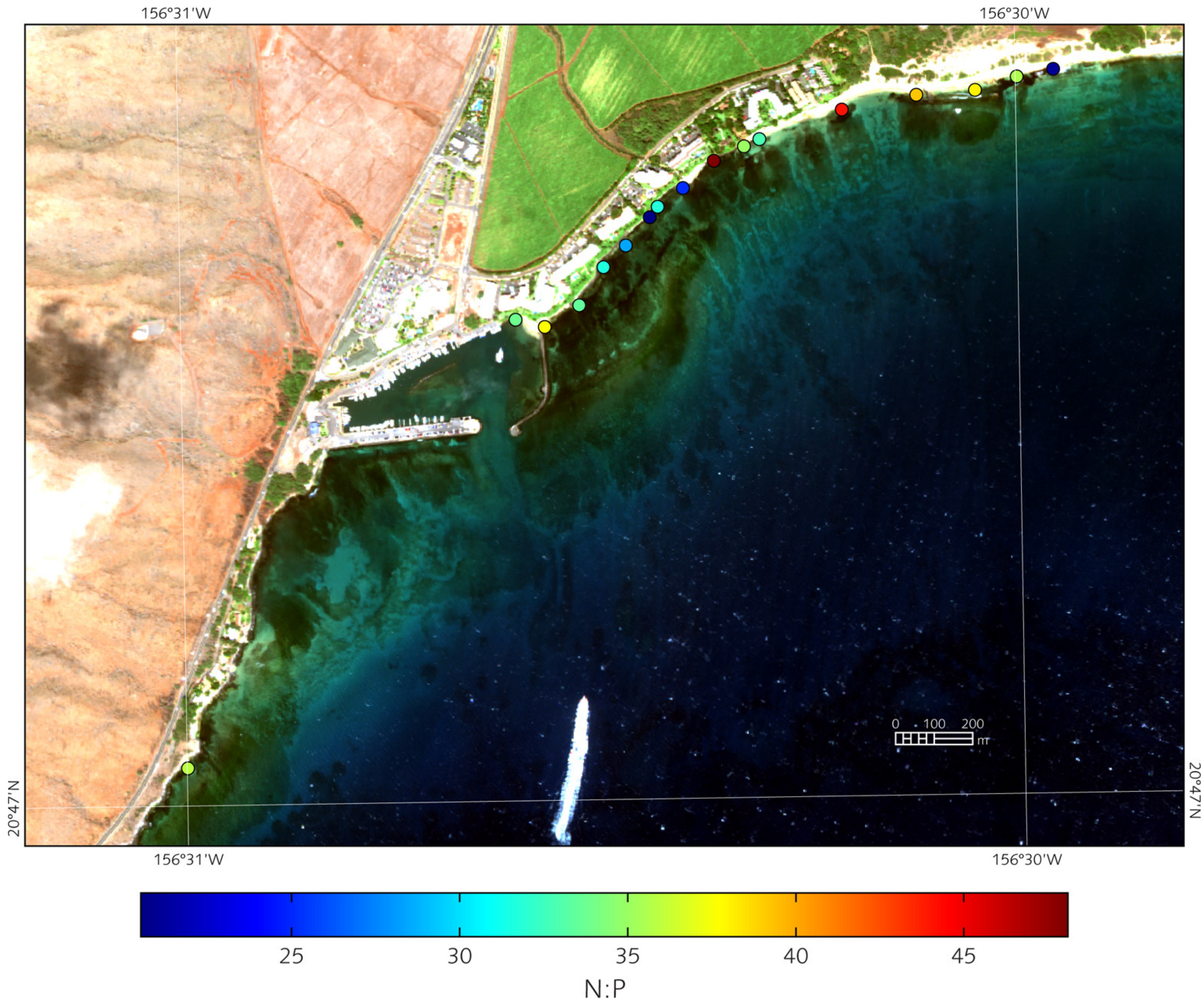


FIGURE 44. Locations and values of the ratio of nitrogen to phosphorus (N:P) in algae sampled along the shoreline of Maalaea Bay.

