ASSESSMENT OF MARINE WATER CHEMISTRY AND BIOTIC COMMUNITY STRUCTURE IN THE VICINITY OF THE OLOWALU TOWN MASTER PLAN OLOWALU, MAUI, HAWAII

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EXECUTIVE SUMMARY

The ownership of the majority of lands surrounding the existing village at Olowalu, West Maui, Hawaii is proposing to develop a Master Planned community (Olowalu Town Master Plan) that encompassed approximately 636.48 acres. The Master Plan for this acreage defines a mixed-use community that will include residential, commercial/business, agriculture, civic, and social interests, as well as parks and open space. While most of the area lies mauka of Honoapiilani Highway, several segments lie on the makai side of the Highway and extend to near the shoreline. The concept for the Olowalu Town Master Plan centers on recognition and appreciation of the value of the natural and cultural resources, and will provide for the long-term stewardship and preservation of these resources.

Evaluation of the nearshore marine environment off the Olowalu Master Plan project site in west Maui was carried out in 2010-2011. Assessment of nearshore marine water chemistry was carried out by evaluating data from 60 water samples that were collected at five ocean sites spaced within the project boundaries. Water samples were collected on transects perpendicular to shore, extending from the shoreline to distances of approximately 500-600 meters (m) offshore. Analysis of fourteen water chemistry constituents included all specific constituents in DOH water quality standards.

Several dissolved nutrients (Si, NO_3^-, PO_4^{3-}, TN and TP) displayed strong horizontal gradients at multiple transect sites, with highest values closest to shore and lowest values at the most seaward sampling locations. Correspondingly, salinity was lowest closest to the shoreline and increased with distance from shore. These gradients were most pronounced at the northern boundary of the project site and weakest in the southern region of the project area southwest of Olowalu Point. These patterns are indicative of groundwater efflux at the shoreline, producing a zone of mixing where nearshore waters are a combination of ocean water and groundwater. In all cases, the nearshore zone of mixing was restricted to a narrow region that extended a maximum of only tens of meters from the shoreline. Beyond this distance, water chemistry at all sites was representative of pristine open coastal waters.

Water chemistry constituents that are not major components of groundwater also displayed distinct gradients with respect to either distance from the shoreline or depth in the water column. Chl *a* and turbidity were generally elevated in nearshore samples with decreasing values moving seaward.

Application of a hydrographic mixing model to the water chemistry data was used to determine if increased nutrient concentrations in nearshore waters are the result of mixing of natural groundwater with oceanic water or inputs from activities on land. The model indicates that, at the time of sampling, there was a distinct subsidy of nitrate nitrogen (NO_3^-) to the ocean at the survey site located near the northern boundary of the property (Site 1) and off the eastern side of Olowalu Point (Site 4). There was no external supply of nitrate at Site 2, located directly off of Olowalu Stream. However, there was a subsidy of phosphate phosphorus (PO_4^{3-}) off Olowalu Stream, which did not occur at any other location.

Evaluating water chemistry from the single sampling in 2010 using DOH specific criteria for Open Coastal Waters indicates many of the measurements in the nearshore areas (within 10 m of the shoreline) exceed standards, particularly for various forms of nitrogen. As these standards do not take into consideration the mixing of high-nutrient, naturally occurring groundwater with ocean water in the nearshore zone, such exceedances are expected and normally occur throughout most Hawaiian nearshore marine areas.

Characterization of the marine habitat and biotic community structure was carried out using a fully georeferenced WorldView-2 multispectral satellite image of the Olowalu area purchased from the Image Library at DigitalGlobe.com (image data originally acquired on February 10, 2010). Ground-truth, termed calibration-validation (cal/val), data derived from georeferenced digital photographs collected *in-situ* at 200 representative points provided the input to create benthic habitat maps of the Olowalu reefs. Spectral data within the satellite image were classified and analyzed using the aforementioned georeferenced ground-truth data, covering an area of about 1.8 million square meters, or 454 acres. Overall coral cover in the mapped area was about 37% of bottom cover, while macroalgae accounted for about 8% of bottom cover; 21% of the bottom was covered with sand and 33% of the bottom consisted of mud and sediment bound in algal turf.

In most open coastal areas of Hawaii physical forces from wave energy are the dominant factors responsible for reef structure and species assemblages. The reefs at Olowalu are considered somewhat unique in that sediment deposition (or lack thereof), rather than wave forces, appears to be the major determinant of physical and biotic reef structure. Along the northern side of Olowalu Point, deposition of terrigenous sediment emanating from Olowalu Stream creates a habitat where coral communities are limited to species and growth forms that can withstand the sub-optimal conditions created by high rates of sediment deposition. South of Olowalu Point, a shallow, wide, triangular-shaped reef flat, formed from deposition of alluvial material from Olowalu Stream, terminates in a fore-reef composed of actively accreting coral assemblages that show little or no effect of sediment stress. Reefs at the southeastern end of the project site (14-Mile Marker) also showed distinct indications of sediment stress, although no major streams discharge regularly in this area.

Populations of reef fish in the area were typical of Hawaii reefs, although numbers of larger fish were very low, likely as a result of fishing pressure. The most abundant families consisted of wrasses, damselfish and surgeonfish. As is generally the case, density of fish was a function of vertical complexity of the benthic surface, with the highest abundance on the outer fore-reef. Reef fish were rarest in the areas with heaviest deposition of mud. Numerous sharks were observed on the inner reef flat.

Overall, results of this study indicate that existing episodic discharge to the ocean of land-derived sediment is the most pervasive stress to the reefs off Olowalu. However, the geographic extent of such deposition is limited and does not impact all areas of the reef. Reef communities on the outer reef flat and fore-reef represent essentially pristine ecological settings unaffected by most activities of man (fishing being the exception).

Engineering analysis indicates that, with full build-out of the planned project, groundwater flow to the ocean will be slightly reduced. Groundwater nutrient fluxes to the ocean will be reduced by about 1% and increased by about 10% for phosphorus and nitrogen, respectively. Combining groundwater flux with episodic surface runoff is projected to result in increases of both nitrogen (13%) and phosphorus (1%) to discharge to the nearshore ocean over present conditions. Depiction of the existing marine environment indicates that, at present, groundwater is so restricted in distribution that there is essentially no effect on marine community structure. Thus, the small changes in groundwater dynamics projected to result from the project do not present a mechanism for future negative effects to offshore marine communities.

A planned component of the Olowalu Town Master Plan is a series of retention basins within the project boundaries for the purpose of retaining stormwater runoff prior to discharge to the ocean. While the project will increase the area of impervious surfaces, the inclusion of retention basins is predicted to result in no change to the discharge of water to the ocean compared to the present scenario. However, should the retention basins function to reduce sediment discharge to the ocean relative to present conditions, they can be viewed as a positive aspect contributing to recovery of impacted reefs.

Planning for the Olowalu Town Master Plan focuses on continued maintenance and stewardship of the unique natural resources of the area. As a result, as long as best management practices are utilized to avoid any unforeseen impacts during the construction and operational phases of the project, and engineering considerations in the design of the retention basins include maximizing sediment trapping, there is no rationale to indicate a potential changes that could be considered negative impacts to the marine environment.

TABLE OF CONTENTS

I. INTRODUCTION AND PURPOSE

Olowalu is located on the foothills of the West Maui Mountains, approximately four miles south of Lahaina Town. Since the termination of sugar cultivation by Pioneer Mill in 1999, the lands surrounding Olowalu have either been utilized for small farming operations or remained fallow. Lands have been subdivided, with a limited number of lots sold to individual purchasers. The ownership of the majority of lands surrounding the existing village are applying for a proposed Master Planned community, called the Olowalu Master Plan, that encompasses approximately 636.48 acres. The Master Plan for this acreage defines a mixed-use community that will include residential, commercial/business, agriculture, civic, and social interests, as well as parks and open space. While most of the area lies mauka of Honoapiilani Highway, several segments lie on the makai side of the Highway and extend to near the shoreline. The concept for the Olowalu Town Master Plan centers on recognition and appreciation of the value of the natural and cultural resources of the land, and will provide for the long-term stewardship and preservation of these resources.

While all planning and construction activities for the Master Plan will place a high priority on maintaining or improving the existing nature of the coastal and marine environments off Olowalu, it remains necessary to address any potential impacts that may be associated with the proposed project. None of the projected land uses include any direct alteration of the coastal areas or nearshore waters. The potential exists, however, for the project to affect the composition and volume of groundwater that flows beneath the project site, as well as possible effects of surface runoff and stream flow that may emanate from the project during storm events. As most of the groundwater and stream flow that could be affected by the project subsequently reaches the ocean, it is recognized that there is potential for the project to affect the marine environment.

In the interest of addressing these concerns and assuring maintenance of existing environmental quality, a baseline assessment of the marine environment and potential impact analysis of the nearshore areas off the Olowalu Town property was conducted in 2010 and 2011. The rationale of this assessment was to evaluate the composition and condition of the existing marine environment, specifically in terms of both water chemistry and coral reef community structure. As the existing condition of the marine environment is the result of factors occurring both in the past and present, particularly groundwater and stream input, the characterization involves evaluating the effects this input has on water quality at the present time, prior to the commencement of any new construction activities. Combining this information with estimates of changes in groundwater and surface water flow rates and chemical composition that could result from the proposed Olowalu Town Master Plan project provides a basis from which to evaluate potential future effects to the marine and anchialine pool environments. Predicted changes in groundwater composition and flow rates have been supplied by Tom Nance Water Resource Engineering (TNWRE 2011). Results of the combined evaluations indicate if, and to what degree, there is potential for negative effects to the marine and aquatic environments from the proposed Olowalu Town project. In addition, these results can provide a basis for implementing mitigation measures to pre-emptively avoid any predicted impacts.

II. CHARACTERIZATION OF WATER CHEMISTRY

A. METHODS

Five water sampling survey sites were established spanning the shoreline boundaries of the Olowalu Town Master Plan (Figure 1). Transect Site 1was located near the northwestern boundary of the project; Transect Site 2 was located directly off the mouth of Olowalu Stream; Sites 3-5 bisected the wide reef flat off Olowalu Point (Figure 1).

Water quality was evaluated at each site on transects that were oriented approximately perpendicular to the shoreline and depth contours. Water samples were collected at nine locations on each transect from just seaward of the shoreline to approximately 400-600 meters (m) offshore. Such a sampling scheme is designed to span the greatest range of salinity with respect to potential freshwater efflux at the shoreline. Sampling was more concentrated in the nearshore zone because this area is most likely to show the effects of shoreline modification. At sample locations where water depth exceeded one meter, two samples were collected: a surface sample collected within approximately 10 centimeters (cm) of the sea surface and a bottom sample collected within 50 cm of the sea floor. At sampling sites where water depth was less than one meter, a single sample from within 10 cm of the surface was collected at each station. In addition, samples were also collected from two wells located upslope of the Olowalu Town shoreline.

Water quality parameters that were evaluated include the 11 specific constituents for open coastal waters (Chapter11-54, Section 06 (b) of the State of Hawaii Department of Health (DOH) Water Quality Standards). These criteria include: total nitrogen (TN), nitrate + nitrite nitrogen (NO_3^- + NO_2^-, hereafter referred to as NO_3^-), ammonium nitrogen (NH_4^+), total phosphorus (TP), Chlorophyll a (Chl *a*), turbidity, temperature, pH and salinity. In addition, silica (Si) and orthophosphate phosphorus (PO_4^{-3}) were also reported because these constituents are indicators of groundwater input and mixing, as well as biotic activity.

Fieldwork was conducted on June 10, 2010 by swimmers working from the shoreline and with the use of a 22-foot boat for offshore sampling. Deep (near bottom) samples were collected using a 1.8 liter Niskin sampling bottle. The bottle was lowered to the desired sampling depth with spring-loaded endcaps held open so water could pass freely through the bottle. At the desired sampling depth, a weighted messenger released from the surface triggered closure of the endcaps, isolating a volume of water.

All water samples were collected in triple-rinsed, one-liter, linear polyethylene bottles. Subsamples for nutrient analyses were immediately placed in 125-milliliter (ml) acid-washed, triple rinsed, polyethylene bottles and stored on ice. Analyses for Si, NH_4^+, PO_4^{3-}, and NO_3^- were performed on filtered samples with a Technicon Autoanalyzer using standard methods for seawater analysis (Strickland and Parsons 1968, Grasshoff 1983). TN and TP were analyzed in a similar fashion following digestion of unfiltered samples. Total organic nitrogen (TON) and total organic phosphorus (TOP) were calculated as the difference between TN and dissolved inorganic N (NO_3^- + NH_4^+), and TP and dissolved inorganic P (PO_4^{3-}), respectively.

Water for other analyses was subsampled from one-liter polyethylene bottles and kept chilled until analysis. Chl *a* was measured by filtering enough water through glass-fiber filters to detect color; pigments on filters were extracted in 90% acetone in the dark at -20° C for 12-24 hours. Fluorescence before and after acidification of the extract was measured with a Turner Designs fluorometer. Salinity was determined using an AGE Model 2100 laboratory salinometer with a readability of 0.0001‰ (ppt). Turbidity was determined using a 90-degree nephelometer and reported in nephelometric turbidity units (NTU) (precision of 0.01 NTU).

In-situ field measurements of continuous vertical profiles of water temperature, salinity, dissolved oxygen and pH were acquired at each sampling station using a RBR Model XR-62 CTD calibrated to factory standards (precision of 0.01°C, 0.001‰, 0.001% O_2 saturation, and 0.001 pH units).

All fieldwork was conducted by Dr. Steven Dollar and Tom Nance. All laboratory analyses were conducted by Marine Analytical Specialists located in Honolulu, HI (Labcode: HI 00009). This analytical laboratory possesses acceptable ratings from EPA-compliant proficiency and quality control testing.

B. RESULTS

1. Horizontal Stratification

Tables 1 and 2 show results of all water chemistry analyses for samples collected off the Olowalu Town site on June 11, 2011. Table 1 shows concentrations of dissolved nutrients in micromolar (μM) units; Table 2 shows concentrations in micrograms per liter (μg/L). Concentrations of eight dissolved nutrient constituents in surface and near bottom samples are plotted as functions of distance from the shoreline in Figure 2. Values of salinity, turbidity, temperature and Chl *a* as functions of distance from shore are shown in Figure 3.

Several patterns of distribution are evident in Tables 1 and 2 and Figures 2 and 3. It can be seen that, on all transects, the concentration of dissolved Si is elevated in samples near the shoreline, with progressively decreasing concentrations with distance from shore (Figure 2). This pattern is most pronounced on Transects 1 and 2 and progressively decreases in magnitude on Transects 3-5. On Transect 5, the value of dissolved Si at the shoreline (14-15 μM) is about seven times lower than on Transect 4, and 30 times lower than on Transect 2. Salinity displays the opposite trend, with sharply lower concentrations in the samples near the shoreline and increasing values with distance from shore (Figure 3).

Other dissolved nutrients, including NO_3^- and to a much lesser degree PO_4^{3-}, also display patterns of decreasing concentrations with distance from shore, although to a much smaller degree than Si. Of note is that the horizontal gradients of Si are greatest on Transect 2, located off the mouth of Olowalu Stream, while the gradient of NO_3^- on Transect 2 is the second lowest within the survey area. As Olowalu Stream was actively discharging to the ocean during and preceding sampling, it is apparent that stream water contains substantial concentrations of Si, but not NO_3^-. It is also evident that on Transect 1, the concentration of NO_3^- is the highest recorded in the study area (~50 μM) and is about two orders of magnitude higher than the shoreline value at Transect 2 (~0.40 μM), although the salinities at both sites are nearly identical (~18‰). As the origin of Transect 1 is well-removed from the mouth of Olowalu Stream, the elevated NO_3^- at Transect 1 is a result of groundwater input at the shoreline.

On all transects the gradients of NO_3^- disappear beyond a distance of about 10-20 m from the shoreline and concentrations are uniformly low across the remainder of the transects. Similarly, there is near uniformity of salinity beyond a distance of 10-20 m from shore at all transect sites (Figures 2 and 3, Tables 1 and 2).

With the exception of Transect 2, located off Olowalu Stream, these patterns are the result of a concentrated input of groundwater to the ocean at or near the shoreline fronting some areas of the Olowalu Town project site. Low salinity groundwater, which typically contains high concentrations of Si, NO_3^-, and PO_4^{3-}, percolates to the ocean at the shoreline, resulting in a narrow nearshore zone of mixing. At the Olowalu survey sites, as with many areas of the Hawaiian Islands, such groundwater percolation results in steep horizontal gradients of increasing salinity and decreasing nutrients with distance from shore (Figure 2).

While groundwater discharge to the ocean is typical along much of the coastline of Maui, there is a high degree of variability in the effect of groundwater input to the ocean. The variability is a result of both the topographic and geologic structure of the shoreline area, as well as degree of mixing with marine waters by oceanographic processes in the nearshore zone. Such variability is evident in the differences between groundwater signatures at the five transect sites at Olowalu Town. Transect Site 1, located at the northern end of the property, displays values of NO_3^- that are three orders of magnitude higher than the shoreline value at Transect 5, located near the southern boundary of the property. However, on all transects, mixing of groundwater to background oceanic conditions occurs in a narrow zone within 10-20 m of the shoreline. Hence, this narrow zone is the only area that could potentially be affected by alteration of groundwater input.

Water chemistry parameters that are not associated with groundwater input (NH_4^+, TON, TOP) also show patterns of decreasing concentration with respect to distance from the shoreline in most transects. As with Si and NO_3^-, the steepest gradients occur in Transects 1 and 2, and the weakest gradient occurs in Transect 5 (Figures 2 and 3, Tables 1 and 2).

Similar to the patterns of dissolved inorganic nutrients, the distribution of Chl *a* on all transects also displays peaks near the shoreline with steeply decreasing gradients with distance from shore. Turbidity on all transects was also elevated in the nearshore samples at all five sampling sites. However, turbidity within five meters of the shoreline on Transect 2, located off the mouth of Olowalu Stream, was at least 10 times higher than the values at any other location. The substantial elevation in turbidity at the shoreline is likely a response of sediment-laden stream water discharging to the ocean. Turbidity of all samples at the offshore ends of the transects was consistently low, with values below 0.30 NTU (Table 1, Figure 3).

2. Vertical Stratification

Tables 1 and 2 and Figures 2 and 3 also show concentrations of water chemistry parameters as functions of distance from shore in samples collected from surface and deep water. It can be seen in Tables 1-2 and Figures 2-3 that, for the constituents that displayed distinct horizontal gradients, there is also variation between surface and near-bottom (deep) samples. Surface values of Si and NO_3^- were generally higher than deep values, while corresponding values of salinity were lower in surface samples relative to deep samples. While the difference between surface and deep samples was not as large as with Si and NO_3^-, there is also slight indication of a pattern of differences in surface and deep concentrations of PO_4^{3-}, but not for TOP and TON. Nearshore mixing of groundwater and ocean water creates a buoyant surface lens of low salinity, high nutrient water that is evident throughout the nearshore region fronting the project site (Tables 1 and 2). With the lack of physical mixing in terms of waves and currents (at least during the time of field sampling), the stratified water column persists along the entire length of some of the sampling transects off the Olowalu Town property.

Nutrient constituents not associated with groundwater input (NH_4^+, DON and DOP) do not exhibit any consistent discernible relationship with respect to vertical stratification. Likewise, turbidity and Chl *a* also showed no consistent trend, with surface values not consistently elevated relative to bottom values (Tables 1-2, Figure 3).

3. Conservative Mixing Analysis

A useful treatment of water chemistry data for interpreting the extent of material input from land is the application of a hydrographic mixing model. In the simplest form, such a model consists of plotting the concentration of a dissolved chemical species as a function of salinity (e.g., Officer 1979, Smith and Atkinson 1992, Dollar and Atkinson 1992). The concept of using such mixing models, which scale nutrient concentrations to salinity, has been adopted by the State of Hawaii Department of Health for establishing a unique set of water quality standards for the West Coast of the Island of Hawaii [Hawaii Administrative Rules, §11-54-06 (d)]. While such standards have not yet been mandated for the other islands, including Maui, application of the method provides a useful means to evaluate the fate of nutrients that reach the ocean from land.

Comparison of the curves produced by the distribution of data with conservative mixing lines provides an indication of the origin and fate of the material being considered. If the parameter in question displays purely conservative behavior (i.e., no input or removal from any process other than physical mixing), data points should fall on, or near, the conservative mixing line. If, however, material from external sources other than naturally occurring groundwater and ocean water is added to the system through processes such as leaching of fertilizer nutrients to groundwater, data points will fall above the mixing line. Conversely, if material is being removed from the system by processes such as biological uptake, data points will fall below the mixing line.

Figure 4 shows plots of the concentrations of Si, NO_3^-, PO_4^{3-}, and NH_4^+ as functions of salinity for the samples collected at each ocean transect station. Each graph also shows conservative mixing lines constructed by connecting the end-member concentrations of open ocean water deemed to be beyond the influence of land (collected 600 m offshore at a depth of approximately 33 m) and groundwater in potable wells located upslope of the Olowalu Town property (Wells No. 4936-01 and 4937-01). While Well 4937-01 had nutrient concentrations indicative of basal groundwater, the concentrations in Well 4936-01 were closer to stream water (Tables 1 and 2).

Dissolved Si represents a check on the model as this material is present in high concentration in both groundwater and streamwater, but is not a major component of fertilizer or other man-made materials (note the similarity of all conservative mixing lines in Figure 4). In addition, Si is not utilized rapidly within the nearshore environment by biological processes.

It can be seen in Figure 4 that data points for all ocean transect sites fall in a linear array on, or very close to, the conservative mixing lines. Linear regression of the concentrations of Si as a function of salinity demonstrates that, for all six transects, there are significant values of R^2 (proportion of variation explained), indicating that the concentration of Si is dependant on salinity ($R^2 = 0.96$; F=0.00). The Y-intercept of the regression of Si as a function of salinity can be interpreted as the expected concentration at a salinity of zero. As groundwater has salinity close to zero (Table 1-2), the Y-intercept can be used to evaluate the relationship between upslope groundwater and groundwater that is entering the ocean at the shoreline. For the potable well sampled upslope of Olowalu Town, the concentration of Si was 843 μM at a salinity of 0.29‰, which would equal a Y-intercept of 850 μM. The upper and lower 95% confidence limits of the Y-intercepts of the regression lines of Si in ocean samples vs. salinity for the combined five transects are 724 and 796 μM, which are slightly lower than the intercept of the well and seawater concentrations. While the bounds of the confidence limits for the regression are slightly different than the value from a single well sample, this result still supports the assumption that Si is behaving as a conservative tracer and that well water sampled from the upslope well is similar in composition to groundwater entering the ocean and ponds at Olowalu Town.

The plots of concentrations of NO_3^- in ocean samples vs. salinity show a different distribution than the Si plots, particularly at Sites 1and 4. Most of the ocean data points for Transects 2, 3 and 5 fall below the well mixing line, and on the streamwater mixing line. Data points for Transects1 and 4 show a markedly different pattern. All data points at salinities below 30‰ lie far above all of the mixing lines. In addition, there is distinct upward concave curvilinearity in the distribution of ocean data points. The location of the points above the mixing line indicates additional subsidies of NO_3^- to groundwater reaching the ocean over that contained in naturally occurring groundwater. Such upward curvilinearity suggest biotic uptake within the nearshore areas. Curvilinearity is most pronounced at the nearshore area of Transect Site 1, which was located on the reef flat off the northern boundary of the Olowalu Town property. The upper and lower confidence limits of the Y-intercepts of the concentrations of NO_3^- from Transect Site 1 are 95-122 μM, while the concentration of NO_3^- in upslope potable water is 34 μM. Hence, at this location, there is about a three-fold increase in NO_3^- to the ocean shoreline from external subsidies compared to what would be expected from simple conservative mixing of natural groundwater and ocean water. On Transect 4, the confidence limits for the Y-intercept are 65-80 μM, indicating about a doubling of the concentration of NO_3^- in groundwater reaching the ocean.

PO_4^{3-} is also a major component of fertilizer and sewage; however, PO_4^{-3} is usually not found to in groundwater to the extent of NO_3^- owing to a high absorptive affinity of phosphorus in soils or rock. It can be seen in Figure 4, however, that the concentration of PO_4^{3-} in groundwater from Well 4937-01 is relatively high (3.30 μM) compared to stream water. Data points from Transects 1and 3 lie within the streamwater-groundwater envelope. However, data points from Transects 2 and 4 lie above the groundwater mixing line. This result presents a completely different scenario for PO_4^{3-} than for Si or NO_3^-. While there was a distinct subsidy of NO_3^- in Transect 1 and no subsidy in Transect 2, the opposite trend occurs for PO_4^{-3}. As streamwater is low in PO_4^{-3}, the substantial subsidy at Transect 2 is not a result of stream discharge. While this analysis identifies that a distinct subsidy of PO_4^{-3} is present in Transect 2, the origin of this material is not readily evident.

The other form of dissolved inorganic nitrogen, NH_4^+, shows a relationship that is different from all other nutrients. With the exception of a single data point from Transect 1, all data points fall above the conservative mixing lines. While plots of concentrations of NH_4^+ vs. salinity exhibit relatively weak linear trends with respect to salinity (Figure 4), there is an indication of upward curvilinearity of the data points. These results suggest there is a source of marine-generated NH_4^+ that is recycled within the nearshore reef areas.

4. Compliance with DOH Criteria

Tables 1 and 2 also show samples that exceed DOH water quality standards for open coastal waters under “wet” and “dry” conditions. The distinction between application of wet and dry criteria is based on whether the survey area receives less than (“dry”) or greater than (“wet”) three million gallons of freshwater input per mile per day. DOH standards include specific criteria for three situations: criteria that are not to be exceeded during either 10% or 2% of the time, and criteria that are not to be exceeded by the geometric mean of samples. All of these criteria are based on comparing replicate data sets collected as time-course series. So evaluation of the “10% or 2% of the time” and “geometric mean” criteria for the single data set presently acquired is not statistically meaningful. However, comparing sample concentrations to these criteria provides an indication of whether water quality is near the stated specific criteria.

Boxed values in Tables 1 and 2 indicate measurements that exceed the DOH 10% standards under “dry” conditions, while boxed and shaded values show measurements that exceed DOH 10% standards under “wet” conditions. In Transect 1, values of NO_3^-, NH_4^+, TN, TP, turbidity and Chl *a* exceeded the wet standards within 10 m of the shoreline. In Transect 2, however, no standards for NO_3^- were exceeded. Such a result is somewhat incongruous in that, at the location where streamwater is clearly affecting marine water chemistry, water quality standards are not exceeded for the constituent that occurs in highest concentration in naturally occurring groundwater. In Transects 3-6 some values of NO_3^-, NH_4^+, TN, TP and Chl *a* within 20 m of the shoreline also exceeded DOH standards

III. EVALUATION OF BIOTIC COMMUNITIES

A. METHODS

The nearshore marine environment at Olowalu consists of diverse assemblages of varied physical structures and biotic communities that represent a relatively unique Hawaiian coral reef habitat. The intent of this study is to describe the overall physical and biotic setting of these features of the marine environment. To obtain such an overview, we employed an approach that has become widely used in the field of coral reef science based on utilizing the optical properties of remote sensing imagery to generate habitat maps. As no detailed benthic habitat maps of the Olowalu region (or most of Maui) presently exist, a main objective of this assessment was to create such maps. In brief, this method involved obtaining commercially available remote sensing satellite imagery of the area of interest. Extensive ground-truth data were collected throughout the marine environment fronting the Olowalu Town Master Plan property. The ground-truth data were then used to develop a classification system that calibrated the spectral information contained in the remote sensing images. The resulting classification scheme was translated on a pixel-by-pixel basis into area coverage of categories of living benthos (e.g., coral, algae), as well as non-living bottom (e.g., sand, mud, rock). Bathymetry was also added to the maps using available LiDAR (Light Detection and Ranging) data.

The survey area encompassed approximately 2.9 miles [4.7 km] of linear coastline and extended from the shoreline to a water depth of approximately 33 feet (10 m), which encompasses an area of about 1,837,000 square meters (m^2) or 454 acres. While it is acknowledged that there are deeper reef areas, these reefs are not likely to be affected by activities on land and, hence, were not part of the present survey. 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 effects of human inputs and subsequent impacts. It is important to note that the purpose of the study was not to generate an exhaustive species list of all biota occupying the area.

All methods utilized in this study to generate nearshore marine habitat maps followed standard procedures for processing coral reef remote sensing imagery (e.g., Andréfouët et al. 2003, Green et al. 2000, Mumby et al. 1998). The benthic habitat map was created based on a fully georeferenced, cloud-free WorldView-2 multispectral satellite image of Olowalu that was purchased from the Image Library at DigitalGlobe.com (image data acquired on February 22, 2010). The image had 2.0 m (6.6 ft) ground sample distance. The WorldView-2 image was processed to highlight submerged features, which revealed areas of different bottom composition.

Fieldwork was carried out on November 5, 2010, and February 27, April 2 and June 12, 2011 by divers working from either a 21-ft. boat or from the shoreline. Field operations consisted of assessing 200 "calibration-validation" (cal/val) sites placed strategically throughout the survey areas. Locations of cal/val sites were selected in the field based on investigator knowledge and visual interpretation of existing satellite "true-color" imagery, with the intent of maximizing coverage of all reef areas within the region of interest. Exact locations of cal/val sites were recorded during the course of field work using a waterproofed GPS with a presumed accuracy of <1 m. Table 3 lists the GPS waypoints, which serve as labels for the cal/val sites, as well as the latitude and longitude of each site.

At each geo-located site, cal/val data were obtained by digitally recording the composition of the benthic surface using an underwater camera fitted with a 14 mm-wide angle lens. To ensure uniformity of the area of data collection, the camera was mounted on a platform centered over a PVC quadrat frame by four legs, similar to a tripod. The base of the frame forms a quadrat with dimensions of 1 m x 0.66 m, which is the same proportion as a photographic frame. Each cal/val site consists of five photo-quadrats arranged in a "cross" pattern ~5 m in diagonal, resulting in total reef surface area of 3.33 m^2, which encompasses an area of approximately four pixels of remote sensing imagery. 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 were extracted from these photographs.

Following fieldwork, the digital images were analyzed by projecting a grid dividing the frame into 100 equal-sized segments. Coral cover by species, as well as bottom cover of benthic algae, motile macro-benthos and non-living categories including sand, mud, bare limestone and rubble, were estimated by tabulating cover types within the segments. Zoom features of computer software and the high resolution of the digital photographs (~10 megapixels) generally allowed delineation of corals to the species level. Total cover of all five photographic frames constituted the cover estimates for each cal/val site. An advantage of using such a photo-quadrat method is that it allows for the collection of far more data per unit time than traditional *in-situ* transect techniques, with little or no loss of data quality or interpretation. Thus, the photo-quadrat technique provides far more extensive coverage of the subject area without any significant loss of information. In addition, the photographic survey method provides a permanent data record that can be utilized for future time-course surveys that are of value in determining changes to reef structure. All photo-quadrats evaluated by point counts are contained in Appendix A.

In the lab, map generation was accomplished by locating cal/val 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 mud/sediment cover. In addition to benthic habitat classifications, maps incorporate depth contours based on available LiDAR data (Figures 5 and 6). The data used to create the maps are compatible with ArcGIS.

Full cross-validation was utilized to evaluate accuracy of the habitat classification. In cross-validation, all but one data point are used to build a classifier, and the classifier is then tested on the withheld point. This process is repeated on every point in the data set. The result is a matrix of classification rates, with correct classifications on the diagonal and incorrect classification off-diagonal (Table 4). Because each classifier is tested on a data point that was not used to build the classifier, the result is unbiased. Also, because the test classifiers use almost all the available data points, they more closely represent the classifier actually used to generate the image product (which used all data points).

To test the accuracy of the classifiers for the Olowalu data coral cover was divided into seven classes between zero cover and greater than 90% coral cover (Table 4). The overall accuracy of the classification (total correct classification divided by total number of data points) is 83%. The ">90% coral" class has the lowest correct classification rate at 70%; 17% of this class is misclassified as "70–90% coral," while 14% of this class is misclassified at one of the five other classes. All of other classes with coral cover between 30% and 90% have classification rates between 75-79%. Classes with coral cover less than 30% had correct rates between 88% and 90%. Thus, slightly greater confusion occurred between the classes describing highest coral cover. In addition, the highest rates of misclassification occur in the two highest cover classes. For example, a total of 30% of the coral in the ">90%) class is rated at lower values. While the overall accuracy of the map product is considered high, the cross-validation suggests that the image product provides a conservative estimate of coral cover in the study area.

Abundance of reef fish was estimated at selected cal/val sites using 10-minute stationary point counts. At these locations, an observer remained at the location of the boat anchor and recorded all fish visible within a 360° viewplane.

B. RESULTS

1. Descriptions of Reef Zones

The area of the nearshore marine environment included in the assessment for the Olowalu Town project extends from approximately the northwestern (Lahaina) end of the project boundary to the area known as "14-mile Marker" at the southeastern boundary of the project property. Within these boundaries there are a variety of zones composed of varied physical composition and biotic communities. Presented below is a descriptive view of these zones from the shoreline to a water depth of about 10 m (33 feet). Example areas of each zone are labeled in Figure 7.

It has been well-documented in the scientific literature that the major determining factor for reef coral community structure in open coastal areas in Hawaii is physical force from wave impacts (e.g., Dollar 1982, Dollar and Tribble, 1992, Grigg 1998, Fletcher et al. 2008). Results of the survey indicate that, while wave stress does play a role in shaping some of the coral communities in the area of study (particularly close to shore on the northwestern side of Olowalu Point), the reefs off Olowalu are largely an exception to this rule. This is the case owing to orientation to both northern and southern swells, and shelter from other islands that minimize the destructive effects from the typical seasonal wave climate. In area such as Olowalu where wave stress does not provide such a prevailing control, other physical or biotic factors provide dominant influence over the composition of coral communities. In the case of Olowalu, the predominant controlling factor appears to be effects from sediment, originating both from terrestrial runoff and resuspension of naturally occurring marine sediment (note that the lack of wave energy may also result in less removal of sediment from coral surfaces than in areas of higher water velocity). The following descriptions of the reef zones focus on the interaction between sediment effects and reef community structure.

a. Northern Reef Platform – Zone A

The nearshore structure of the entirety of the Olowalu area consists of a wide, shallow inner reef flat with water depth less than 5 m (see the bathymetric contour maps shown in Figures 5 and 6). The shoreline area extending from the northern boundary of the Olowalu Town property to the mouth of Olowalu Stream (Zone A in Figure 7) consists of rounded boulder beaches extending from the vegetation line to the intertidal zone (Figure 8, top). The intertidal area consists of a berm of boulders and beachrock that grades into a subtidal platform composed of fossil limestone. From the shoreline to a depth of approximately 2 m (within the wave impact zone), the reef platform is essentially barren of macrofauna. Seaward of this depth, coral colonies occur on the bottom in increasing density with increasing depth. These colonies are interspersed over hard bottom that is covered with a layer of dark-colored terrigenous sediment (Figures 9 and 10). The predominant corals in this region consist of hemispherical branching colonies of *Pocillopora meandrina* and lobate growth forms of *Porites lobata*. Most of what can be considered individual coral colonies are small in size and separated by areas of the limestone platform that are covered with dark-colored sediment. The nearshore reef flat extends to a water depth of about 5-10 m, at which point bottom composition turns into a plain of gray sand.

b. Olowalu Stream Discharge - Zone B

Directly off the mouth of Olowalu Stream (Zone B in Figure 7), bottom composition is similar to Zone A, except that sediment deposition on the bottom is thicker and corals are less abundant (Figures 11 and 12). The substantially lower coral cover in the area off the stream mouth suggests that continual or episodic discharge of terrigenous material has a significant effect on coral community structure.

c. West Olowalu Outer Reef Platform – Zone C

Areas of sediment deposition on the reef platform are still evident south of the point of discharge of Olowalu Stream. However, coral cover is higher here than north of the stream mouth (Figure 13). Relief of the bottom is also greater compared to north of the stream, resulting in greater levels of coral colony amalgamation into "super-colonies" that are elevated above the reef platform. Possibly as a result of sediment cover on most non-coral substratum, both motile invertebrates (e.g., sea urchins) and fleshy benthic macroalgae are nearly absent from Zones A-C.

d. West Olowalu Inner Reef Platform - Zone D

The shallow subtidal area fronting most of the northwestern side of Olowalu Point is composed of a limestone bench interspersed with pockets of sand and rubble (Zone D in Figure 7). Living corals in this zone are sparse and restricted to heads of *Pocillopora meandrina*. Encrusting coralline algae are common on dead coral heads and rubble fragments (Figure 14).

e. Reef Crest - Zone E

While the topographic compositions of Zones A-D are typical of most of the nearshore reef zones in West Maui, a unique feature of the Olowalu area is the wide semi-circular reef flat that extends from the old breakwater structure southward around Olowalu Point. The shoreline throughout the central section of the Olowalu project site differs from the boulder beach to the north and consists of white sand beaches that extend across the reef flat (Figure 8, center). The outer edge of the northwestern region of the reef flat consists of a reef crest composed of deposited coral rubble (Zone E in Figure 7). The reef crest is emergent at low tide and absorbs the full force of breaking wave, resulting in a lack of any biotic colonization (Figure 15).

f. Inner Reef Flat – Zone F

Inshore of the reef crest, the entire reef flat is shallow (less than 2 m in depth) and consists of sand channels that bisect the limestone platform (Zone F in Figure 7). Interspersed throughout the platform are bands and patches of coral, with upward growth limited by the surface of the water column (Figures 16 and 17). The most abundant coral species, *Porites lobata,* often occurs as “microatolls” where the upper surfaces of large round colonies consist of non-living areas owing to exposure to the atmosphere at low tide. Like large-scale atolls, growth of these colonies continues laterally rather than vertically, increasing the diameter of the colony (Figure 18). The upper surfaces of many of the microatolls, as well as wide areas of the reef surface, are covered with the invasive species of brown algae *Acanthophora specifera* (Figure 18 and 19). With distance southward over the inner flat, the reef surface becomes progressively more covered with algal turfs that trap sediment and less with living coral (Figures 20 and 21).

g. Outer Reef Flat - Zone G

The outer region of the reef platform is substantially different from the inner flat in that water depth is slightly greater and topographical structure grades into a series of spurs and grooves oriented perpendicular to the shoreline. While coral cover on the outer flat is greater than on the inner flat, much of the bottom still shows evidence of effects from sediment deposition (Figure 22).

h. Fore Reef – Zone H

The outer fore reef flat platform off Olowalu Point provides an ideal habitat for optimal coral growth, as is reflected in the expansive reef structures that typify the area shown as Zone H in Figure 7. These reefs consist primarily of expansive mounds of interconnected colonies of finger coral (*Porites compressa*) (Figures 23 and 24) and large (up to several meters in diameter) helmet-shaped colonies of *Porites lobata* (Figures 25-26). The coral-covered knolls extend seaward to abrupt vertical faces at the edge of sand flats (Figure 24). As virtually all of the limestone structure of the reef surface is colonized with living coral, these reefs can be considered "climax" communities. Owing to the expansive growth of branching finger coral, and little indication of breakage or fracturing of the reef structure, this area does not appear to have been affected by damaging wave impacts for a period of at least many decades (if ever). In addition, there is little or no evidence of any effects of sediment deposition, as in the more inshore areas. As noted above, the existence of actively accreting reefs in an open coastal environment is a relatively unique situation for Hawaii.

i. Southeast Reefs (Mile Marker 14) – Zone I

The north and the south ends of the project area differ in that the broad spur-and-groove fringing reef absent from the northern area continues from Olowalu Point to the southern property boundary. Near the southern end of the project site, an area known as "14-Mile Marker" is a high-use recreational area for snorkelers and kayakers. Part of the attraction of this area is the presence of an elevated section of reef close to the beach (Zone I in Figure 7). While coral cover and species diversity are higher in this particular area than on the surrounding reefs, a somewhat surprising observation was the extent of dead coral patches throughout the zone (Figure 27-28). While the appearance of the dead coral areas seems to be the result of sediment deposition, there are no streams in the area, as on the northern side of the study area. While the observed mortality may be a result of past episodic events of surface runoff following torrential rains, examination of the surface of many of the corals indicates settlement of sand, rather than mud (Figure 29). In any event, while the structure of the reefs to the south of Olowalu Point are distinctly different than those to the north of the Point, coral community structure in both areas is affected by sediment deposition that impacts coral settlement and growth. These sediment control factors do not control reef structure off the central area of the Olowalu region beyond the reef flat.

2. Quantification of Benthic Cover

Combining the percent cover data for all 200 cal/points provides an estimate of the overall reef structure for the 454 acres of reef surveyed. Total coral coverage of the survey area was 43%. The most abundant coral, *Porites lobata,* comprised 17% of bottom cover and 40% of coral cover. The second most abundant coral was *Porites compressa* (12% bottom cover, 29% coral cover), followed by *Montipora capitata* and *M. patula* with combined bottom cover of 10% and 23% coral cover). *Pocillopora meandrina* accounted for about 2% of bottom cover and 4% of coral cover. Seven other coral species were observed at cal/val sites and accounted for less than 2% bottom cover and 4% bottom cover. Hence, five species of coral accounted for 96% of coral cover throughout the survey area.

Considering non-coral substratum, sand accounted for about 21% of bottom cover, while algal turf (including turf covered with mud) covered about 26% of the bottom. Macroalgae comprised about 3.4% of bottom cover, while bare limestone was encountered on 6% of the bottom. Mud comprised about 1.2% of benthic cover.

3. Habitat Mapping

Figures 30-32 show satellite images of the Olowalu region overlayed with color coded circles that represent percent bottom cover of coral, algae and mud (including turf-bound sediment) at each of the 200 cal/val sampling points. In addition, these figures also include maps of coral, algae and mud (including turf-bound sediment) generated by classification schemes produced from the cal/val points. Overall, the maps provide a good representation of the spatial distribution of the zonal composition described in the previous section. The densest coral cover can be seen along the outer reef crest off Olowalu Point (Figure 30); algae is most dense on the nearshore reef platform (Figure 31); mud and turf-bound sediment are clearly most abundant off the area where Olowalu Stream discharges (Figure 32). 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 the physical composition of the system and proximity of point source material input from land.

An important attribute of remote sensing mapping is the ability to evaluate the total area of study with equal weight. Table 5 shows coverage estimates of seven abundance classes of the main types of benthic cover within the mapped area (coral, algae, sand and mud). For coral, the highest area cover is the 10-30% class, accounting for about 476 x 10^3 m^2, while the lowest abundance is seen in the class where coral covers greater than 90% of the bottom ($51x10^3$ m^2). Over the entire mapped area, coral cover accounts for about 38% of map area. This value is slightly lower than the 43% coral cover calculated as the mean value from cal/val points. Such a difference is not unexpected as investigator selection of the cal/val locations in the field is likely to be somewhat biased toward areas of higher coral cover.

With respect to algae, the highest cover (by a factor of almost three) is the class with no algae, with the two highest cover classes of algae (>70%) accounting for the smallest areas of coverage (total of $16x10^3$ m^2). Over the entire reef, macroalgae comprised about 8% of bottom cover.

Of the non-coral/algae bottom types, sand comprised about 21% of bottom cover, while mud and turf-bound sediment covered about 33% of the bottom. Hence, about 54% of the bottom of the entire mapped area consists of sand, mud and turf-bound sediment, while 46% consists of coral and macroalgae.

It is worth noting that around 1881, the channel of Olowalu Stream was diverted from a flowpath that intersected the shoreline south of Olowalu Point to the present location north of the point. Based on the habitat mapping performed for this assessment, any effects to marine communities from discharge of sediment at the former region of discharge have been eliminated in the ensuing 130 years. As the average projected time for Hawaiian reef communities to reach a "climax" state is on the order of 50 years for wave-sheltered coastal areas (Dollar 1982, Grigg and Maragos 1974), the 130 period since stream diversion appears to be more than twice the period required for coral community recovery, assuming that the original stream discharge exerted a similar impact as the present stream discharge.

4. Other Benthic Invertebrates

The major taxa of benthic organisms, other than corals, occurring on the reef off Olowalu are sea urchins (Echinoidea) and sea cucumbers (Holothuroidea). The most abundant urchins are the two species that bore into limestone surfaces, *Echinometra matheai* and *Echinostrephus aciculatus*. These urchins are most common on the outer fore reef although densities of these urchins are not as high as on other reefs throughout Hawaii owing to the near complete coverage of the bottom by living coral. Less abundant, but ubiquitous, across the reef front are the larger species of urchins, *Tripneustes gratilla*, *Echinothrix diadema* and *Heterocentrotus mammilatus*. Urchins of any species are rare or absent from the reef platform on the north side of the project site where much of bottom was covered with terrigenous sediment. The most common sea cucumbers are the species *Holothuria atra* and *H. mauritiana*, which occur mainly on the sandy regions of the inner reef flats. Sea stars, predominantly *Linckia* spp., are observed in low numbers over the entire nearshore region. No crown-of-thorns starfish (*Acanthaster planci*) were observed during the course of the present survey.

Marine flora on the outer reef front are dominated by encrusting calcareous algae that covers bared limestone surfaces and the non-living parts of coral skeletons. The most common forms of encrusting algae are *Porolithon* spp. and *Peysonellia rubra,* which grows on the bases of *Porites compressa* branches. On the shallow reef flat, most of the solid structure of the reef surface is covered with a thin layer of algal turf, which affectively binds sediment. Frondose benthic algae consists primarily of the invasive species *Acanthophora specifera*, which comprises a high percentage of bottom cover in the nearshore areas of the reef flat to the south of Olowalu Point. Other species of macroalgae (particularly *Ulva* spp. and *Hypnea musciformis*) that dominate bottom cover in other nearshore areas of Maui were not observed in high abundance on the Olowalu reefs. The areas where these two species are abundant (i,e., Maalaea, Kihei) are characterized by nearshore reef flats that are subjected to substantial wave action and water motion. The inner reef flats at Olowalu are not subjected to such water motion and are normally very calm. Hence, the environmental setting is not suitable for colonization by these two species, although it is well suited for *Acanthophora*.

The design of the reef survey was such that no cryptic organisms or species living within interstitial spaces of the reef surface were enumerated. However, no dominant communities of these classes of biota were observed during surveys at any of the study stations.