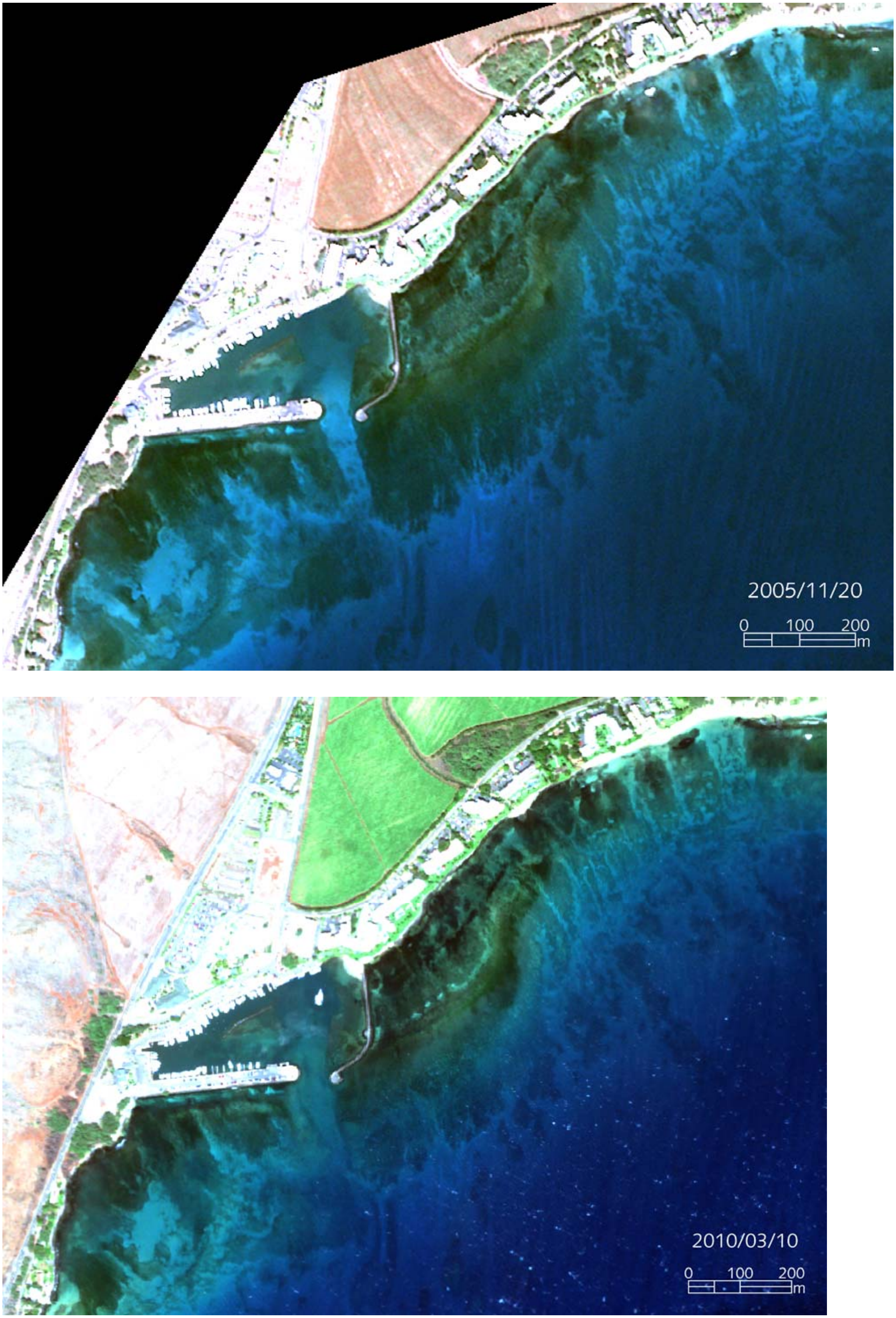


FIGURE 45. Satellite images of Maalaea Bay from 2005 (top) and 2010 (bottom). Note difference in appearance of reef offshore of Harbor entrance channel.