5. Reef Fish Community Structure

Results of stationary count fish surveys are shown for the northern reef (Zone A, Table 6-a), the reef flat (Zone F, Table 6-b) and the outer reef front (Zone H, Table 6-c). Overall, abundance of reef fish was lowest on the reef flat, with a total of 29 species observed. The number of species observed at five survey sites ranged from 5 to 18, and the number of individuals ranged from 33 to 103 (Table 6-a). Dominant fish species on the reef flat include a variety of wrasses (Labridae), damselfish (Pomocentridae) and small parrotfish (Scaridae). At one site on the inner reef flat a large school of *Mulloidichthys flavolineatus* (yellow-striped goatfish) was encountered.

Abundance of fish on the northern reef platform (Zone A) was intermediate between the lower abundance on the inner reef flat (Zone F) and the outer reef face (Zone H). A total of 33 species were observed at three sites, with the number of species per site ranging from 13 to 20, and the number of individuals per site ranging from 45 to 113 (Table 6-b). As on the reef flat, the most abundant families were the wrasses (Labridae), damselfish (Pomocentridae) and surgeonfish (Acanthuridae). Of note were the comparatively low numbers of butterfly fish (Family Chaetodontidae) on both the inner reef flat and the northern reef platform.

Fish abundance was highest on the outer reef front with a total of 53 species observed. Number of species observed at eight survey sites ranged from 11 to 30, with the number of individuals per site ranging from 54 to 471 (Table 6-c). The most abundant species on the outer reefs included 11 species of wrasses, with the saddleback wrasse (*Thalassoma duperrey*) the most common. Thirteen species of surgeonfish (Acanthuridae) were encountered, with the brown surgeonfish (*Acanthurus nigrofuscus*) occurring at every survey site. Damselfish (Pomocentridae) were also abundant, particularly the species *Chromis vanderbilti*. The triggerfishes *Melanichthys* spp. were commonly seen congregating in the water column. Juvenile reef fishes were most abundant at the deeper reef habitats within the matrix created by branching stands of *Porites compressa*. The lattice structure formed by this coral provides a sheltered refuge for small fish. Juveniles belonged mostly to the family Acanthuridae (surgeonfishes), with representatives from the families Labridae (wrasses), Mullidae (goat fishes), and Chaetodontidae (butterfly fishes). While not part of the stationary point surveys, numerous small black-tip reef sharks (*Carcharhinus limbatus*) were observed on the inner reef flat south of Olowalu Point.

Although the reefs along the project area (particularly on the outer reef face) harbor an abundant and diverse fish fauna, it is also apparent that the area is subjected to a high degree of fishing pressure. A near-complete lack of fishes considered good "food fish" clearly indicated heavy fishing pressure. No carangids (e.g., jacks, papio) were sighted, although several small omilu (*Caranx melamphygus*) were sighted in inshore areas of the reef flat. Similarly, the scarcity of larger goatfishes and parrotfishes suggests that these species are impacted by fishing pressure. Inspection under ledges and large coral heads revealed fair numbers of squirrelfish (Family Holocentridae), but fewer than would be expected in an unfished area. No spiny lobsters were observed.

6. Threatened or Endangered Species

Four species of marine animals that occur in Hawaiian waters and have been declared threatened or endangered by Federal jurisdiction may occur in the vicinity of the project site. The threatened green sea turtle (*Chelonia mydas*) occurs commonly throughout Hawaiian waters and is known to feed on selected species of macroalgae. Several green turtles were encountered during the course of fieldwork. The endangered hawksbill turtle (*Eretmochelys imbricata*) is found infrequently in waters off Maui, but regularly nest in South Maui.

Populations of the endangered humpback whale (*Megaptera novaeangliae*) spend the winter months in the Hawaiian Islands. While humpback whales are abundant in the waters offshore of Olowalu in the winter months, it is not common for whales to occupy the very shallow nearshore areas that are the focus of this survey. The Hawaiian Monk Seal (*Monachus schauinslandi)*, is an endangered earless seal that is endemic to the Hawaiian Islands. While the majority of the population of Monk Seals occurs in the uninhabited Northwestern Hawaiian Islands, individuals are routinely observed resting on beaches around the main Islands and have the potential to occur at the project site.

IV. DISCUSSION and CONCLUSIONS

The purpose of this assessment is to assemble the information to make valid evaluations of the potential for impact to the marine environments from the proposed Olowalu Master Plan project. The information collected in this study provides the basis to understand the processes that are operating to affect reef processes in the nearshore ocean, so as to be able to address any concerns that might be raised in the planning process regarding these factors.

The proposed Olowalu Master Plan project does not include plans for any direct alteration of the shoreline or offshore areas. Therefore, potential impacts to the marine environment can only be considered from activities on land that may result in delivery of materials (primarily freshwater and nutrients) to the ocean through surface runoff or infiltration to groundwater on land with subsequent discharge to the ocean. To evaluate the possible magnitude of these processes, a report has been prepared by Tom Nance Water Resource Engineering (TNWRE) entitled "*Impact on Water Resources of the Olowalu Town Project*" (dated July 2011). Below is a summary of the information provided in the TNWRE report, along with conclusions regarding the potential effects of the project on the marine environment.

A basic assumption is that groundwater in the inland portion of the watershed moves toward and ultimately discharges at the shoreline. During transit through the aquifer to the shoreline, dissolved nutrients (nitrogen and phosphorus) may be supplemented by natural or anthropogenic inputs, or may be consumed by natural processes (not considering removal by pumping). There is an existing non-potable irrigation system which serves ongoing agricultural and landscape irrigation in the project area consisting of an upgradient diversion from Olowalu Stream at 502-foot elevation, a 1.1-mile long conveyance ditch and tunnel system, and an open storage reservoir at an elevation of about 360 feet.

A membrane bioreactor (MBR) treatment plant will be constructed onsite to treat project-generated wastewater to R-1 (tertiary) quality. Most of the treated effluent will be reused for irrigation. About 100 acres within the project have been identified for this irrigation reuse. Early in the project's development, and possibly on a continuous basis at full build out, the non-potable irrigation system will provide supplemental supply to these areas. In wet periods when there is an excess of R-1 treated effluent, the excess will pass through a two-acre "constructed" wetland and the effluent from the wetland will be disposed of in a large (4.7-acre) leach field.

The project site is crossed by Olowalu Stream and several other much smaller and unnamed normally dry gulches. As a result of the increase in impervious surfaces that will be created by the Olowalu Town project, peak rates of runoff and runoff volume have the potential to be higher when compared to the present (see TNWRE report). The intent of the drainage system designed for the project is to provide sufficient volume in onsite retention basins so that peak runoff rates and volumes for a 100-year, 24-hour design storm will not be increased over existing conditions. By providing these retention volumes, runoff rates and volumes for lesser storms would actually be less than for existing conditions. It is also likely that retention basins will reduce delivery of sediment to the ocean, as heavier particulate material should settle out.

Using the State Commission on Water Resource Management's methodology for establishing the sustainable yield of the Olowalu Aquifer System, groundwater discharging along the Olowalu Town project's shoreline is approximated as seven million gallons per day (MGD). As a first order approximation, it is assumed that existing surface runoff to the shoreline averages 2.3 MGD year-round and that 85% of this occurs at the point of shoreline discharge of Olowalu Stream. The remainder represents about one-third of the 20 inches of annual rainfall on the 635-acre project site.

The treated R-1 effluent available for irrigation reuse is generally estimated at 85% of the within-building potable water use. The remaining 15% would be lost in conveyance hardware, lost to evaporation and leakage at the wastewater treatment plant, or simply not be discharged into the wastewater system at the points of use.

About 100 acres in four land use categories (Public/Quasi Public, Park/Open Space, Agriculture, and the Highway) have been identified for the irrigation reuse of the R-1 treated wastewater. At full build out, it is estimated that about 0.24 MGD of the R-1 effluent would be used for this irrigation. The remainder, ultimately amounting to 0.14 MGD, would be directed into the two-acre constructed wetland and then disposed of in the 4.7-acre leach field.

Based on expected water use and wastewater generation amounts, estimates can be made regarding changes to groundwater flowrate and the loading of nitrogen and phosphorus as discharged along the project's shoreline. Based on flux rates, nutrient utilization rates and concentrations of nitrogen and phosphorus in groundwater, R-1 effluent, and fertilizers used in landscaping, TNWRE estimates that, with full project build-out, groundwater flowrate discharged into the marine environment will be reduced by 6%, nitrogen discharge to the ocean will be increased by about 10%, and phosphorus discharge will be decreased by about 1%.

Two factors affect changes to surface runoff resulting from project development: greater use of Olowalu Ditch and the changes to rainfall-runoff. It has been previously estimated that the project would use an average of 0.39 MGD from the ditch, an apparent increase over present use. The ditch flow is now measured at a location close to the system's storage reservoir and about 1.1 miles downstream from the point of stream diversion. Based on observations, it appears that the project's use of Olowalu Ditch can be supplied by appropriate repair and maintenance of the ditch and that this use will not create a difference in surface water discharge at the shoreline by Olowalu Stream.

Present surface runoff from the project's 635-acre area was estimated as one-third of its 20 inches of annual rainfall. This is equivalent to 0.31 MGD as a year-round average. The project's retention basins are to be designed to keep post-development peak rates and volumes of runoff at the same or less than existing conditions for a 100-year, 24-hour design storm. The installed retention volumes for this hypothetical design storm will have a more substantial impact on smaller rainfall events, meaning that the actual surface runoff from the project site will be less than under the existing, undeveloped condition. Since it is virtually impossible to estimate that reduction for the spectrum of actual rainfall-runoff events that will occur, it is simply assumed that there will be no increase in surface runoff discharge along the shoreline.

Water quality data of surface runoff from developed areas are scarce and widely varying. In general, these data indicate that nitrogen and phosphorus levels in stormwater runoff are lower than background levels in groundwater. On this basis, and as an order of magnitude estimate, it is assumed that increases of 30 μM of nitrogen and 2 μM of phosphorus will occur. For an average discharge of 0.31 MGD, the increased loading would amount to 1.08 pounds per day of nitrogen and 0.16 pounds per day of phosphorus. Thus, the total change in nutrient loading to the ocean from the project taking into account both groundwater discharge and surface water discharge would equal an increases in nitrogen by about 13% and phosphorus by about 1% over existing conditions (TNWRE 2011).

These results from TNWRE indicate there will be little change over existing conditions in the concentrations of nitrogen and phosphorus in groundwater discharging at the shoreline. The results of the analyses of nutrient concentrations in the nearshore regions presented in this report indicate that, at present, effects to nutrient concentrations from input from land can only be detected in the sub-tidal zone very close to the shoreline at selected locations. The extent of these effects does not reach the offshore areas that constitute viable “reef” habitats with accompanying biotic communities. In addition, nutrient subsidies from land are contained within a thin surface layer that does not come into contact with the reef surface. As a result, on both horizontal and vertical scales there is little contact between groundwater and biotic communities.

Because there is a predicted small (~6%) reduction in groundwater discharge over present conditions as a result of the project, the extent of offshore effects would be reduced even further owing to more rapid mixing of the smaller volume of discharged groundwater to background marine concentration. According to estimates produced by TNWRE, while there is an increase of groundwater nitrogen flux to the ocean of about 10% under full development, there is a corresponding decrease in phosphorus is about 1%. Combined with surface runoff, the total flux of water from the project site to the ocean should result in an increase of 13% for nitrogen and 1% for phosphorus. However, as surface flow is restricted to only periods of heavy rainfall, groundwater discharge will constitute the major change to water and nutrient flux at the shoreline. Unless there is flux of phosphorus in groundwater to match the flux of nitrogen, there is no potential for the nitrogen subsidy to be utilized. At the location where groundwater flux was greatest within the Olowalu study area (Transect 1) the DIN:DIP ratio for the three samples collected nearest to the shoreline where groundwater input was most pronounced ranged from 65-104. The DIN:DIP of marine plants is about 30:1 (Smith and Atkinson 1983). Hence, the nearshore waters that are most influenced by groundwater input at Olowalu already have excess N in relation to P with respect to the required ratios for algal uptake. Hence, small additions of N without corresponding P do not have the potential to result in increased algal biomass.

Characterization of the benthic communities off Olowalu reveals significant effects from the deposition of terrigenous sediments entering the ocean through discharge from Olowalu Stream. As a result, any land management activity that could lessen the delivery of sediment to the ocean can be viewed as a positive action. Retention basins designed to capture storm runoff will offset the increased area of impervious surfaces of the Olowalu Town project such that there will be no change in volume of surface runoff relative to present conditions. However, while there should be no change in volume runoff, it might be expected that the retention basins could function as sediment traps, resulting in a decrease in sediment discharge, particularly during high intensity rainfall events. As it is not the volume of streamwater *per se* discharged to the ocean that affects biotic composition, but rather the sediment loads of streamwater, it is possible that the net effect of the project might result in an overall improvement of offshore reefs. Any future design considerations for the retention basins should focus on maximizing sediment trapping as well as runoff.

In summary, results of the baseline assessment of the marine environment off the proposed Olowalu Master Plan project site on west Maui reveal a diverse set of distinct reef habitats, some of which are essentially unaffected by input from land, and some of which are greatly influenced from input from land. Groundwater flow to the ocean is restricted in both magnitude and area extent (in terms of horizontal gradients from the shoreline and locations along the shoreline). In addition, groundwater input is retained within a buoyant surface lens that does not come in contact with the reef surface. Surface water discharge is evident along the northern boundary of the project site owing to input from Olowalu Stream.

Offshore coral reef communities consist of assemblages that are somewhat atypical of most Hawaiian reefs. Along the northern side of Olowalu Point, reef community structure is largely influenced by input of terrigenous sediment emanating from stream discharge. The southern side of Olowalu Point is characterized by a wide, shallow, wave-sheltered reef flat, which is not a common habitat found in Hawaii. The outer reefs consist of extensive actively accreting coral formations where growth and community composition are not controlled by wave forces, as is the typical situation on most Hawaiian open coastal areas. Along the southern side of the Olowalu survey area reefs exhibit effects of sediment, although of a different nature than along the northern perimeter.

An engineering evaluation of all water supply and use for the project reveals that, even at full buildout, there should be no substantial changes in either groundwater flow rate to the ocean or composition of groundwater. As groundwater presently has essentially no effect on existing marine communities, the small changes to groundwater fluxes associated with the project will have no negative impacts to the ocean. Retention basins that will be an integral part of the proposed project should serve to trap terrestrial sediment prior to ocean discharge, which will hopefully mediate some of the stress associated with sediment discharge. A major focus of the Olowalu project will be on the recognition, appreciation and long-term stewardship and preservation of the natural and cultural resources of the land. Thus, all activities associated with the project should concentrate on maintenance of undisturbed areas and improvement of stressed areas. All of these considerations indicate that the proposed Olowalu project will not have any significant negative effects on the coastal ocean offshore of the property.

V. SUMMARY

1. Evaluation of the nearshore marine environment off the Olowalu Master Plan project site in West Maui was carried out in 2010-2011. Assessment of nearshore marine water chemistry was carried out by evaluating data from 60 water samples that were collected at five ocean sites spaced within the project boundaries. Water samples were collected on transects perpendicular to shore, extending from the shoreline to distances of approximately 500-600 m offshore. Analysis of fourteen water chemistry constituents included all specific constituents in DOH water quality standards.

2. Several dissolved nutrients (Si, NO_3^-, PO_4^{3-}, TN and TP) displayed strong horizontal gradients at several ocean transect sites with highest values closest to shore and lowest values at the most seaward sampling locations. Correspondingly, salinity was lowest closest to the shoreline and increased with distance from shore. These gradients were most pronounced at the northern boundary of the project site and weakest at the southern region of the project area southwest of Olowalu Point. These patterns are indicative of groundwater efflux at the shoreline, producing a zone of mixing where nearshore waters are a combination of ocean water and groundwater. In all cases, the nearshore zone of mixing was restricted to a narrow zone that extended a maximum of only tens of meters from the shoreline. Beyond this distance, water chemistry at all sites was representative of pristine open coastal waters.

3. Water chemistry constituents that are not major components of groundwater also displayed distinct gradients with respect to distance from the shoreline. In particular, Chl *a* and turbidity were generally elevated in nearshore samples with decreasing values moving seaward.

4. Application of a hydrographic mixing model to the water chemistry data was used to indicate if increased nutrient concentrations in nearshore waters are the result of mixing of natural groundwater with oceanic water, or are the result of inputs from activities on land. The model indicates that, at the time of sampling, there was a distinct subsidy of nitrate nitrogen (NO_3^-) to the ocean at survey sites located near the northern boundary of the property (Site 1) and off the eastern side of Olowalu Point (Site 4). There was no external supply of nitrate at Site 2, located directly off Olowalu Stream. However, there was a subsidy of phosphate phosphorus (PO_4^{3-}) off Olowalu Stream, which did not occur at any other

location.

5. Evaluating water chemistry from the single sampling in 2010 using DOH specific criteria for Open Coastal Waters indicates that many of the measurements in the nearshore areas (within 10-20 m of the shoreline) exceed standards, particularly for various forms of nitrogen. As these standards do not take into consideration of mixing of high-nutrient, naturally-occurring groundwater with ocean water in the nearshore zone, such exceedances are expected.

6. Characterization of the marine habitat and biotic community structure was carried out using a fully georeferenced WorldView-2 multispectral satellite image of the Olowalu area purchased from the Image Library at DigitalGlobe.com (image data originally acquired on February 10, 2010). Ground-truth data derived from georeferenced digital photographs collected at 200 representative points provided the input to create benthic habitat maps of the Olowalu reefs. Ground-truth data and resulting computer generated maps provided estimates of occurrence of living coral cover, as well as cover of algae, sand and mud throughout the various zones of the reef environment.

7. Analysis of spectral data within the satellite image was classified using georeferenced ground-truth data and covered an area of about 1.8 million square meters, or 454 acres. Overall coral cover in the mapped area was about 37% of bottom cover, while living coral cover within the calibration photo-quadrats equaled about 40% of bottom cover. The difference in cover values using the two estimates is a result of selection of calibration-validation points that are likely biased toward areas of higher coral cover. Macroalgae accounted for about 8% of bottom cover, 21% of the bottom was covered with sand, and 33% of the bottom consisted of mud and sediment bound in algal turf.

8. In most open coastal areas of Hawaii the dominant factor responsible for the physical structure of reefs and species assemblages is stress from wave energy. The reefs at Olowalu are somewhat unique in that sediment deposition (or lack thereof), rather than wave forces, appears to be the major determinant of physical and biotic reef structure. Along the northern side of Olowalu Point, deposition of terrigenous sediment emanating from Olowalu Stream creates a habitat where coral communities are limited to species and growth forms that can withstand the sub-optimal conditions created by sediment deposition. South of Olowalu Point, a shallow, wide, triangular-shaped reef flat, formed from deposition of alluvial material from Olowalu Stream, terminates in a fore-reef composed of actively accreting corals assemblages that show little or no effect of sediment stress. Reefs at that southeastern end of the project site (14-Mile Marker) also showed distinct indications of sediment stress, although no major streams discharge regularly in this area.

9. Motile macro-invertebrates on the reef consist primarily of several species of sea urchins. These species include the bio-eroding burrowing urchins *Echinometra matheai* and *Echinostrephus aciculatus*, and the larger slate pencil urchin (*Heterocentrotus mammilatus*), the collector urchin (*Tripneustes gratilla*) and the long-spined urchin (*Echinothrix diadema*). Urchins were rare in the zones covered by sediment. Other macrobenthos observed consist of sea cucumbers, primarily on the sandy areas of the reef flats, and starfish. The coral-eating crown-of-thorns starfish (*Acanthaster planci*) was not observed in the study area.

10. Populations of reef fish in the area were typical of Hawaii reefs, although numbers of larger fish were low, likely as a result of fishing pressure. The most abundant families consist of wrasses, damselfish and surgeonfish. As is generally the case, density of fish was a function of vertical complexity of the benthic surface, with the highest abundance on the outer fore-reef. Reef fish were rarest in the areas with heaviest deposition of mud. Numerous small sharks were observed on the inner reef flat south of Olowalu Point.

11. Overall, results of this study indicate that the existing episodic discharge to the ocean of land-derived sediment is the most pervasive stress to the reefs off Olowalu. However, the area extent of such deposition is limited and does not affect all areas of the reef. Reef communities on the outer reef flat and fore reef represent essentially pristine ecological settings unaffected by most activities of man (with the exception of fishing).

12. Engineering analysis indicates that, with full build-out of the planned project, there will be changes in groundwater that include a small reduction in flow rate and phosphorus discharge and an increase in nitrogen discharge to the nearshore ocean compared to present conditions. The changes with combined groundwater and surface runoff from episode storm events, is predicted to increase both phosphorus and nitrogen flux to the ocean by small amounts. Depiction of the existing marine environment indicates that, at present, groundwater is so restricted in distribution that there is essentially no effect on marine community structure. Thus, the small changes in groundwater dynamics projected to result from the project do not present a mechanism for future negative effects to offshore marine communities.

13. A planned component of the Olowalu Town Master Plan is a series of retention basins within the project site for the purpose of retaining storm water runoff prior to discharge to the ocean. While the project will increase the area of impervious surfaces, the inclusion of retention basins is predicted to result in no change to discharge of water to the ocean compared to the present scenario. However, with respect to impacts to coral communities, the most important aspect of the retention basins is a potential reduction in discharge of terrigenous sediment.

14. Planning of the Olowalu Town Master Plan focuses on continued maintenance and stewardship of the unique natural resources of the area. As a result, as long as best management practices are utilized to avoid any unforeseen impacts during the construction and operational phases of the project, and engineering considerations in the design of the retention basins focus on maximizing sediment trapping, there is no rationale to indicate the potential for negative impacts to the marine environment.

15. The studies conducted for this report, particularly the water quality analyses and coral reef habitat maps, can serve as an initial baseline for any monitoring programs that may be required for the project.

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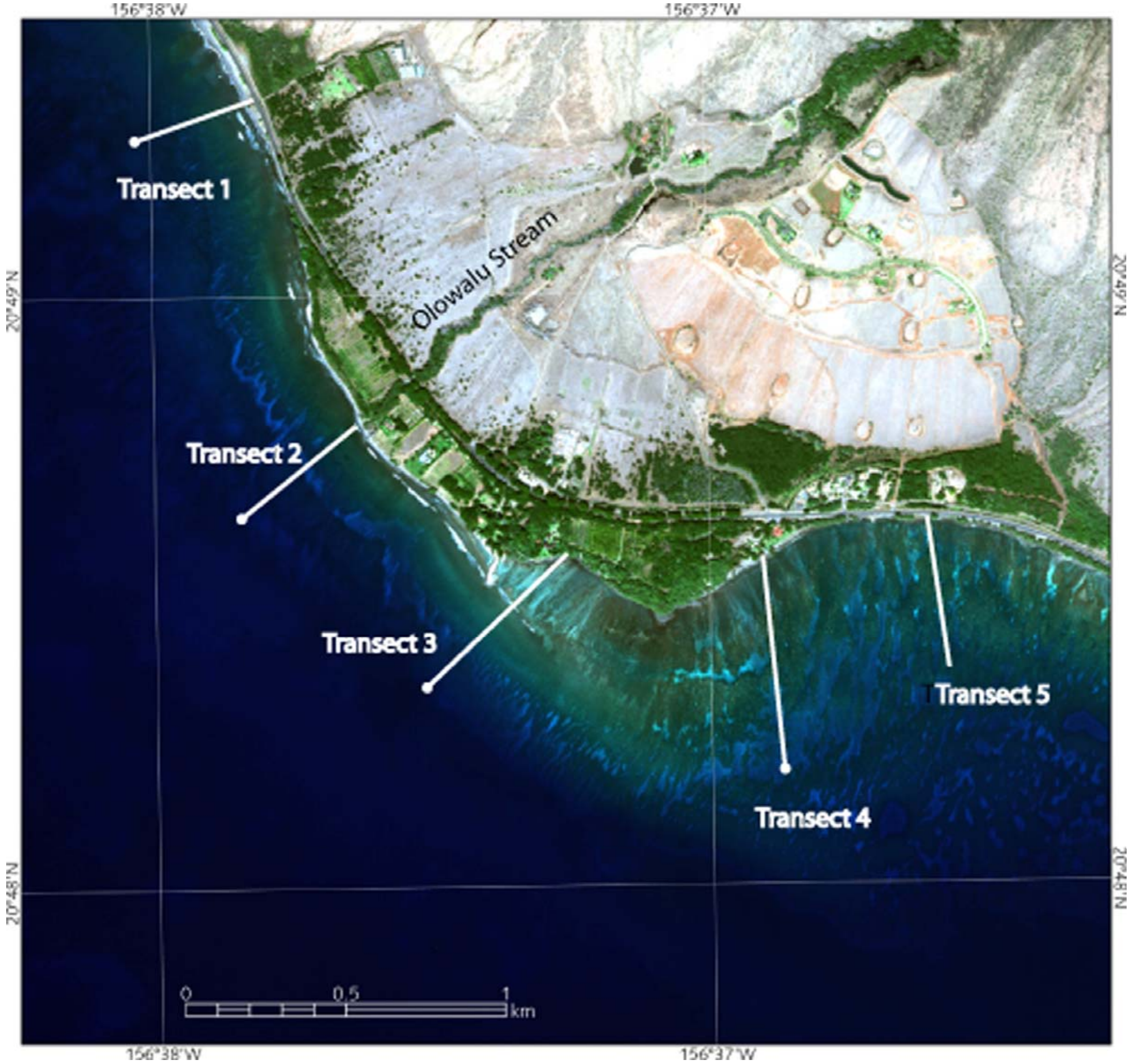


FIGURE 1. Satellite image of Olowalu, Maui, Hawaii showing locations of five water sampling transects that extend from the shoreline to 400-600 meters offshore. Nine sampling stations were located on each transect.

TABLE 1. Water chemistry measurements (nutrient concentrations in micromolar units) from five ocean water transects, two streams and two groundwater wells collected in the vicinity of the Olowalu Town project on June 11, 2010. Abbreviations as follows: DFS=distance from shore; S=surface; D=deep; BDL=below detection limit. Also shown are the State of Hawaii, Department of Health (DOH) "not to exceed more than 10% of the time" and "not to exceed more than 2% of the time" water quality standards for open coastal waters under "dry" and "wet" conditions. Boxed values exceed DOH 10% "dry" standards; boxed and shaded values exceed DOH 10% "wet" standards. For sampling site locations, see Figure 1.

TRANSECT SITE	DFS (m)	PO_4^{3-} (μM)	NO_3^- (μM)	NH_4^+ (μM)	Si (μM)	TOP (μM)	TON (μM)	TP (μM)	TN (μM)	TURB (NTU)	SALINITY (ppt)	pH (std.units)	CHL a (μg/L)	TEMP (deg.C)	O2 % Sat
Olowalu 1	0S	0.56	50.12	8.48	310.16	1.08	14.72	1.64	73.32	0.79	18.942	7.88	2.48	24.79	101.0
	1S	1.08	57.76	13.12	354.32	1.32	10.96	2.40	81.84	1.54	17.389	7.81	5.12	24.72	101.1
	2S	0.24	19.48	0.24	178.92	1.24	6.40	1.48	26.12	0.56	25.669	8.04	1.13	24.59	101.4
	5S	0.16	2.36	0.88	84.80	1.08	9.48	1.24	12.72	0.45	30.874	8.07	0.51	24.76	100.8
	10S	0.09	0.14	0.62	25.98	0.46	8.29	0.55	9.05	0.63	33.551	8.06	2.01	24.90	101.7
	20S	0.05	0.10	0.02	12.83	0.33	8.11	0.38	8.23	0.36	34.238	8.07	0.61	24.92	104.2
	50S	0.07	BDL	0.08	5.73	0.32	5.91	0.39	5.99	0.28	34.616	8.14	0.14	26.16	105.2
	50D	0.04	0.02	0.10	5.35	0.30	7.08	0.34	7.20	0.29	34.620	8.14	0.36	26.10	105.7
	150S	0.04	0.02	0.12	6.55	0.29	6.84	0.33	6.98	0.42	34.600	8.16	0.07	25.95	103.6
	150D	0.01	0.03	0.10	2.45	0.33	7.13	0.34	7.26	0.17	34.787	8.18	0.05	25.97	101.3
	400S	0.07	0.04	0.80	2.69	0.42	7.04	0.49	7.88	0.14	34.811	8.18	0.07	26.01	102.9
	400D	0.02	0.05	0.43	2.05	0.33	6.87	0.35	7.35	0.18	34.787	8.19	0.06	25.88	102.2
Olowalu 2	0S	0.52	0.36	5.68	427.84	0.80	9.40	1.32	15.44	16.90	18.198	7.21	1.74	25.58	109.3
	1S	2.28	0.40	3.72	322.60	0.60	22.48	2.88	26.60	5.91	21.315	7.59	1.25	25.57	109.7
	2S	1.04	0.68	5.68	181.88	1.24	21.84	2.28	28.20	3.79	28.616	7.74	0.35	25.58	109.9
	5S	0.55	0.64	2.38	107.85	0.35	8.91	0.90	11.93	3.88	32.228	7.74	0.29	25.57	110.4
	10S	0.15	0.11	1.48	4.89	0.47	8.76	0.62	10.35	0.53	34.707	8.10	0.99	25.56	109.0
	20S	0.05	0.07	0.07	4.27	0.36	7.66	0.41	7.80	0.29	34.690	8.13	0.38	25.56	108.4
	50S	0.20	0.19	0.21	2.55	0.42	7.25	0.62	7.65	0.13	34.801	8.14	0.05	26.02	101.4
	50D	0.13	0.11	0.48	2.32	0.40	7.18	0.53	7.77	0.16	34.814	8.14	0.13	26.07	99.8
	200S	0.04	0.05	0.18	1.99	0.33	7.49	0.37	7.72	0.14	34.800	8.17	0.04	25.99	101.1
	200D	0.04	0.08	0.34	1.78	0.35	6.92	0.39	7.34	0.13	34.813	8.16	0.04	25.87	100.5
	500S	0.03	0.01	0.03	1.82	0.36	7.13	0.39	7.17	0.11	34.778	8.19	0.03	25.98	104.5
	500D	0.18	0.02	0.28	1.58	0.42	7.61	0.60	7.91	0.16	34.780	8.20	0.02	25.49	107.0
Olowalu 3	0S	0.68	1.08	3.80	148.52	0.96	10.20	1.64	15.08	0.55	26.230	7.90	0.74	25.80	113.3
	1S	0.52	0.92	1.96	129.24	0.96	13.04	1.48	15.92	0.55	28.411	8.06	0.92	25.83	113.7
	10S	0.14	0.07	0.29	25.73	0.38	7.61	0.52	7.97	0.42	33.883	8.11	0.64	25.79	110.1
	20S	0.06	0.04	0.17	24.06	0.29	7.92	0.35	8.13	0.29	33.797	8.08	0.19	25.81	113.3
	40S	0.05	0.05	0.07	6.99	0.29	6.78	0.34	6.90	0.18	34.663	8.15	0.18	25.81	110.7
	60S	0.06	0.08	0.11	3.54	0.30	6.42	0.36	6.61	0.22	34.813	8.12	0.07	25.89	105.5
	100S	0.08	0.23	0.07	1.60	0.30	6.08	0.38	6.38	0.12	34.855	8.14	0.05	26.12	101.4
	100D	0.13	0.12	BDL	1.54	0.40	6.54	0.53	6.66	0.11	34.853	8.14	0.06	26.17	100.5
	300S	0.02	0.17	0.01	1.67	0.33	6.18	0.35	6.36	0.12	34.823	8.18	0.05	26.00	104.1
	300D	0.06	0.12	0.04	1.54	0.33	6.10	0.39	6.26	0.09	34.828	8.18	0.03	26.01	103.4
	600S	0.02	0.09	0.07	1.42	0.33	6.51	0.35	6.67	0.10	34.818	8.19	0.08	25.91	104.0
	600D	0.08	0.06	0.06	1.28	0.42	6.29	0.50	6.41	0.07	34.800	8.20	0.04	25.51	105.8
Olowalu 4	0S	0.27	5.11	0.65	104.30	0.31	7.26	0.58	13.02	0.70	32.679	8.01	1.45	26.31	103.3
	1S	0.17	2.16	0.77	58.45	0.35	7.48	0.52	10.41	0.94	33.920	8.20	0.37	26.29	101.0
	10S	0.06	0.46	2.35	16.41	0.30	7.83	0.36	10.64	0.73	34.905	8.30	0.39	26.28	98.3
	20S	0.04	0.03	0.34	8.45	0.29	8.29	0.33	8.66	0.53	35.142	8.27	0.24	26.23	96.4
	40S	0.04	BDL	0.07	12.05	0.30	8.54	0.34	8.61	0.49	34.829	8.08	0.20	26.20	93.3
	60S	0.06	0.02	0.30	4.67	0.30	7.26	0.36	7.58	0.37	35.059	8.03	0.09	26.19	92.4
	100s	0.14	0.41	0.43	2.69	0.36	6.39	0.50	7.23	0.17	34.906	8.06	0.85	26.02	101.2
	100d	0.03	0.35	0.09	2.21	0.30	6.02	0.33	6.46	0.14	34.910	8.06	0.09	26.02	92.2
	300S	0.04	0.47	0.09	2.00	0.36	5.34	0.40	5.90	0.17	34.930	8.03	0.05	25.56	94.5
	300D	0.24	0.51	0.11	2.20	0.30	6.01	0.54	6.63	0.19	34.890	8.07	0.10	26.06	92.8
	600S	0.15	0.30	0.10	2.22	0.38	5.62	0.53	6.02	0.30	34.844	8.15	0.09	25.13	103.6
	600D	0.06	0.30	0.11	1.26	0.37	5.48	0.43	5.89	0.10	34.827	8.18	0.06	25.90	104.1
Olowalu 5	0S	0.10	0.09	0.41	14.03	0.28	6.49	0.38	6.99	0.40	34.262	8.02	0.19	26.03	103.8
	1S	0.04	0.03	0.23	15.47	0.26	6.82	0.30	7.08	0.45	34.193	8.03	0.62	25.93	101.3
	2S	0.03	0.04	0.39	7.51	0.30	6.93	0.33	7.36	0.38	34.600	8.04	1.01	25.97	102.5
	5S	0.08	0.06	0.39	3.79	0.30	6.40	0.38	6.85	0.30	34.835	8.06	0.13	25.97	101.5
	10S	0.14	0.03	0.08	3.86	0.26	5.81	0.40	5.92	0.22	34.818	8.06	0.18	26.01	100.9
	20S	0.09	0.08	0.63	3.71	0.46	5.94	0.55	6.65	0.28	34.832	8.05	0.51	25.93	94.7
	50S	0.05	0.32	0.13	1.75	0.39	7.05	0.44	7.50	0.17	34.858	8.10	0.09	25.85	98.7
	50D	0.12	0.31	0.19	2.13	0.36	5.19	0.48	5.69	0.23	34.847	8.10	0.15	25.95	96.1
	200S	0.08	0.35	0.11	1.69	0.39	5.87	0.47	6.33	0.18	34.840	8.12	0.06	25.93	100.5
	200D	0.14	0.39	0.21	1.75	0.37	5.34	0.51	5.94	0.16	34.841	8.13	0.05	25.92	95.0
	500S	0.22	0.29	0.30	1.43	0.22	6.28	0.44	6.87	0.16	34.830	8.15	0.04	25.89	102.8
	500D	0.07	0.21	0.15	1.41	0.33	5.62	0.40	5.98	0.11	34.826	8.16	0.03	25.94	100.1
Streams	210	0.40	0.20	0.80	697.50	1.50	22.40	1.90	23.40		0.177				
	520	0.60	0.40	0.80	720.80	1.70	20.20	2.30	21.40		0.160				
Wells	4936-01	0.70	4.00	0.90	759.70	1.60	16.70	2.30	21.60		0.175				
	4937-01	3.30	34.40	2.10	843.50	1.70	2.80	5.00	39.30		0.294				
DOH WQS	DRY	10%	0.71	0.36				0.96	12.86	0.50	*	***	0.50	**	****
		2%	1.43	0.64				1.45	17.86	1.00			1.00		
	WET	10%	1.00	0.61				1.29	17.85	1.25	*	***	0.90	**	****
		2%	1.78	1.07				1.93	25.00	2.00			1.75		

* Salinity shall not vary more than ten percent form natural or seasonal changes considering hydrologic input and oceanographic conditions.

** Temperature shall not vary by more than one degree C. from ambient conditions.

***pH shall not deviate more than 0.5 units from a value of 8.1.

****Dissolved Oxygen not to be below 75% saturation.

TABLE 2. Water chemistry measurements (nutrient concentrations in µg/L) from five ocean water transects, two streams and two groundwater wells collected in the vicinity of the Olowalu Town project on June 11, 2010. Abbreviations as follows: DFS=distance from shore; S=surface; D=deep; BDL=below detection limit. Also shown are the State of Hawaii, Department of Health (DOH) "not to exceed more than 10% of the time" and "not to exceed more than 2% of the time" water quality standards for open coastal waters under "dry" and "wet" conditions.Boxed values exceed DOH 10% "dry" standards; boxed and shaded values exceed DOH 10% "wet" standards. For sampling site locations, see Figure 1.

TRANSECT SITE	DFS (m)	PO$_4^{3-}$ (µg/L)	NO$_3^-$ (µg/L)	NH$_4^+$ (µg/L)	Si (µg/L)	TOP (µg/L)	TON (µg/L)	TP (µg/L)	TN (µg/L)	TURB (NTU)	SALINITY (ppt)	pH (std.units)	CHL a (µg/L)	TEMP (deg.C)	O2 % Sat
Oluwalu 1	0S	17.36	701.7	118.77	8715	33.48	206.1	50.84	1026	0.79	18.942	7.88	2.48	24.79	101.0
	1S	33.48	808.6	183.76	9956	40.92	153.4	74.40	1146	1.54	17.389	7.81	5.12	24.72	101.1
	2S	7.44	272.7	3.36	5028	38.44	89.60	45.88	365.7	0.56	25.669	8.04	1.13	24.59	101.4
	5S	4.96	33.04	12.33	2383	33.48	132.7	38.44	178.1	0.45	30.874	8.07	0.51	24.76	100.8
	10S	2.79	1.96	8.68	730.0	14.26	116.1	17.05	126.7	0.63	33.551	8.06	2.01	24.90	101.7
	20S	1.55	1.40	0.28	360.5	10.23	113.5	11.78	115.2	0.36	34.238	8.07	0.61	24.92	104.2
	50S	2.17	BDL	1.12	161.0	9.92	82.74	12.09	83.9	0.28	34.616	8.14	0.14	26.16	105.2
	50D	1.24	0.28	1.40	150.3	9.30	99.12	10.54	100.8	0.29	34.620	8.14	0.36	26.10	105.7
	150S	1.24	0.28	1.68	184.1	8.99	95.76	10.23	97.7	0.42	34.600	8.16	0.07	25.95	103.6
	150D	0.31	0.42	1.40	68.8	10.23	99.82	10.54	101.6	0.17	34.787	8.18	0.05	25.97	101.3
	400S	2.17	0.56	11.20	75.6	13.02	98.56	15.19	110.3	0.14	34.811	8.18	0.07	26.01	102.9
	400D	0.62	0.70	6.02	57.6	10.23	96.18	10.85	102.9	0.18	34.787	8.19	0.06	25.88	102.2
Oluwalu 2	0S	16.12	5.04	79.55	12022	24.80	131.6	40.92	216.2	16.90	18.198	7.21	1.74	25.58	109.3
	1S	70.68	5.60	52.10	9065	18.60	314.7	89.28	372.4	5.91	21.315	7.59	1.25	25.57	109.7
	2S	32.24	9.52	79.55	5111	38.44	305.8	70.68	394.8	3.79	28.616	7.74	0.35	25.58	109.9
	5S	17.05	8.96	33.33	3031	10.85	124.7	27.90	167.0	3.88	32.228	7.74	0.29	25.57	110.4
	10S	4.65	1.54	20.73	137.4	14.57	122.6	19.22	144.9	0.53	34.707	8.10	0.99	25.56	109.0
	20S	1.55	0.98	0.98	120.0	11.16	107.2	12.71	109.2	0.29	34.690	8.13	0.38	25.56	108.4
	50S	6.20	2.66	2.94	71.7	13.02	101.5	19.22	107.1	0.13	34.801	8.14	0.05	26.02	101.4
	50D	4.03	1.54	6.72	65.2	12.40	100.5	16.43	108.8	0.16	34.814	8.14	0.13	26.07	99.8
	200S	1.24	0.70	2.52	55.9	10.23	104.9	11.47	108.1	0.14	34.800	8.17	0.04	25.99	101.1
	200D	1.24	1.12	4.76	50.0	10.85	96.88	12.09	102.8	0.13	34.813	8.16	0.04	25.87	100.5
	500S	0.93	0.14	0.42	51.1	11.16	99.82	12.09	100.4	0.11	34.778	8.19	0.03	25.98	104.5
	500D	5.58	0.28	3.92	44.4	13.02	106.5	18.60	110.7	0.16	34.780	8.20	0.02	25.49	107.0
Oluwalu 3	0S	21.08	15.12	53.22	4173	29.76	142.8	50.84	211.1	0.55	26.230	7.90	0.74	25.80	113.3
	1S	16.12	12.88	27.45	3632	29.76	182.6	45.88	222.9	0.55	28.411	8.06	0.92	25.83	113.7
	10S	4.34	0.98	4.06	723.0	11.78	106.5	16.12	111.6	0.42	33.883	8.11	0.64	25.79	110.1
	20S	1.86	0.56	2.38	676.1	8.99	110.9	10.85	113.8	0.29	33.797	8.08	0.19	25.81	113.3
	40S	1.55	0.70	0.98	196.4	8.99	94.92	10.54	96.6	0.18	34.663	8.15	0.18	25.81	110.7
	60S	1.86	1.12	1.54	99.5	9.30	89.88	11.16	92.5	0.22	34.813	8.12	0.07	25.89	105.5
	100S	2.48	3.22	0.98	45.0	9.30	85.12	11.78	89.3	0.12	34.855	8.14	0.05	26.12	101.4
	100D	4.03	1.68	BDL	43.3	12.40	91.56	16.43	93.2	0.11	34.853	8.14	0.06	26.17	100.5
	300S	0.62	2.38	0.14	46.9	10.23	86.52	10.85	89.0	0.12	34.823	8.18	0.05	26.00	104.1
	300D	1.86	1.68	0.56	43.3	10.23	85.40	12.09	87.6	0.09	34.828	8.18	0.03	26.01	103.4
	600S	0.62	1.26	0.98	39.9	10.23	91.14	10.85	93.4	0.10	34.818	8.19	0.08	25.91	104.0
	600D	2.48	0.84	0.84	36.0	13.02	88.06	15.50	89.7	0.07	34.800	8.20	0.04	25.51	105.8
Oluwalu 4	0S	8.37	71.54	9.10	2931	9.61	101.6	17.98	182.3	0.70	32.679	8.01	1.45	26.31	103.3
	1S	5.27	30.24	10.78	1642	10.85	104.7	16.12	145.7	0.94	33.920	8.20	0.37	26.29	101.0
	10S	1.86	6.44	32.91	461.1	9.30	109.6	11.16	149.0	0.73	34.905	8.30	0.39	26.28	98.3
	20S	1.24	0.42	4.76	237.4	8.99	116.1	10.23	121.2	0.53	35.142	8.27	0.24	26.23	96.4
	40S	1.24	BDL	0.98	338.6	9.30	119.6	10.54	120.5	0.49	34.829	8.08	0.20	26.20	93.3
	60S	1.86	0.28	4.20	131.2	9.30	101.6	11.16	106.1	0.37	35.059	8.03	0.09	26.19	92.4
	100s	4.34	5.74	6.02	75.6	11.16	89.46	15.50	101.2	0.17	34.906	8.06	0.85	26.02	101.2
	100d	0.93	4.90	1.26	62.1	9.30	84.28	10.23	90.4	0.14	34.910	8.06	0.09	26.02	92.2
	300S	1.24	6.58	1.26	56.2	11.16	74.76	12.40	82.6	0.17	34.930	8.03	0.05	25.56	94.5
	300D	7.44	7.14	1.54	61.8	9.30	84.14	16.74	92.8	0.19	34.890	8.07	0.10	26.06	92.8
	600S	4.65	4.20	1.40	62.4	11.78	78.68	16.43	84.3	0.30	34.844	8.15	0.09	25.13	103.6
	600D	1.86	4.20	1.54	35.4	11.47	76.72	13.33	82.5	0.10	34.827	8.18	0.06	25.90	104.1
Oluwalu 5	0S	3.10	1.26	5.74	394.2	8.68	90.86	11.78	97.9	0.40	34.262	8.02	0.19	26.03	103.8
	1S	1.24	0.42	3.22	434.7	8.06	95.48	9.30	99.1	0.45	34.193	8.03	0.62	25.93	101.3
	2S	0.93	0.56	5.46	211.0	9.30	97.02	10.23	103.0	0.38	34.600	8.04	1.01	25.97	102.5
	5S	2.48	0.84	5.46	106.5	9.30	89.60	11.78	95.9	0.30	34.835	8.06	0.13	25.97	101.5
	10S	4.34	0.42	1.12	108.5	8.06	81.34	12.40	82.9	0.22	34.818	8.06	0.18	26.01	100.9
	20S	2.79	1.12	8.82	104.3	14.26	83.16	17.05	93.1	0.28	34.832	8.05	0.51	25.93	94.7
	50S	1.55	4.48	1.82	49.2	12.09	98.70	13.64	105.0	0.17	34.858	8.10	0.09	25.85	98.7
	50D	3.72	4.34	2.66	59.9	11.16	72.66	14.88	79.7	0.23	34.847	8.10	0.15	25.95	96.1
	200S	2.48	4.90	1.54	47.5	12.09	82.18	14.57	88.6	0.18	34.840	8.12	0.06	25.93	100.5
	200D	4.34	5.46	2.94	49.2	11.47	74.76	15.81	83.2	0.16	34.841	8.13	0.05	25.92	95.0
	500S	6.82	4.06	4.20	40.2	6.82	87.92	13.64	96.2	0.16	34.830	8.15	0.04	25.89	102.8
	500D	2.17	2.94	2.10	39.6	10.23	78.68	12.40	83.7	0.11	34.826	8.16	0.03	25.94	100.1
Streams	210	12.40	2.80	11.20	19600	46.50	313.6	58.90	327.6		0.177				
	520	18.60	5.60	11.20	20254	52.70	282.8	71.30	299.6		0.160				
Wells	4936-01	21.70	56.00	12.60	21348	49.60	233.8	71.30	302.4		0.175				
	4937-01	102.3	481.6	29.40	23702	52.70	39.20	155.0	550.2		0.294				
DOH WQS	DRY	10%	10.00	5.00				30.00	180.00	0.50	*	***	0.50	**	****
		2%	20.00	9.00				45.00	250.00	1.00			1.00		
	WET	10%	14.00	8.50				40.00	250.00	1.25	*	***	0.90	**	****
		2%	25.00	15.00				60.00	350.00	2.00			1.75		

* Salinity shall not vary more than ten percent form natural or seasonal changes considering hydrologic input and oceanographic conditions.