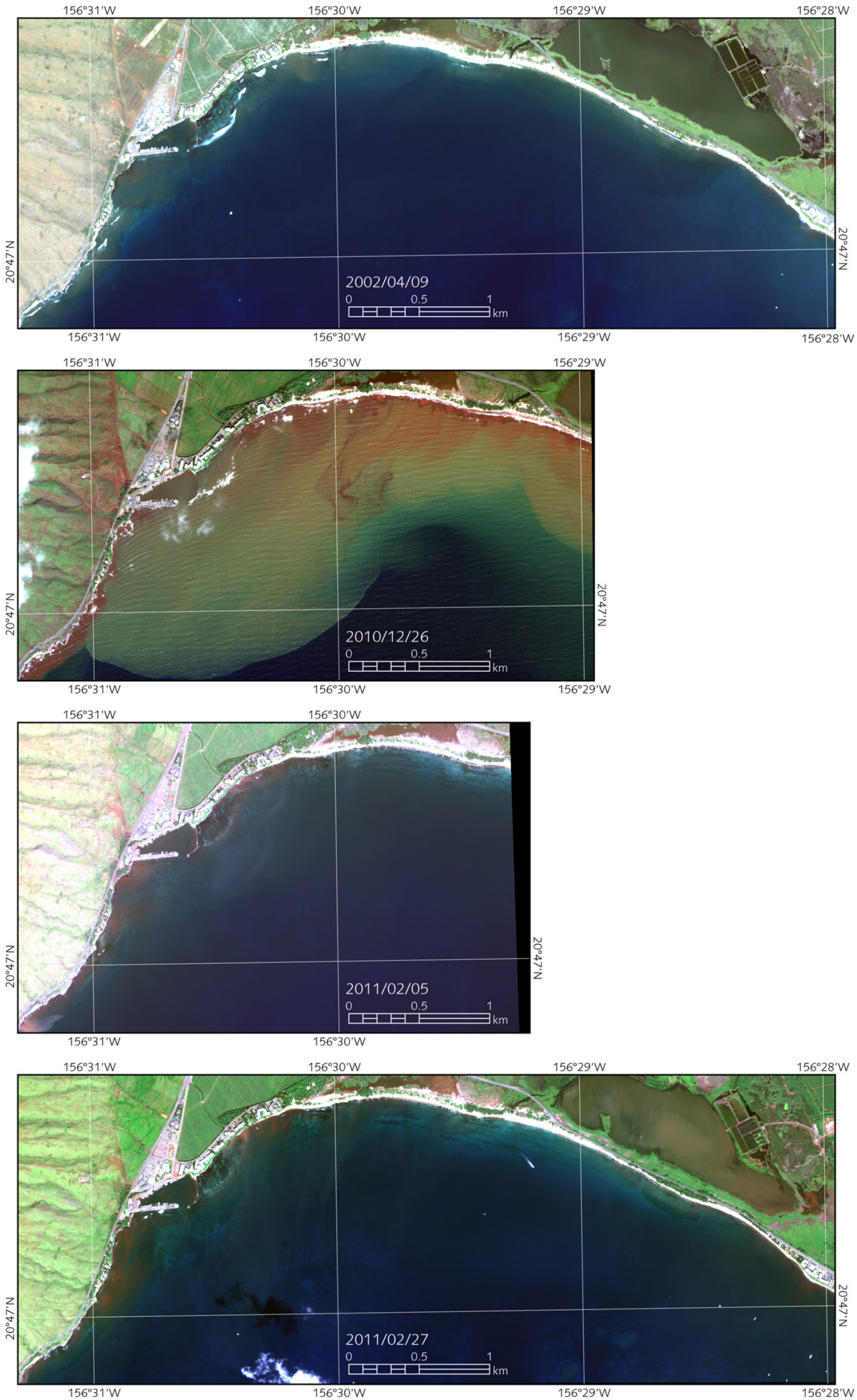


FIGURE 46. Satellite images of Maalaea Bay from 2002, 2010 and 2011. Note sediment plumes throughout nearshore areas in all images.