** Temperature shall not vary by more than one degree C. from ambient conditions.

***pH shall not deviate more than 0.5 units from a value of 8.1.

****Dissolved Oxygen not to be below 75% saturation.

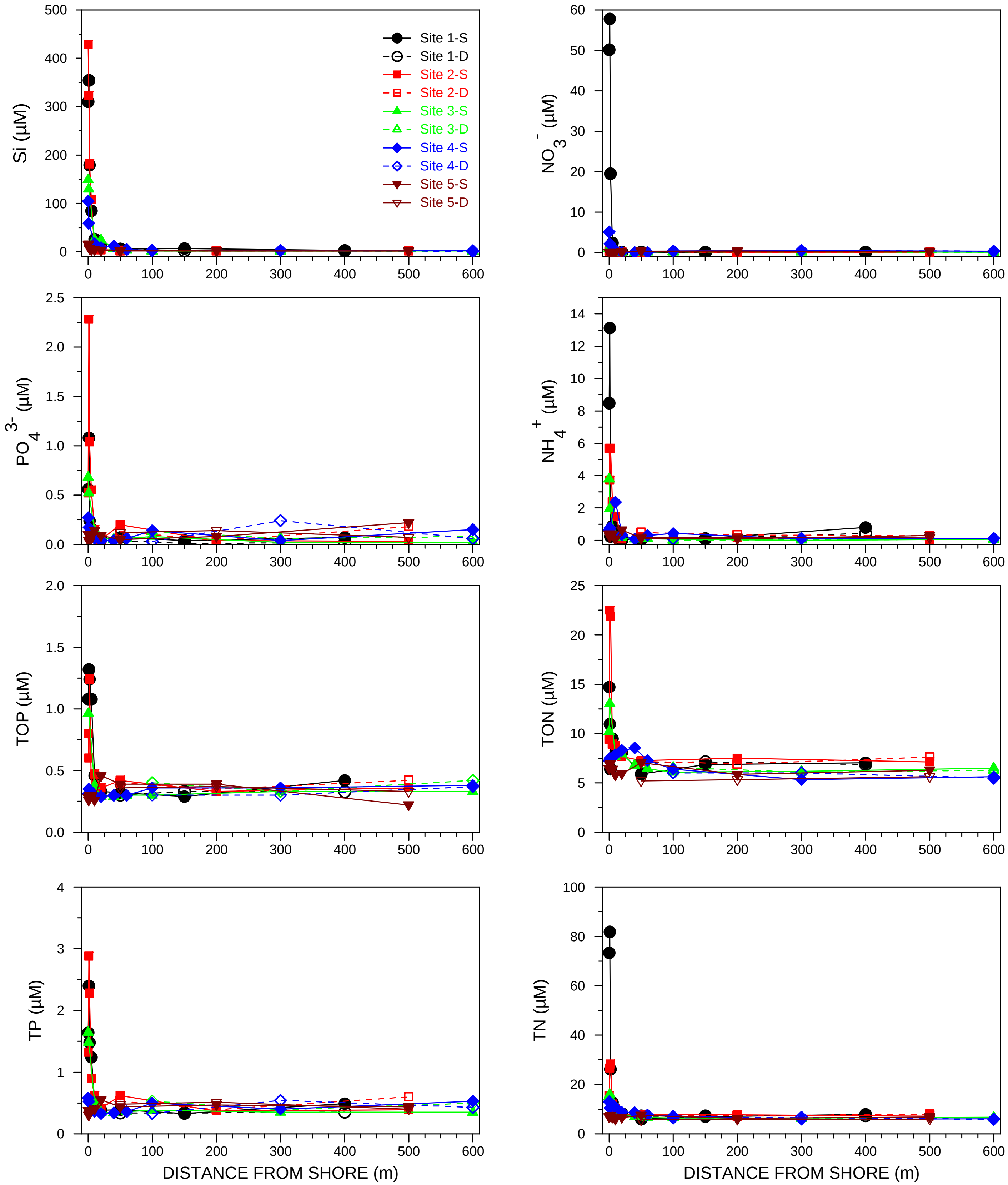


FIGURE 2. Plots of dissolved nutrients in surface (S) and deep (D) samples collected on June 11, 2010 as a function of distance from the shoreline in the vicinity of Olowalu Town project. For site locations, see Figure 1.

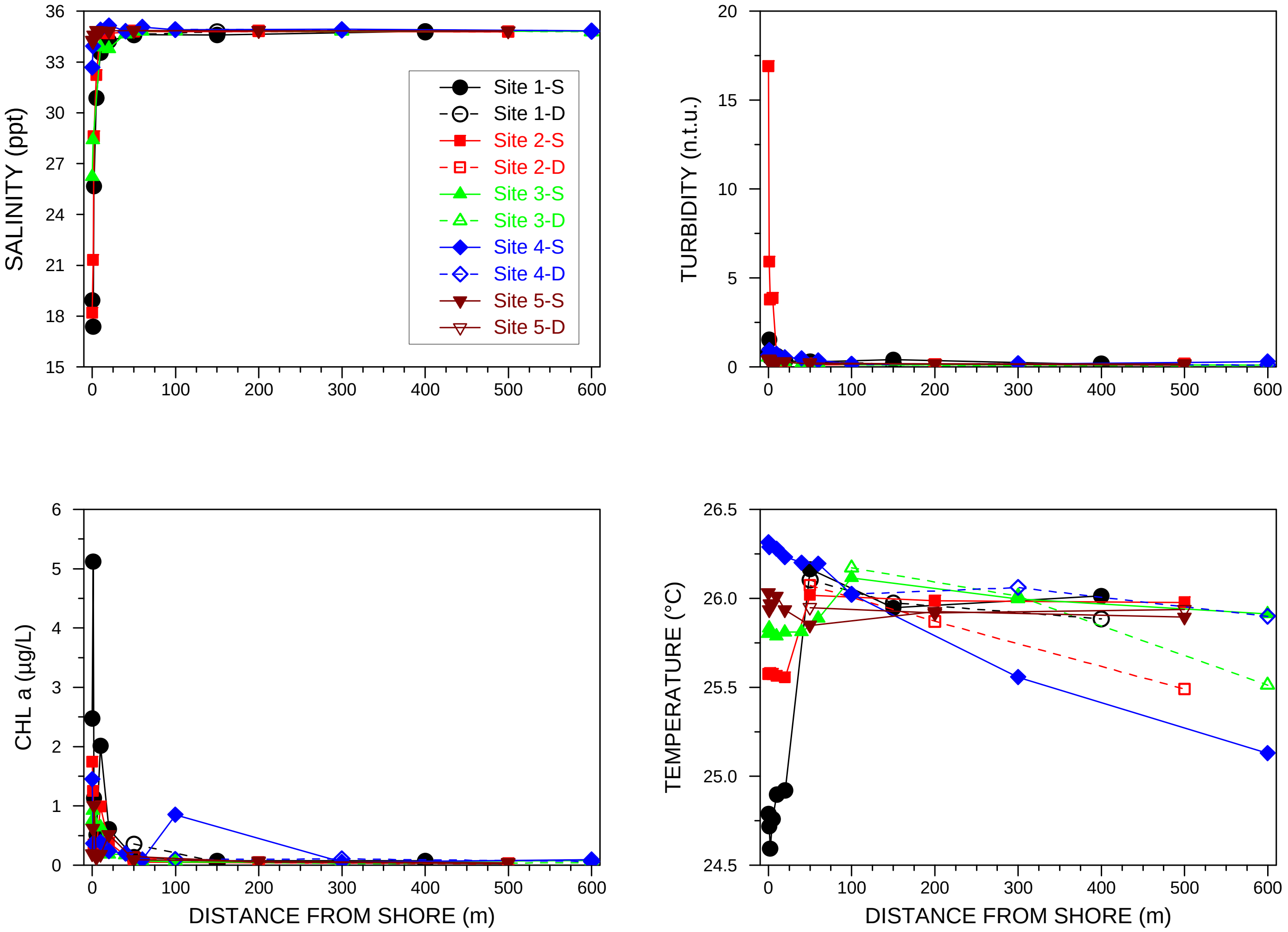


FIGURE 3. Plots of water chemistry constituents in surface (S) and deep (D) samples collected on June 11, 2010 as a function of distance from the shoreline in the vicinity of Olowalu Town project. For site locations, see Figure 1.

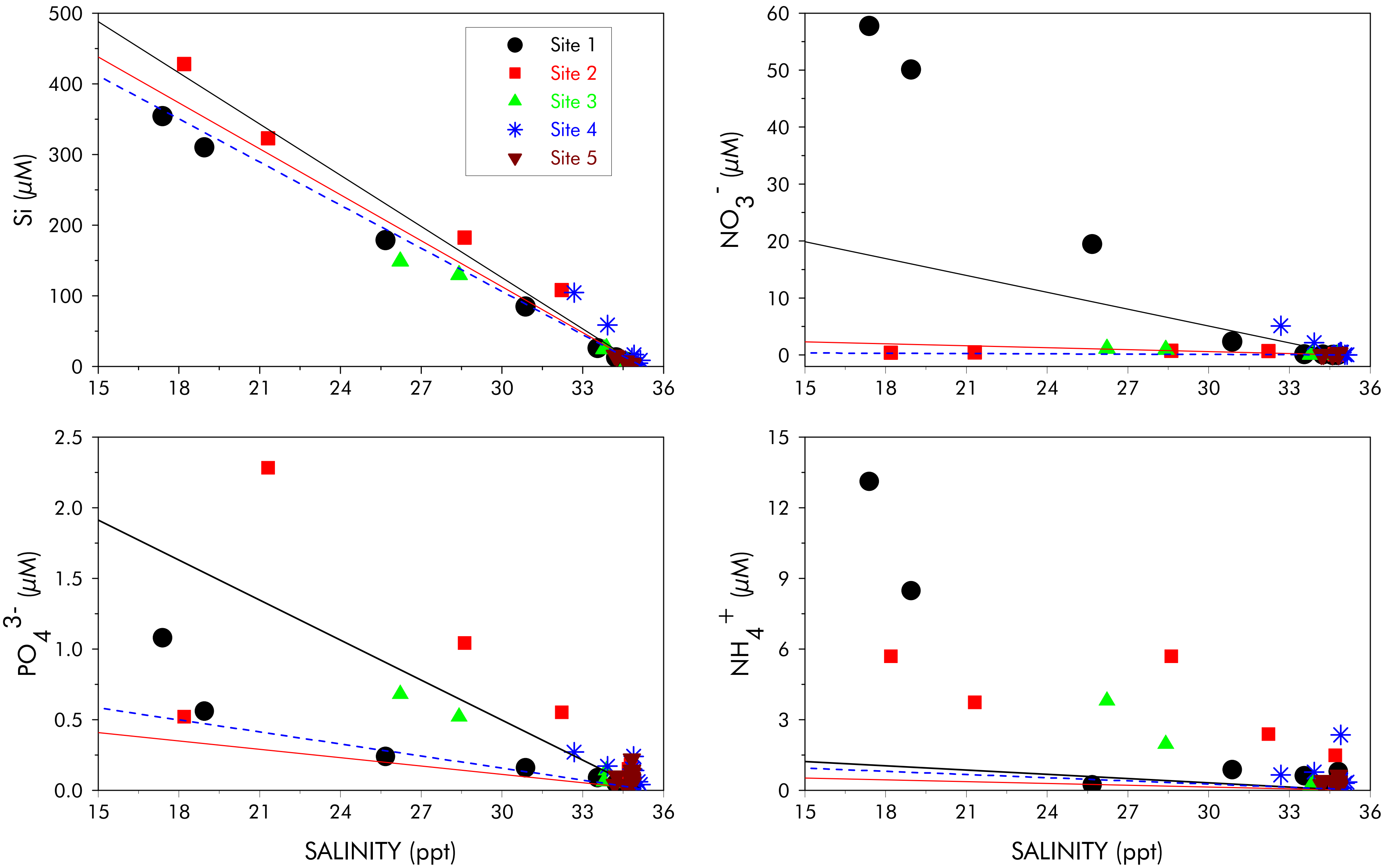


FIGURE 4. Mixing diagram showing concentration of dissolved nutrients from samples collected offshore of the Olowalu Town project on June 11, 2010 as functions of salinity. Conservative mixing lines, constructed by connecting the concentrations in open coastal water with water from two groundwater wells located upslope of the project site are also shown (red line=well #4936-01; black line=well#4937-01); blue dashed line is average Olowalu Stream water. For sampling site locations, see Figure 1.

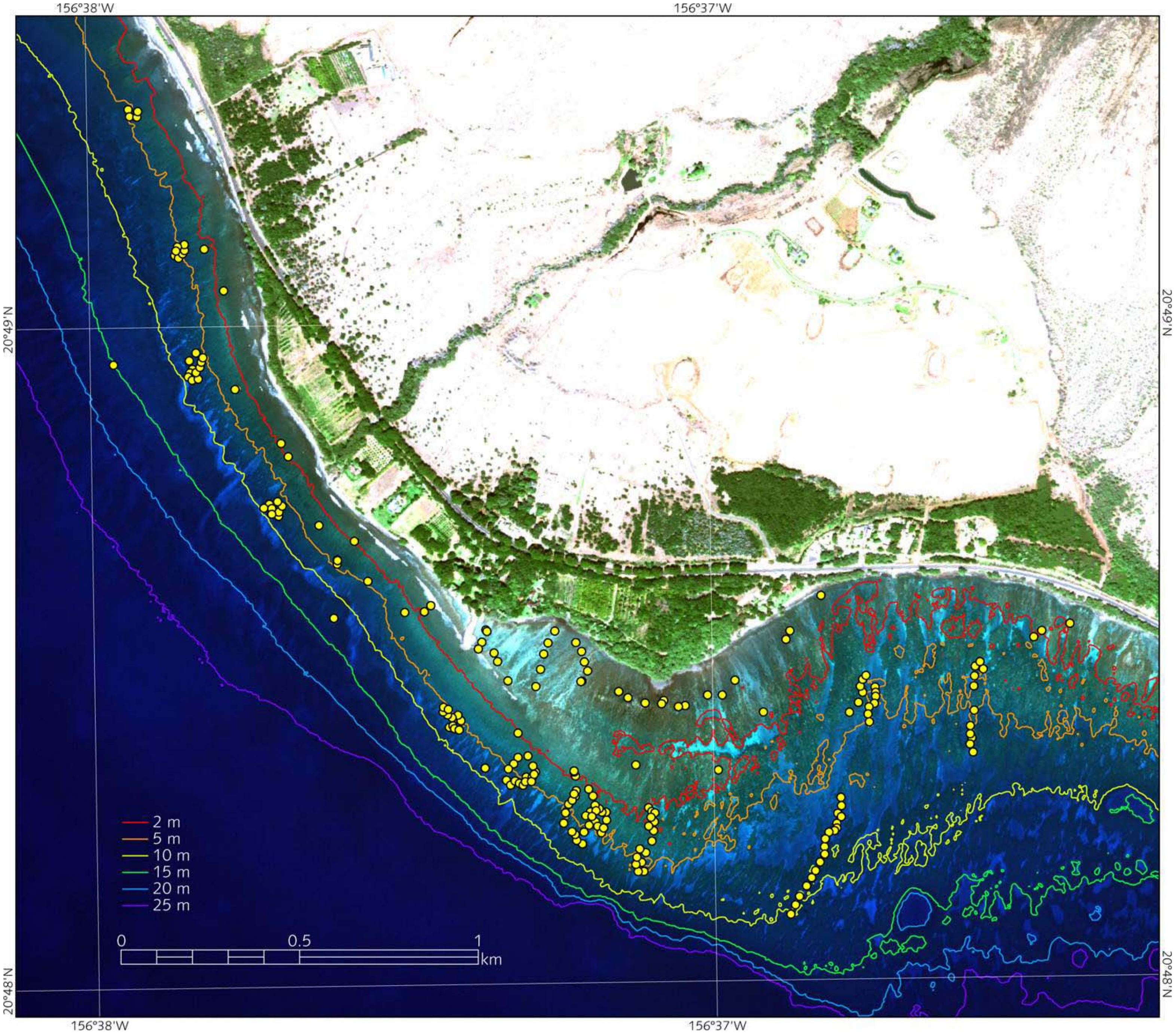


FIGURE 5. Satellite image of study area off Olowalu, Maui, Hawaii showing depth contours and locations of 200 reef survey calibration/validation sites (yellow circles).

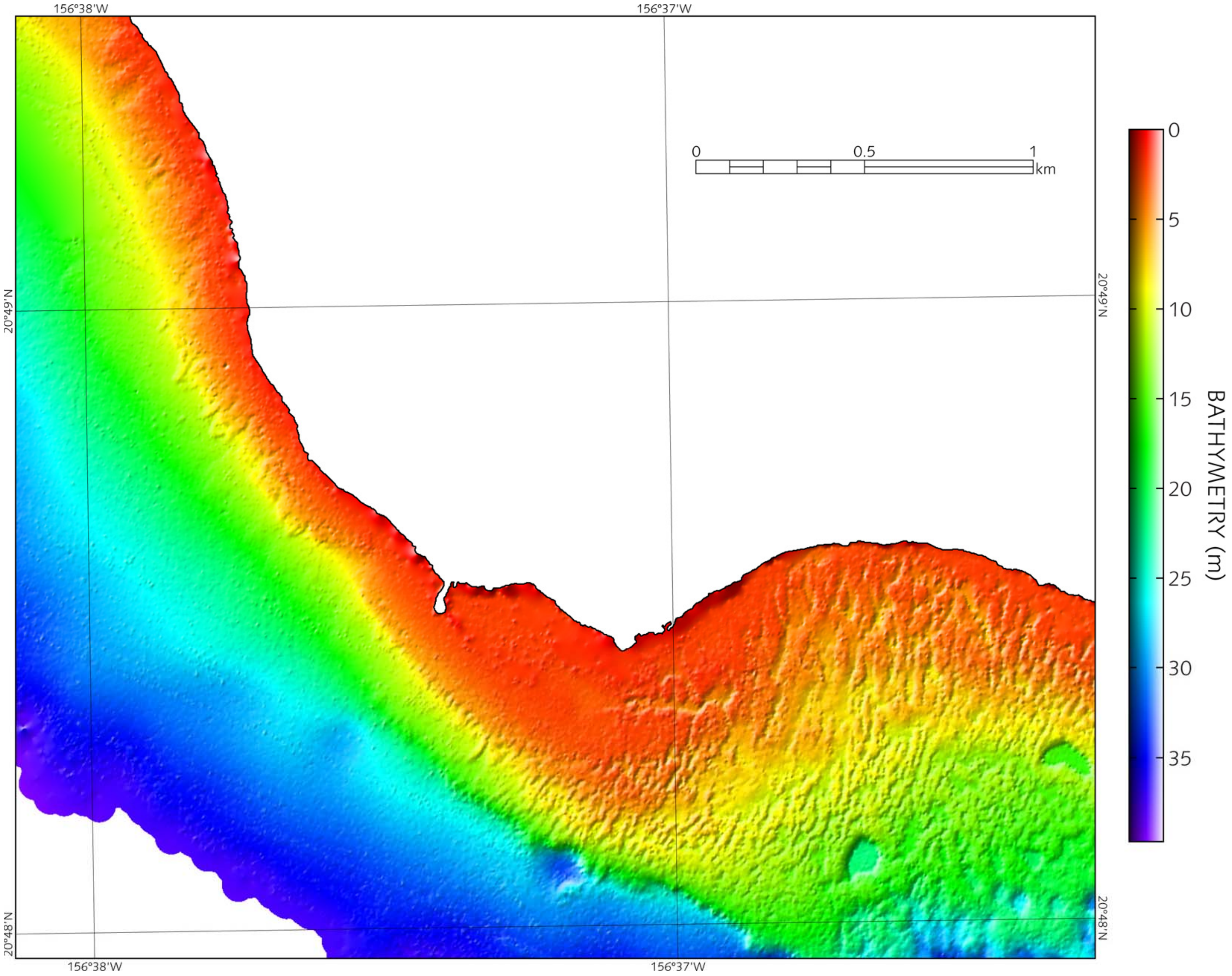


FIGURE 6. Three-dimensional color-coded bathymetry of nearshore marine environment off of Olowalu, Maui (land is white). Note significantly greater rugosity of reef structure on east side of Olowalu Point relative to west side. Data provided by SHOALS (Scanning Hydrographic Operational Airbourne Lidar Survey).

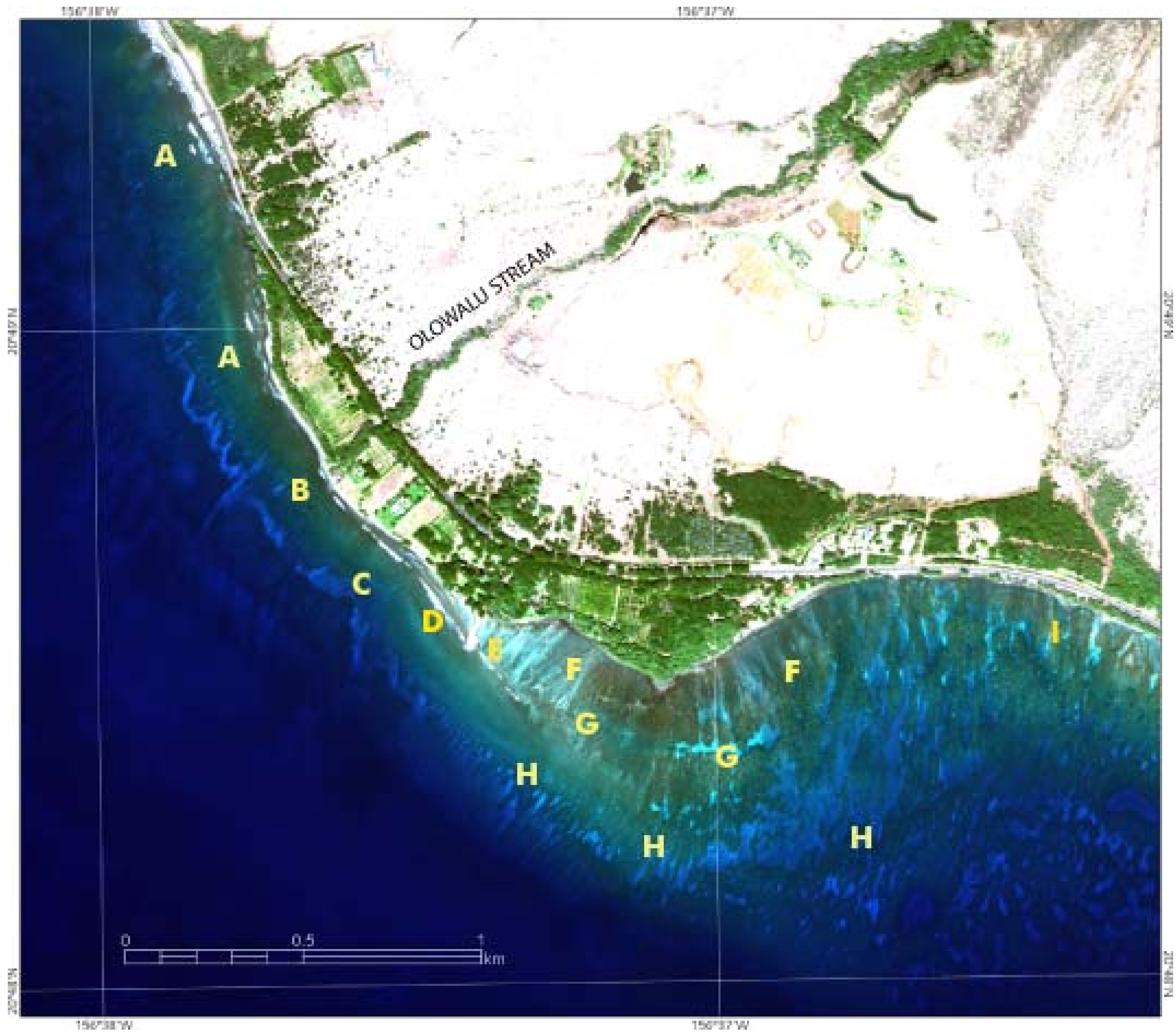


FIGURE 7. Satellite image of coastal and reef area of Olowalu, Maui, Hawaii . Letters designate regions of various reef zones described in text.

FIGURE 8. Views of shoreline at northern end (top) central (middle) and southern end (bottom) of Olowalu Town project site.

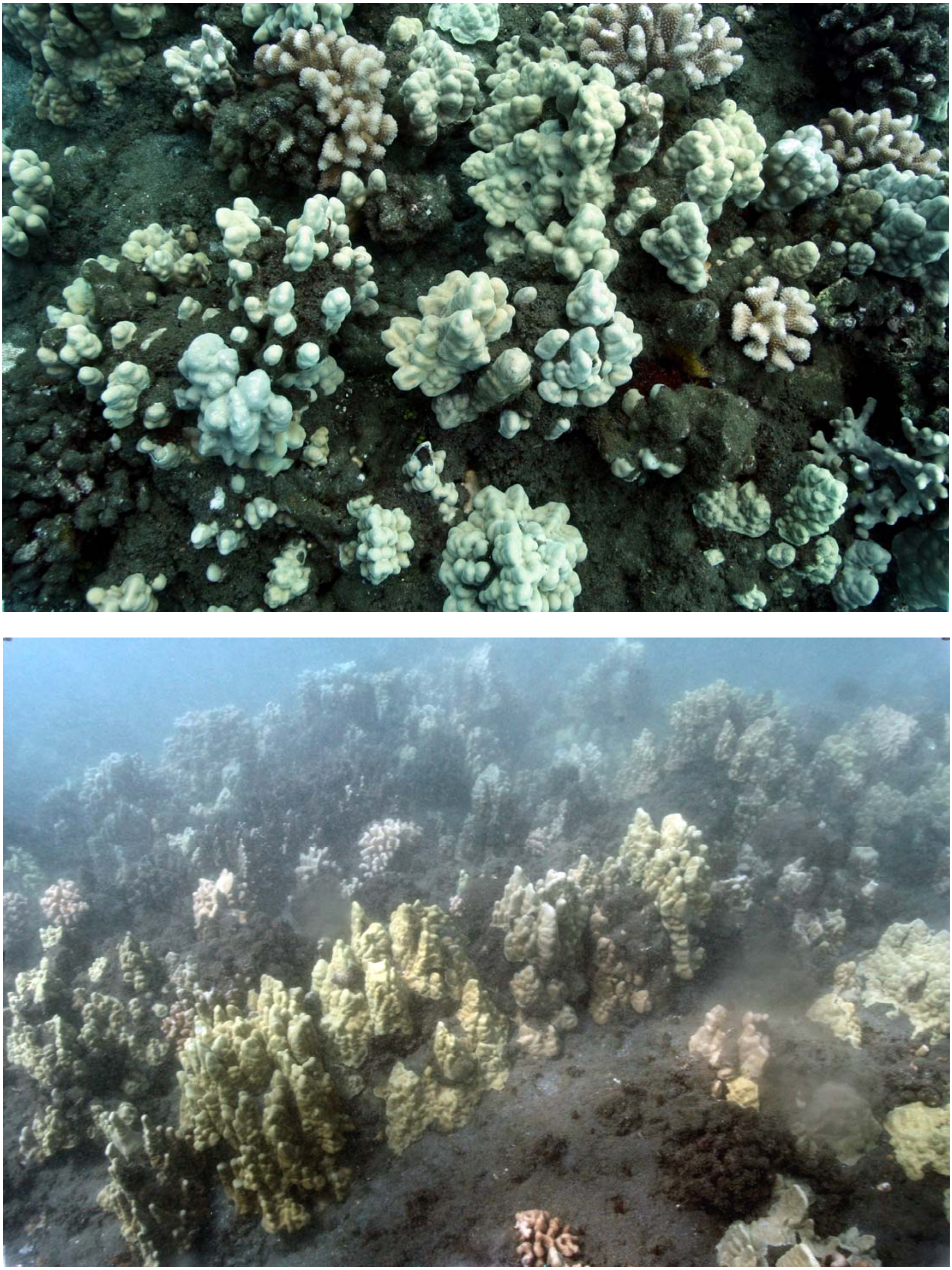


FIGURE 9. Reef platform typifying Zone A (see Figure 7) near northern boundary of Olowalu Town project site, and north of the discharge area of Olowalu Stream. Predominant species of coral in both photos is *Porites lobata*. Note layer of mud on reef surface between coral colonies.

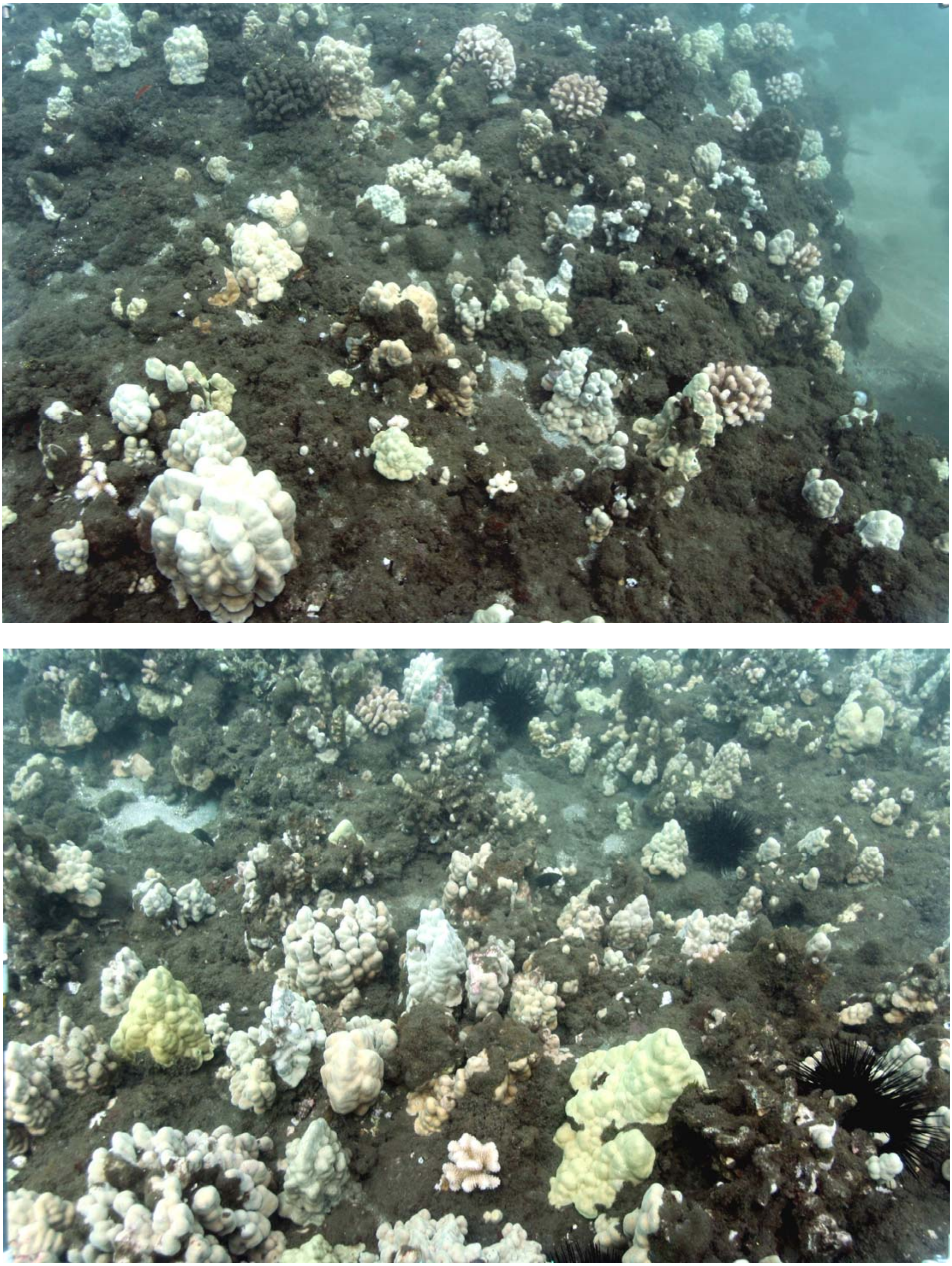


FIGURE 10. Two examples of the reef platform in Zone A north of Olowalu Point. Predominant corals in both photos are *Porites lobata* (tan and green knobby colonies) and *Pocillopora meandrina* (round branching colonies). Not bottom cover of dark colored sediment between corals.

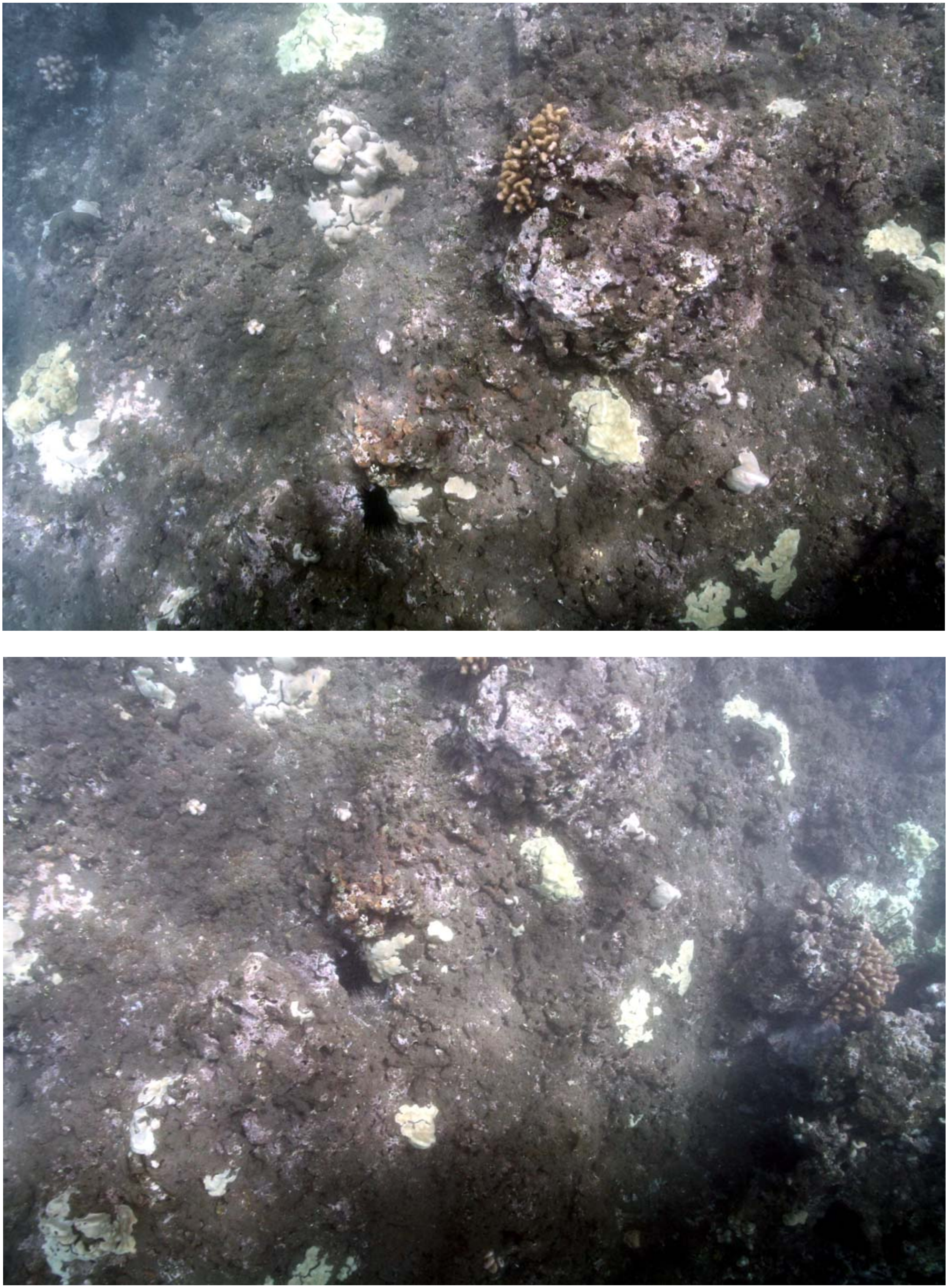


FIGURE 11. Two views of reef surface near point of discharge of Olowalu Stream (see Zone B in Figure 7).

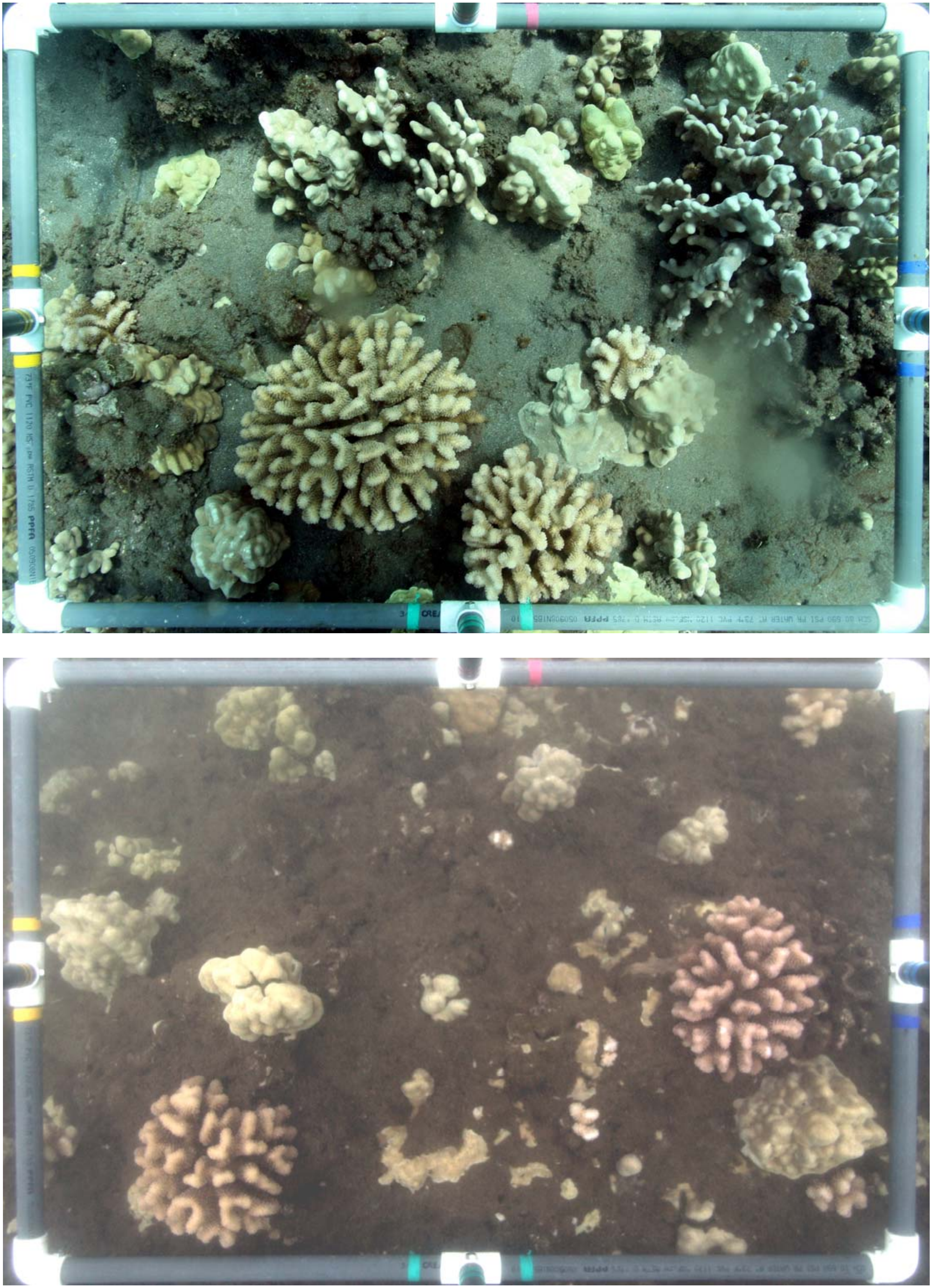


FIGURE 12. Two examples of photoquadrats taken in Zone B (see Figure 7) near the point where Olowalu Stream discharges to the ocean. Note significant deposition of muddy sediment between corals.

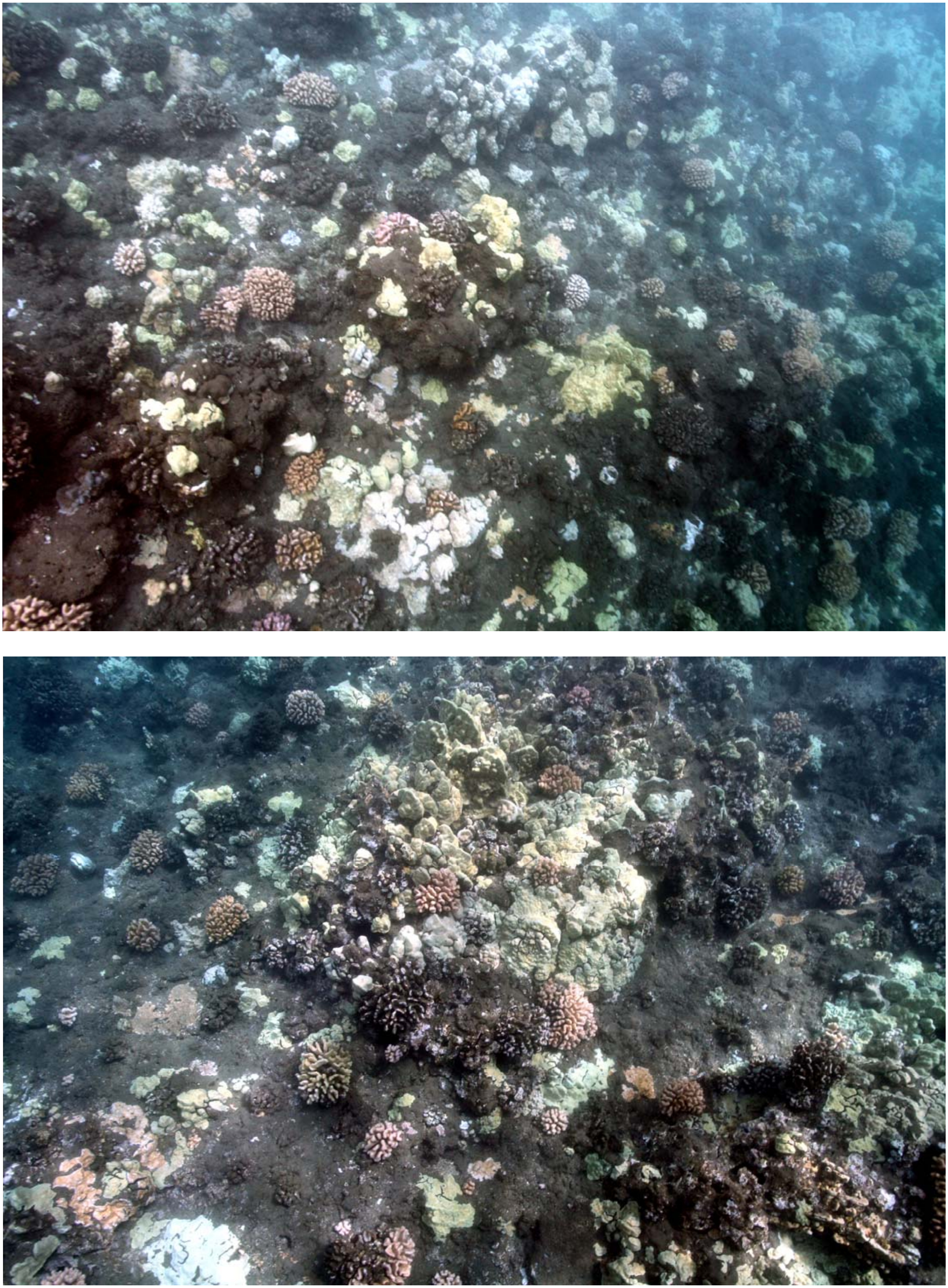
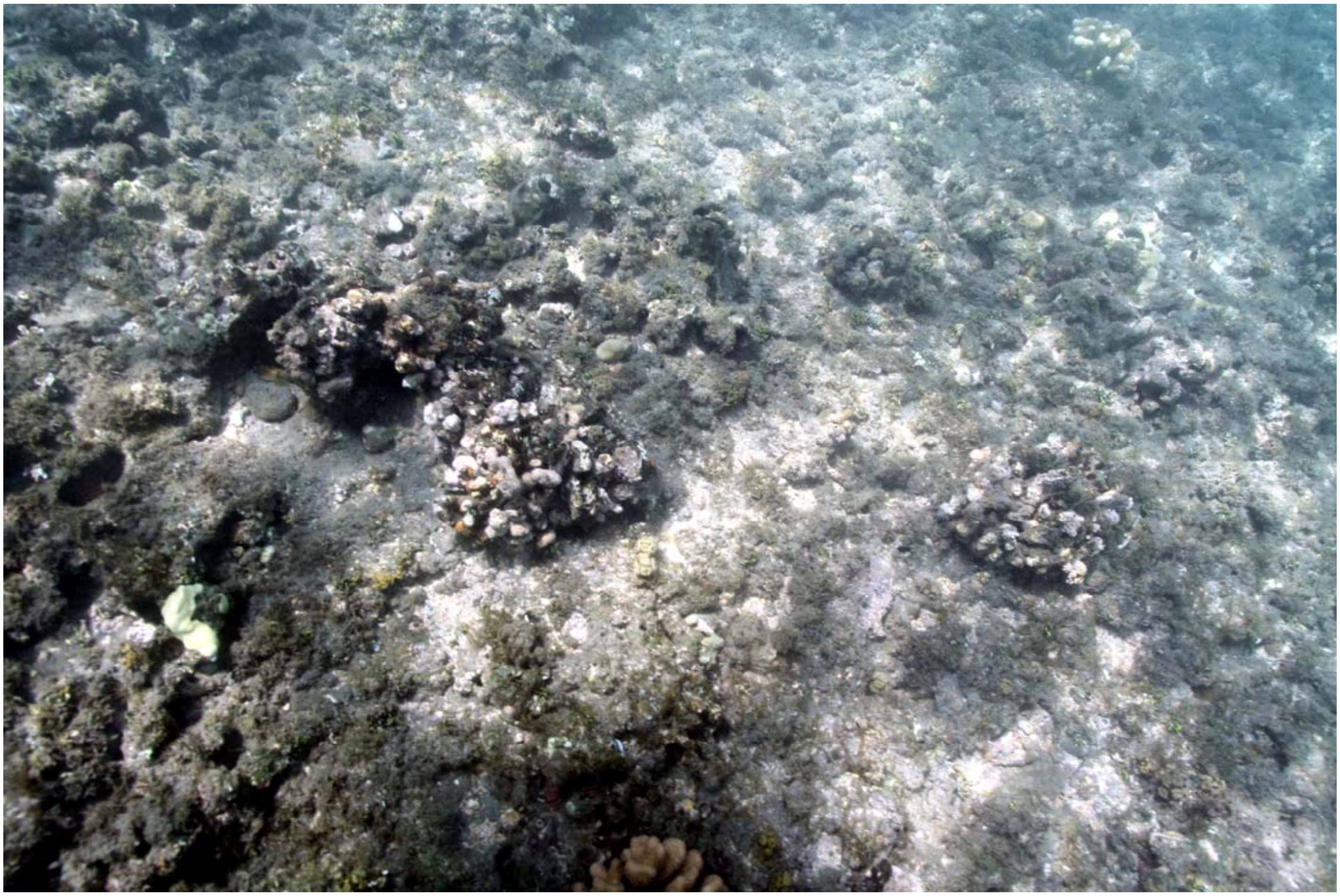


FIGURE 13. Two examples of coral communities on southwest reef platform (Zone C in Figure 7) located between Olowalu Stream Discharge and Olowalu Point. Note higher density of corals and lower levels of deposited mud on bottom compared to Zones A and B.