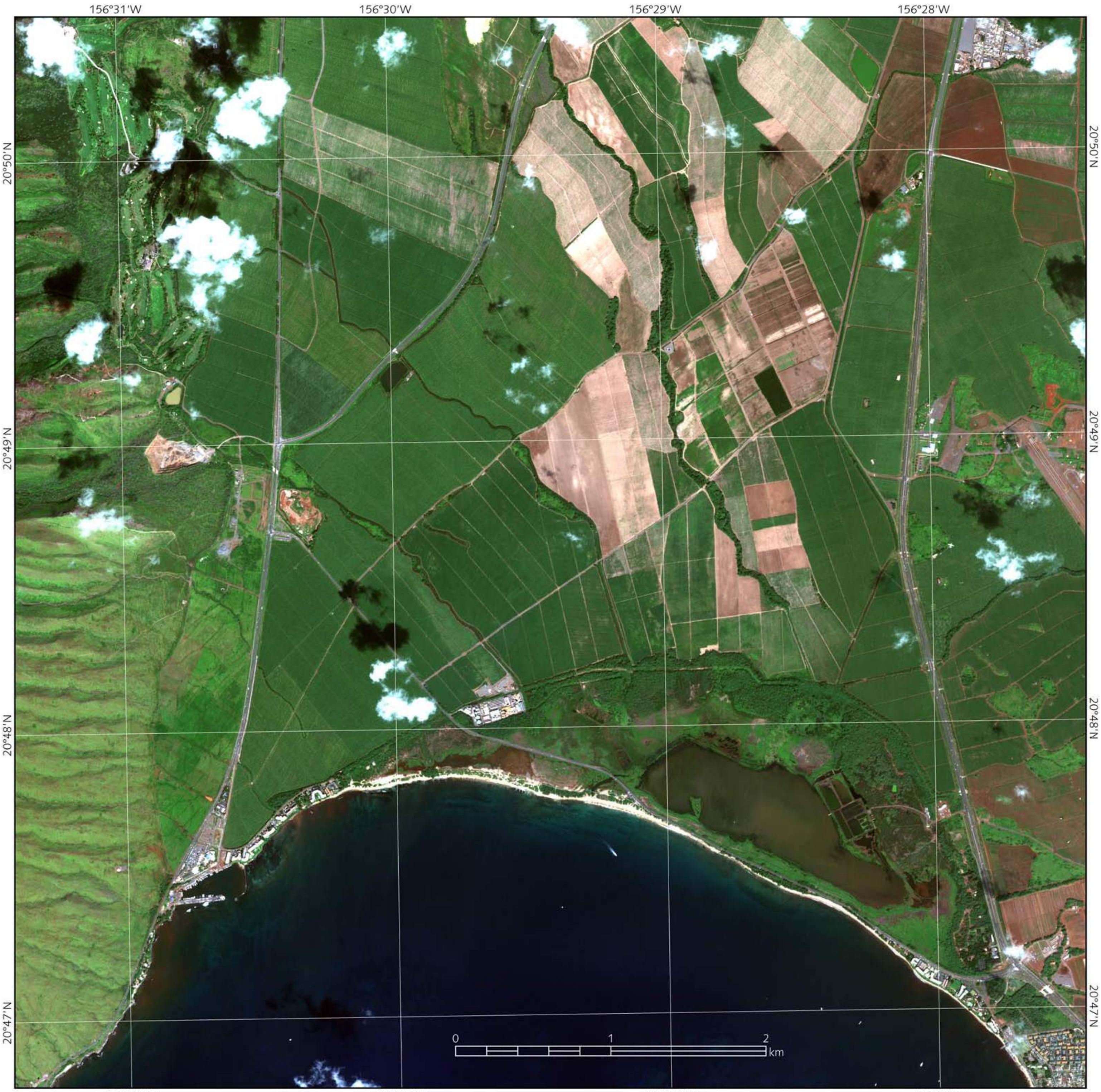


FIGURE 47. Satellite images of Maalaea Bay and upslope area of agricultural development.