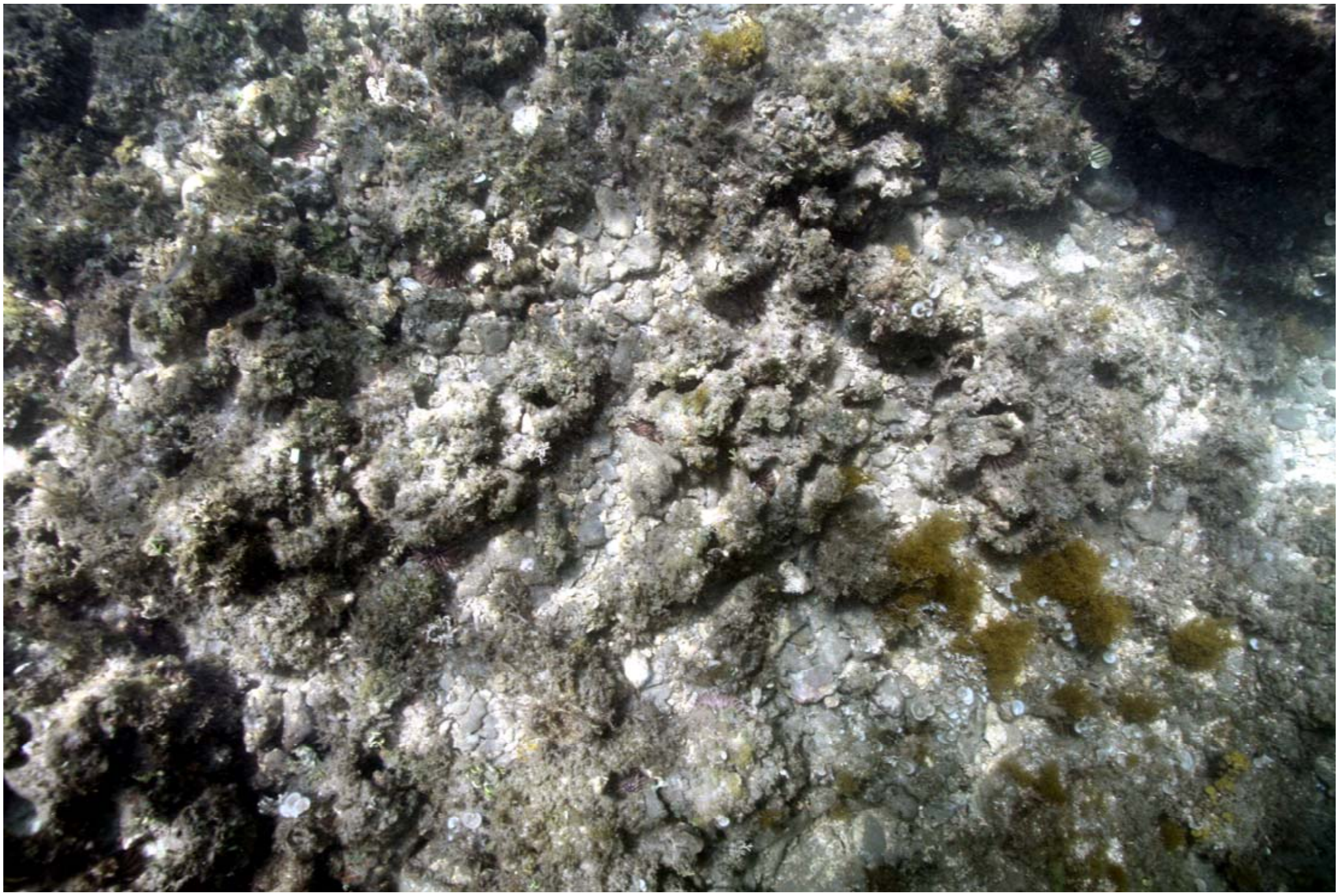


FIGURE 14. Two views of shallow inner reef platform on the north side of Olowalu Point (see Zone D in Figure 7).

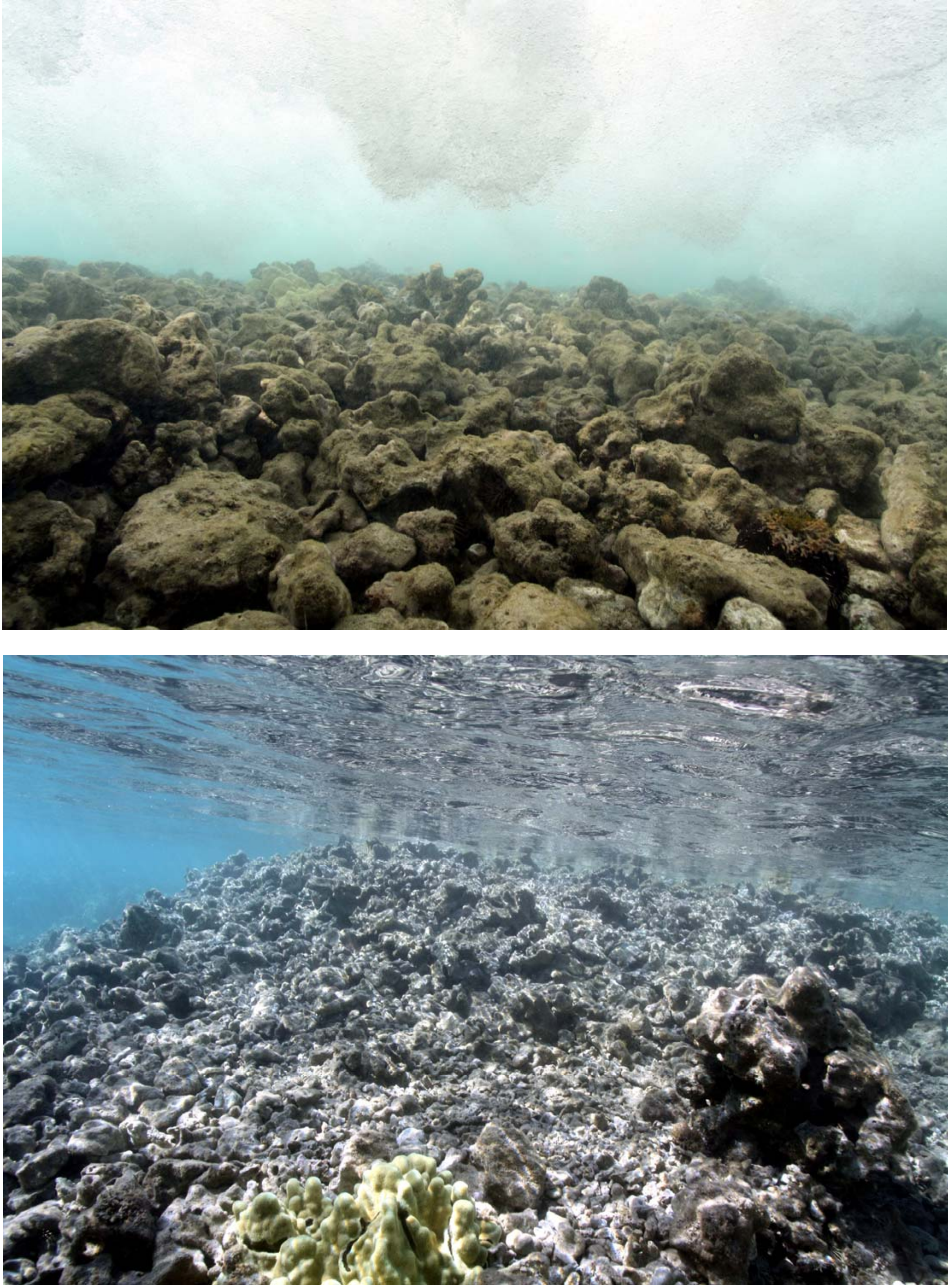
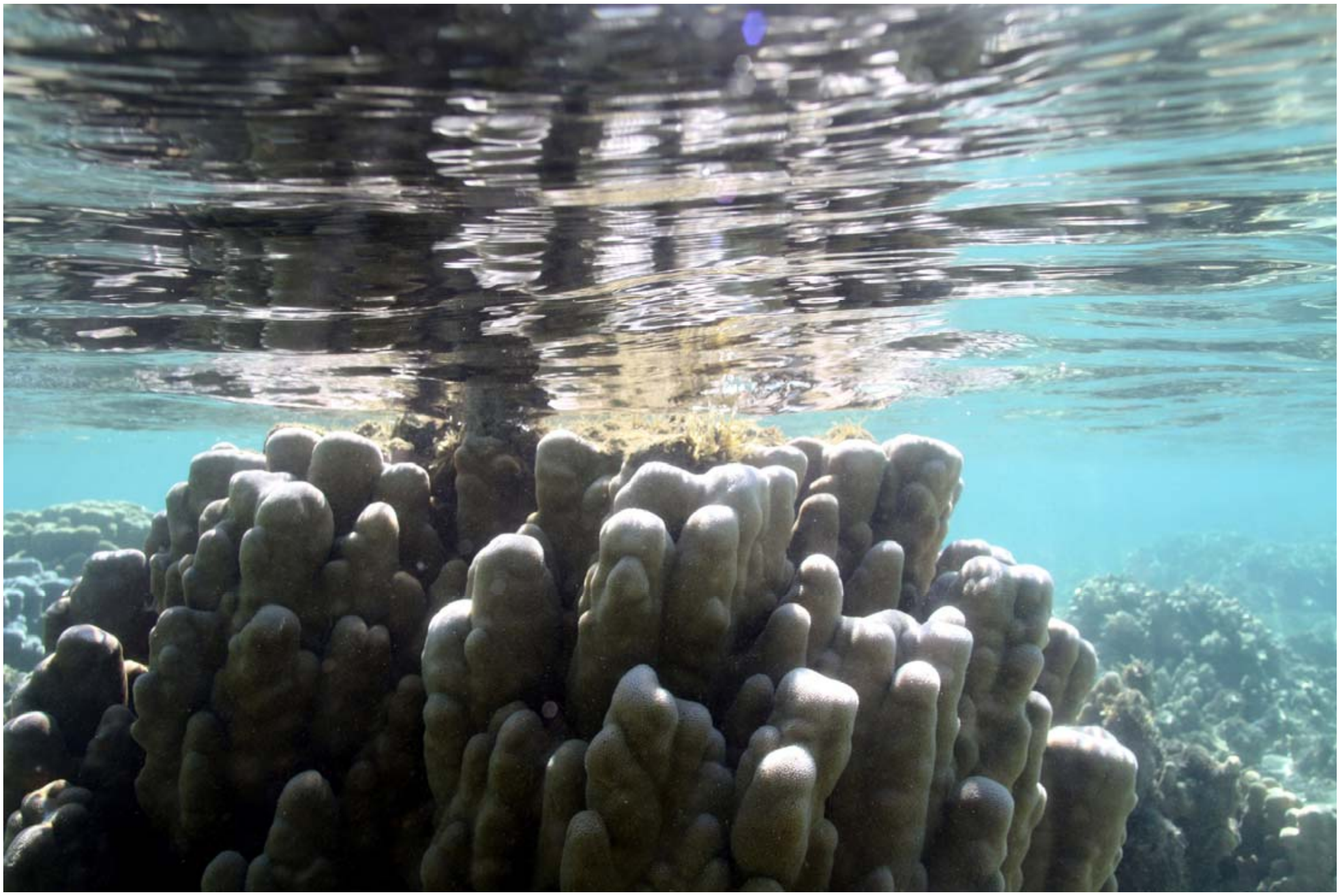


FIGURE 15. Reef crest (Zone E in Figure 7) off the south side of old pier off Olowalu Point. Reef crest is emergent at low tide and absorbs the force of breaking waves (top photo). Not the lack of living coral on the upper surface of the crest in both photos.



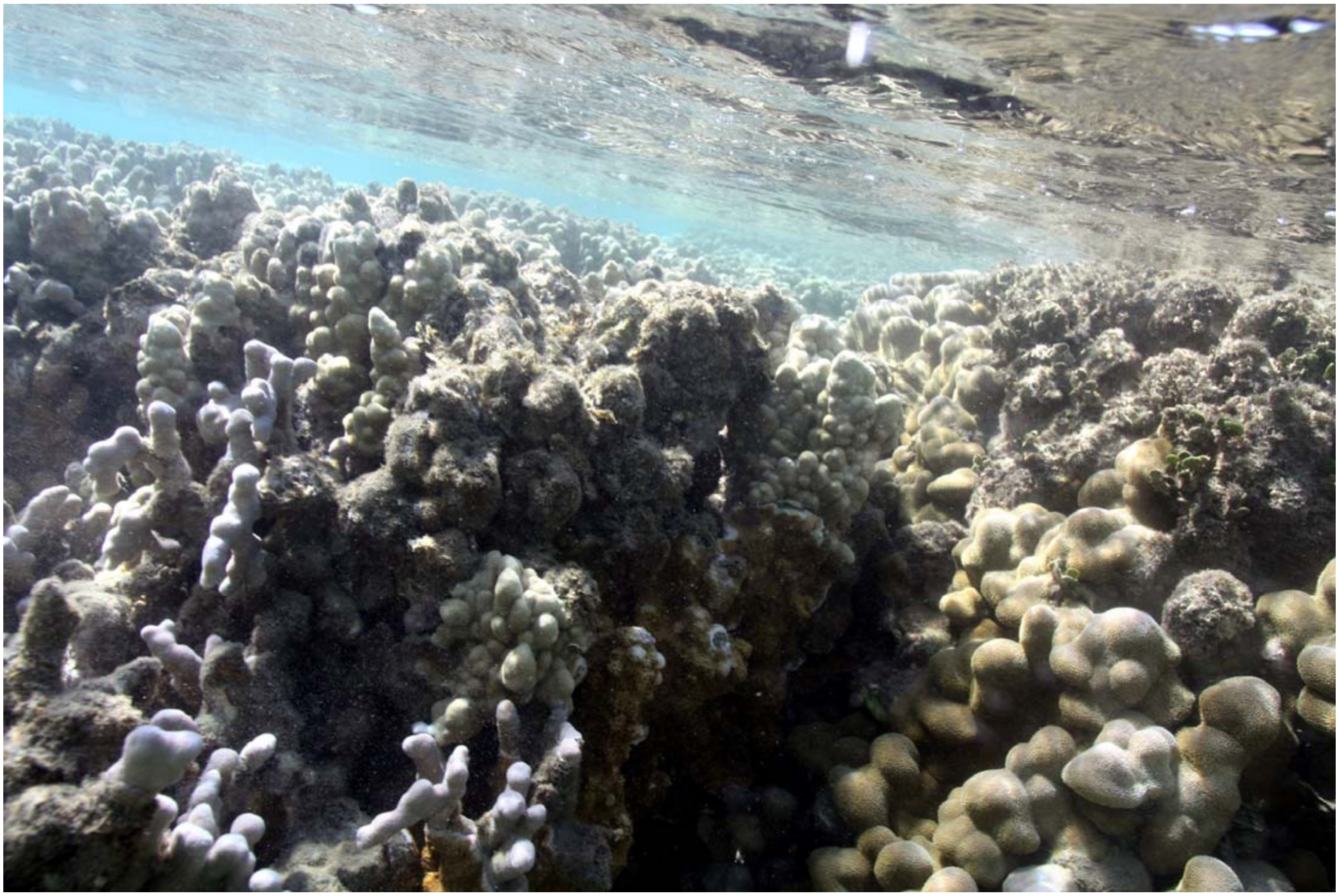


FIGURE 16. Two examples of coral growth to the surface of the water column on inner reef flat off Olowalu Point (Zone F in Figure 7). Predominant coral in both photos is *Porites compressa*.

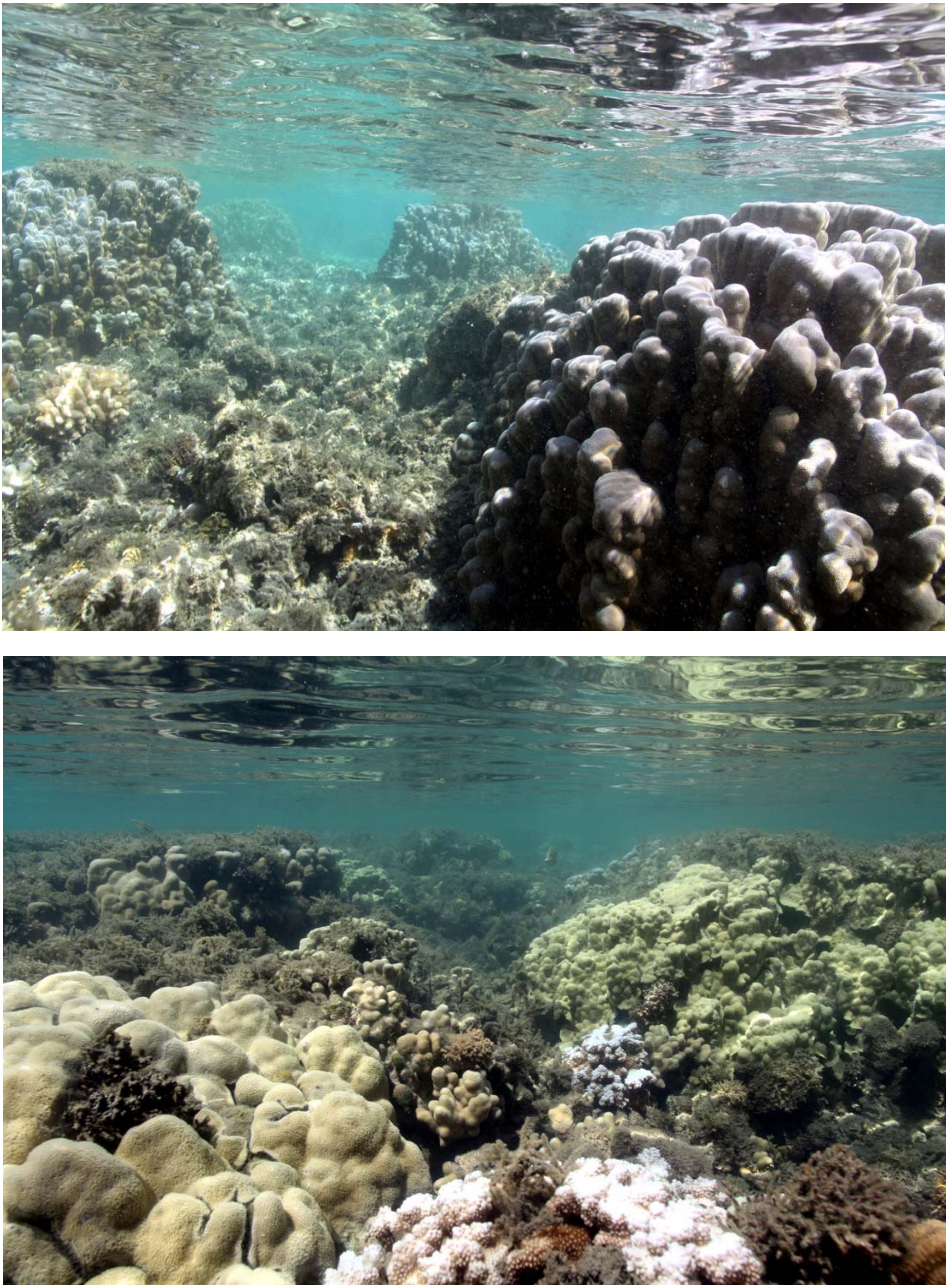


FIGURE 17. Two views of inner reef flat landward of reef crest off Olowalu Point. Predominant corals in both photos are *Porites lobata*.

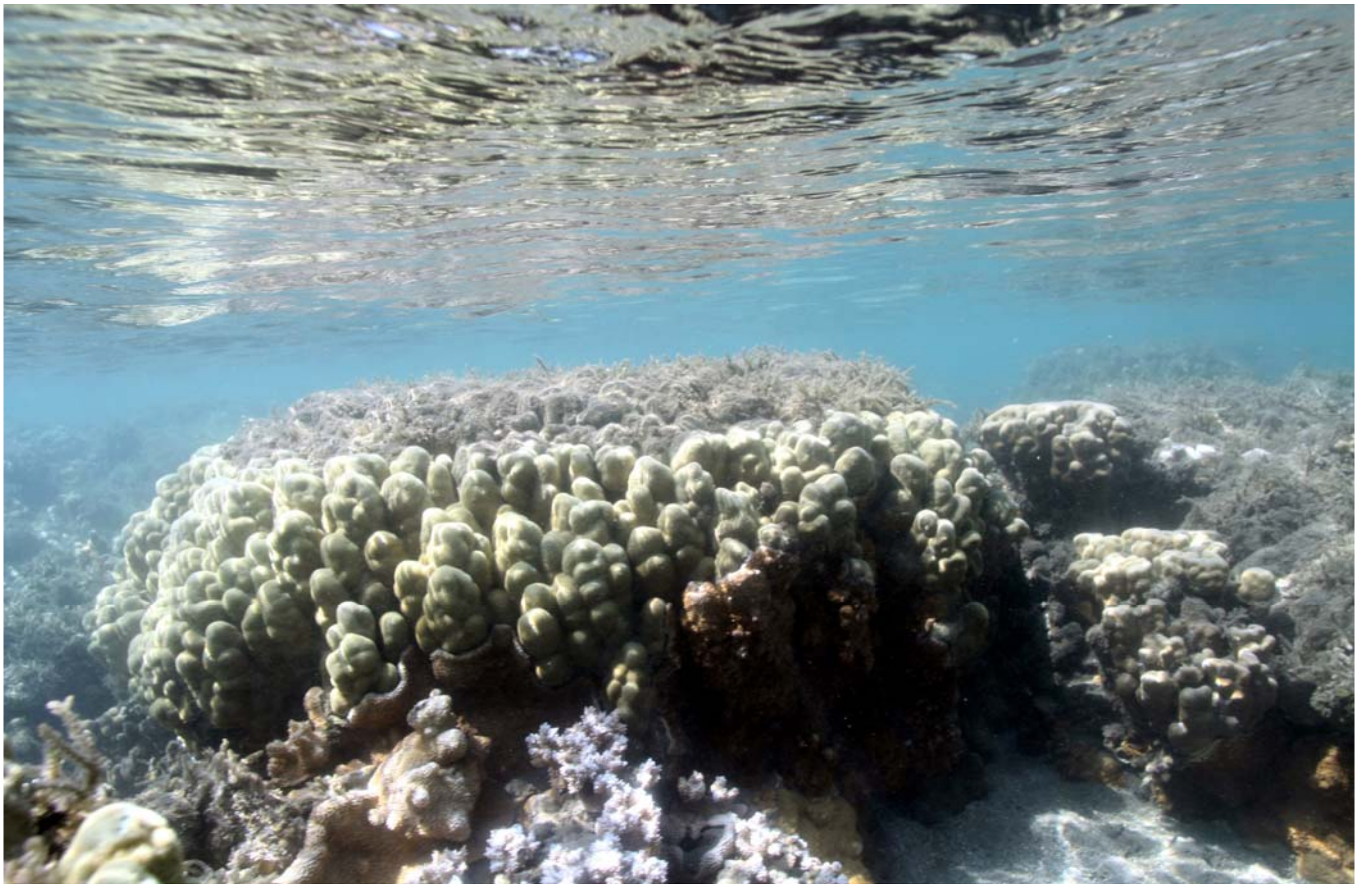
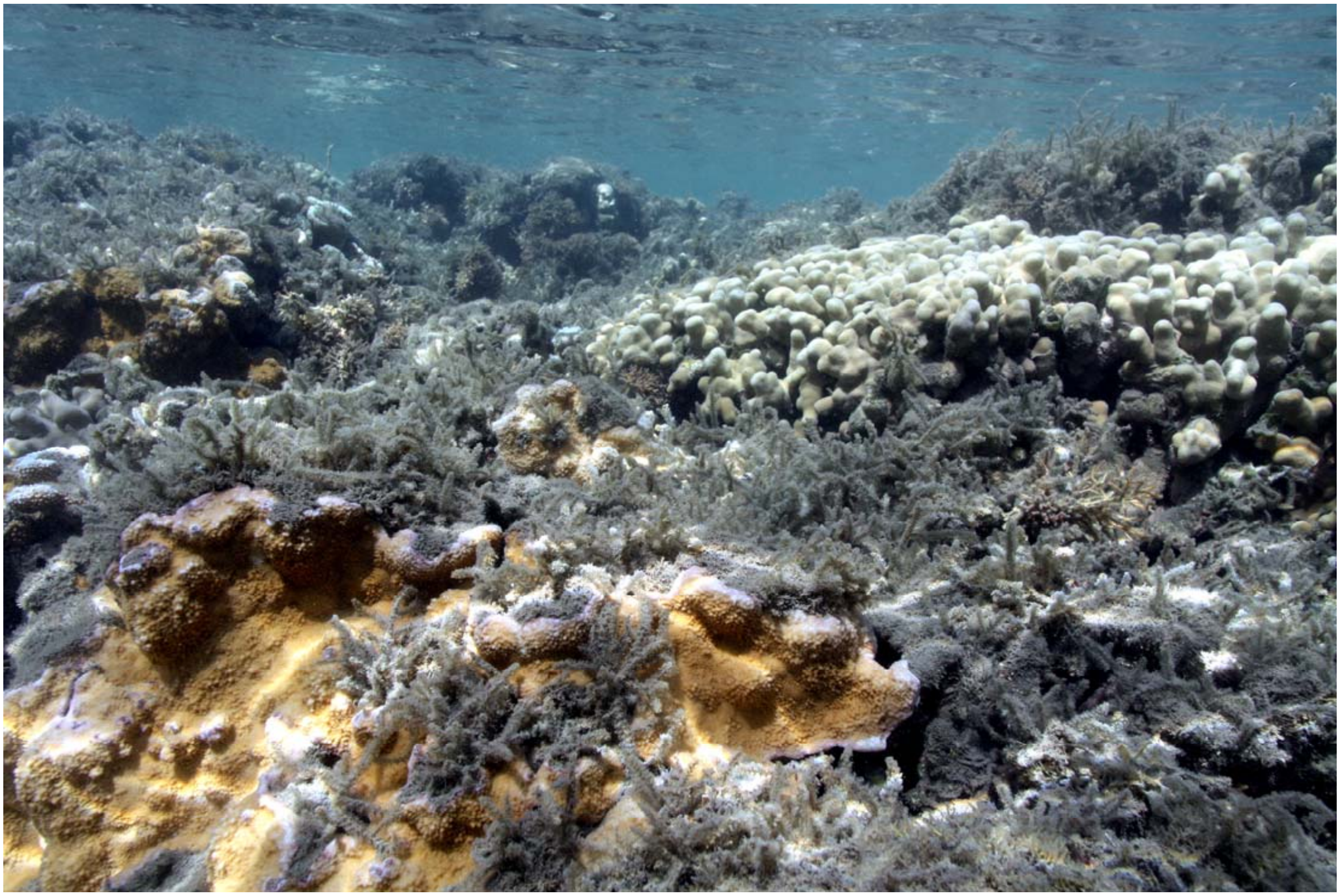


FIGURE 18. Two examples of "microatolls" on inner reef flat (Zone F in Figure 7) off southern side of Olowalu Point. Upward growth of colonies is limited by surface of water, resulting in lateral growth, thus increasing the diameter of the coral. Live coral cover on the upper surface is limited, and in most cases is replaced by the alien algae *Acanthophora specifera*.



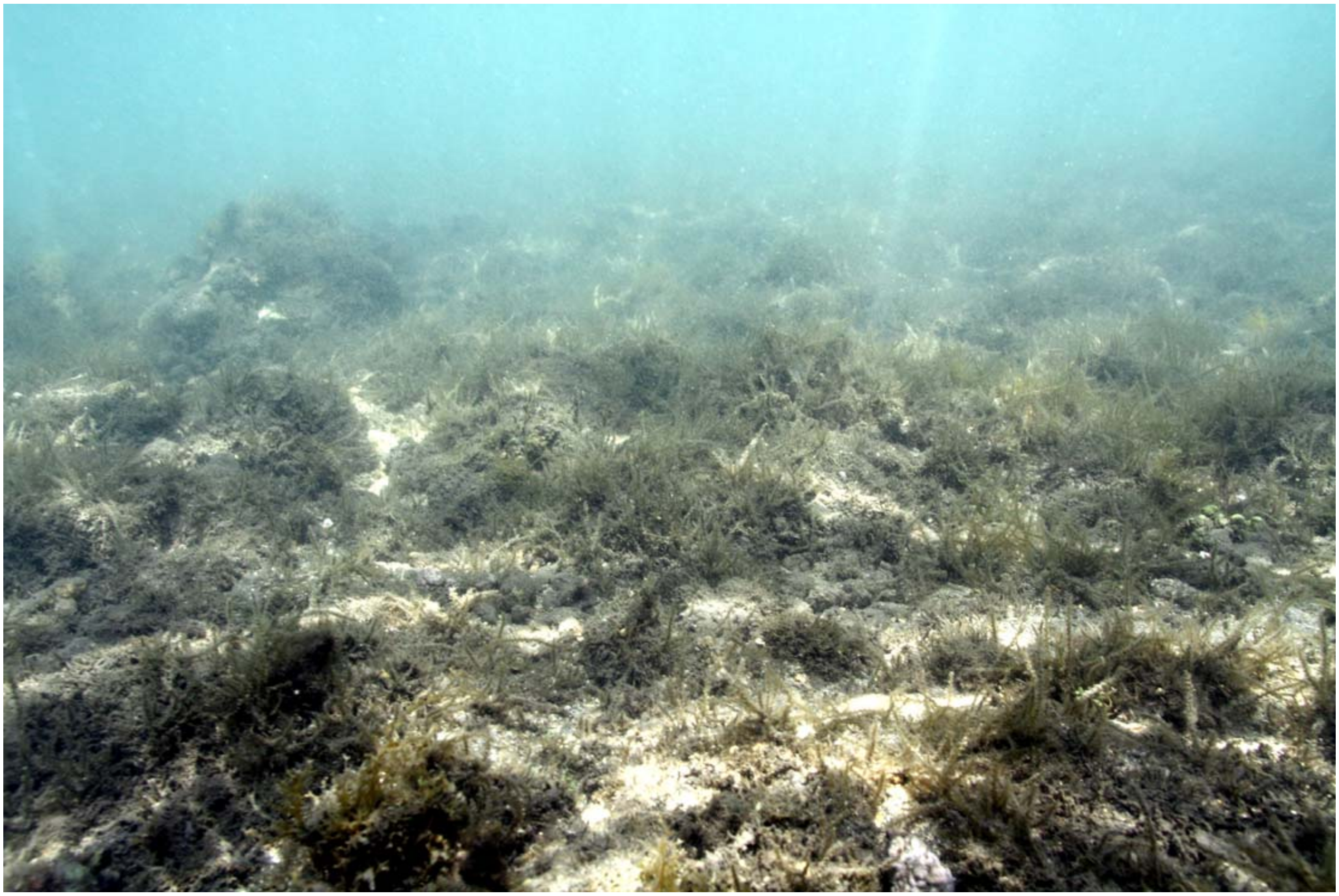


FIGURE 19. Patches of the invasive algae *Acanthophora specifera* covers much of the reef surface (top), as well sandy bottom (bottom) on the nearshore inner reef flat at Olowalu (Zone F in Figure 7).

FIGURE 20. Partially dead coral colonies covered with algal turf in southern region of the reef flat off Olowalu (Zone F in Figure 7).

FIGURE 21. Partially dead coral colonies covered with algal turf in southern region of the reef flat off Olowalu (Zone F in Figure 7).

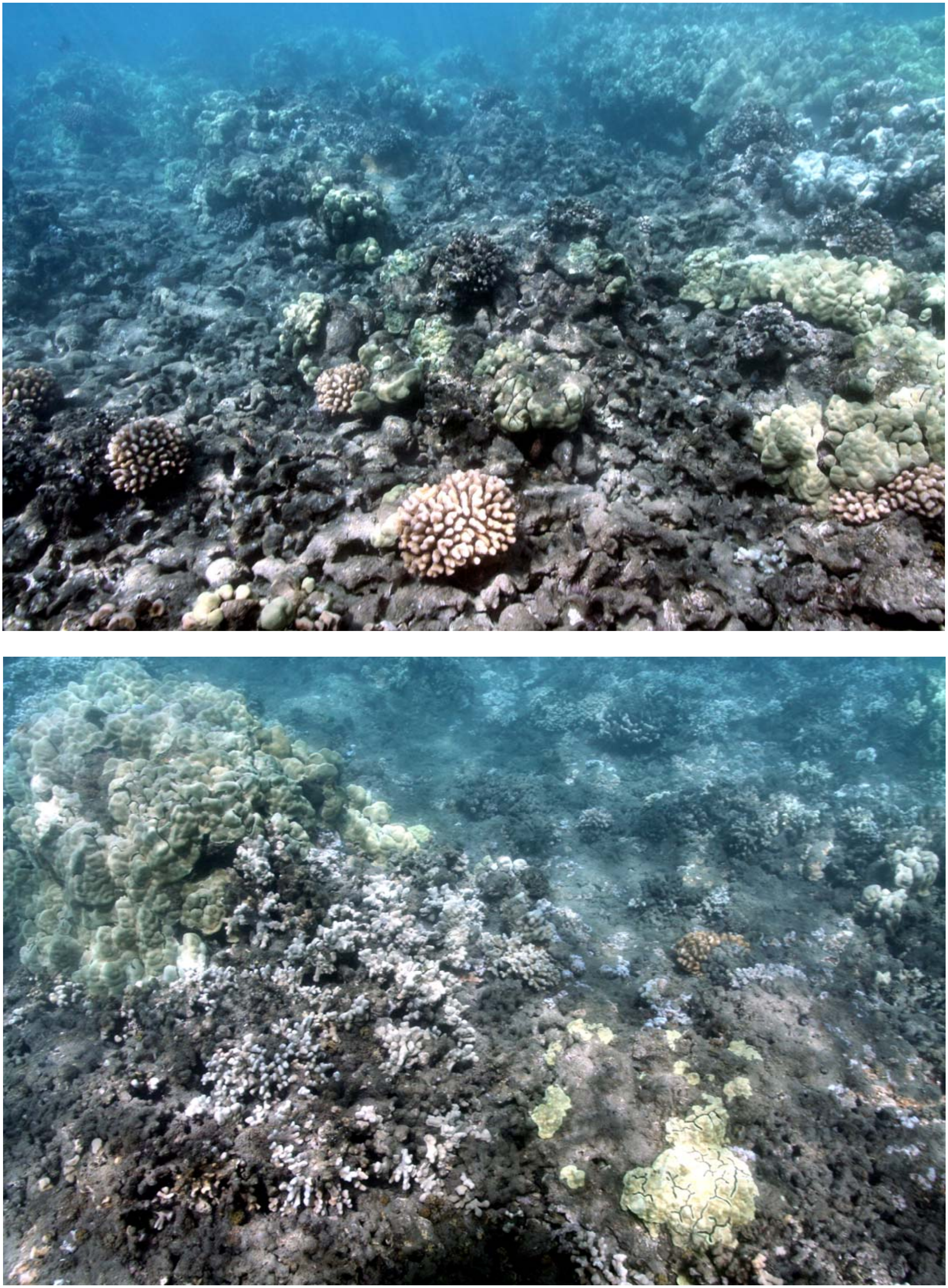


FIGURE 22. Two views of outer reef flat (Zone G in Figure 7). Coral cover is higher than on inner reef flat, although evidence of sediment effects are still visible.

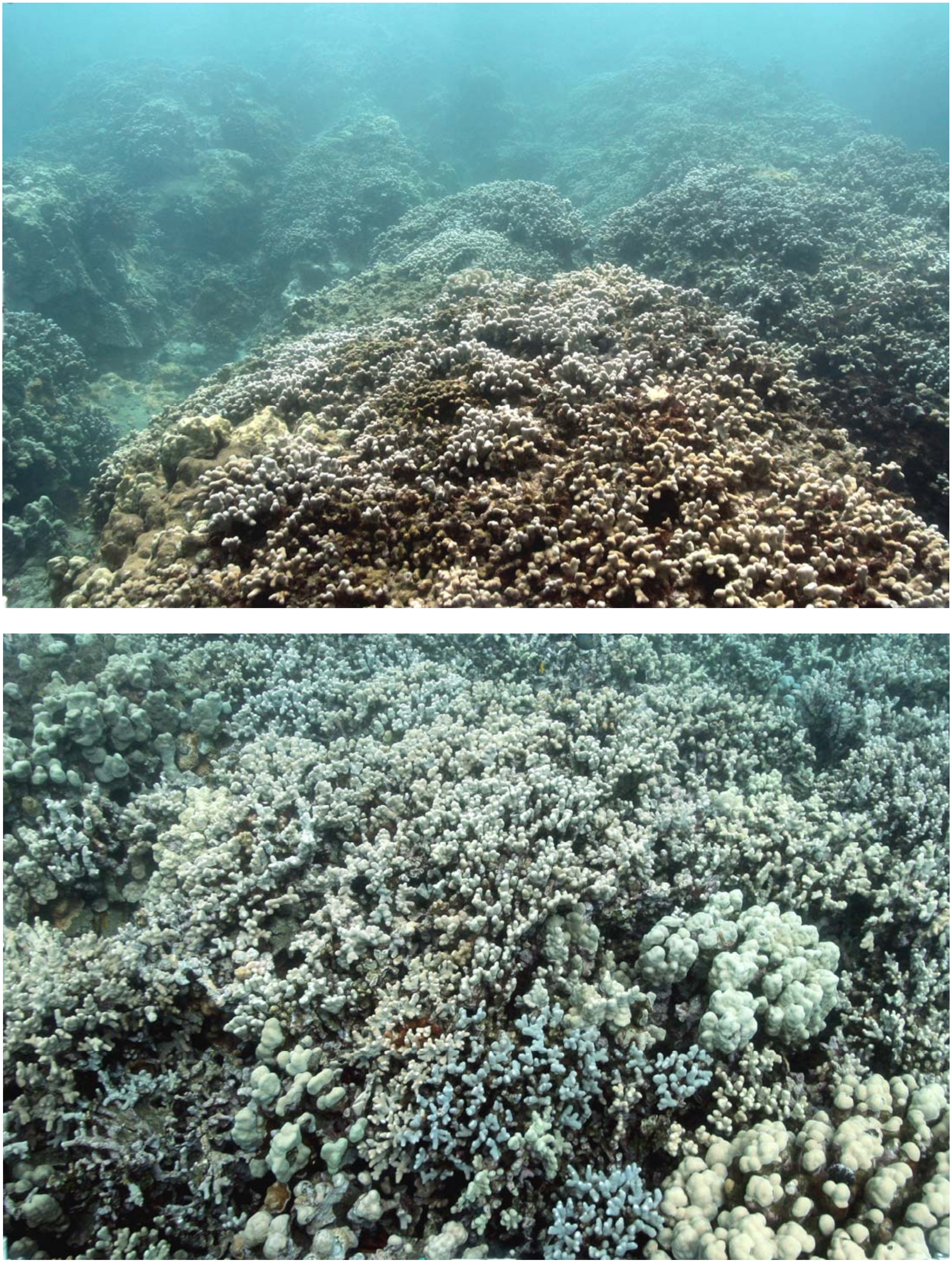


FIGURE 23. Expanses of interconnected mats of finger coral (*Porites compressa*) on the outer reef face at Olowalu (Zone H in Figure 7). Without disturbance from episodic wave stress, these colonies have amalgated over time to form true reefs in the sense that they are accreting limestone. Such accretion is relatively rare in exposed coastal areas of Hawaii.

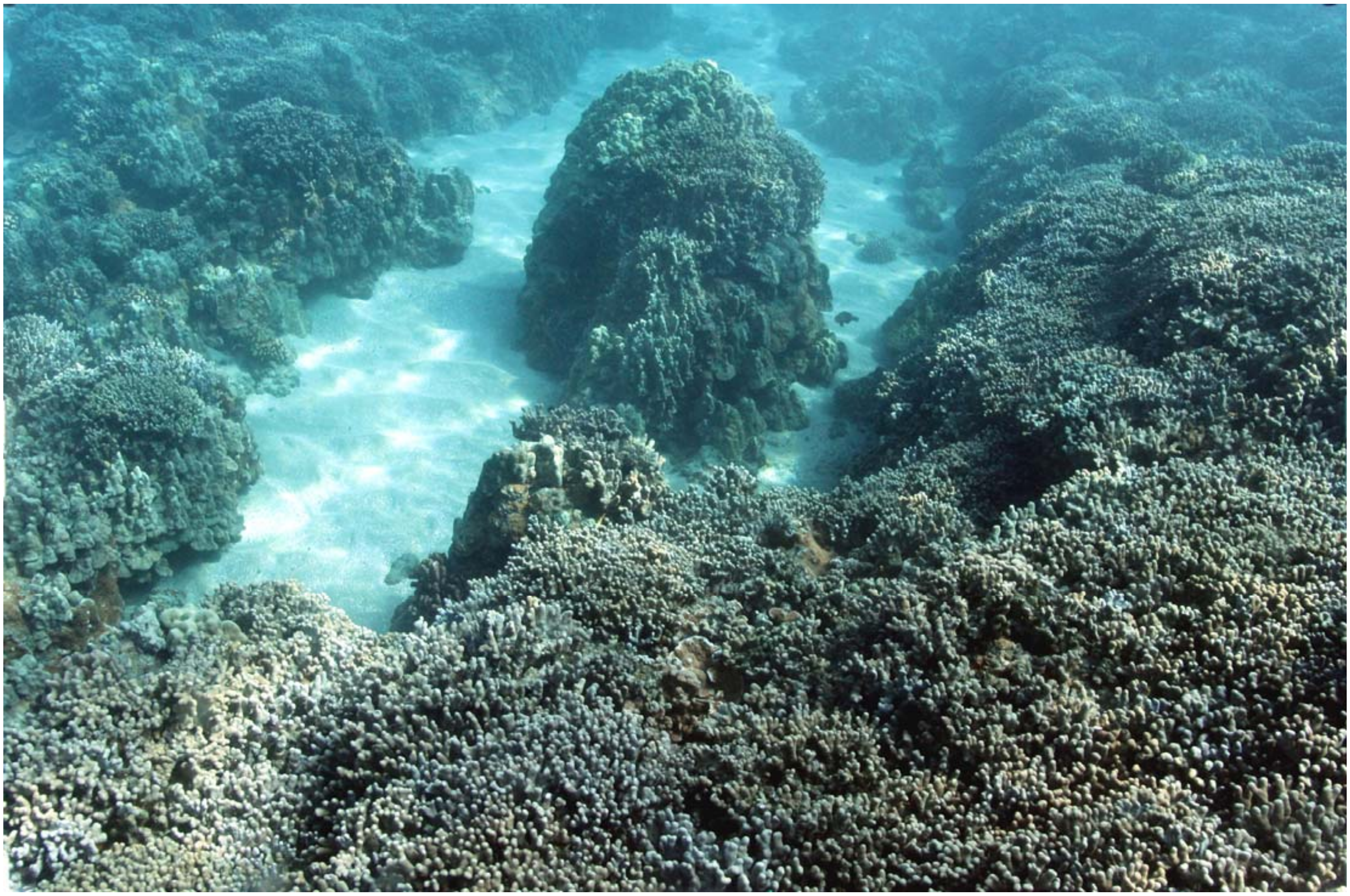


FIGURE 24. Two areas of expansive growth of interconnected mats of finger coral (*Porites compressa*) at the outer edge of the reef face off Olowalu Point (Zone H in Figure 7). The seaward edge of the reef in the top photo drops to a bed of sand that extends seaward.