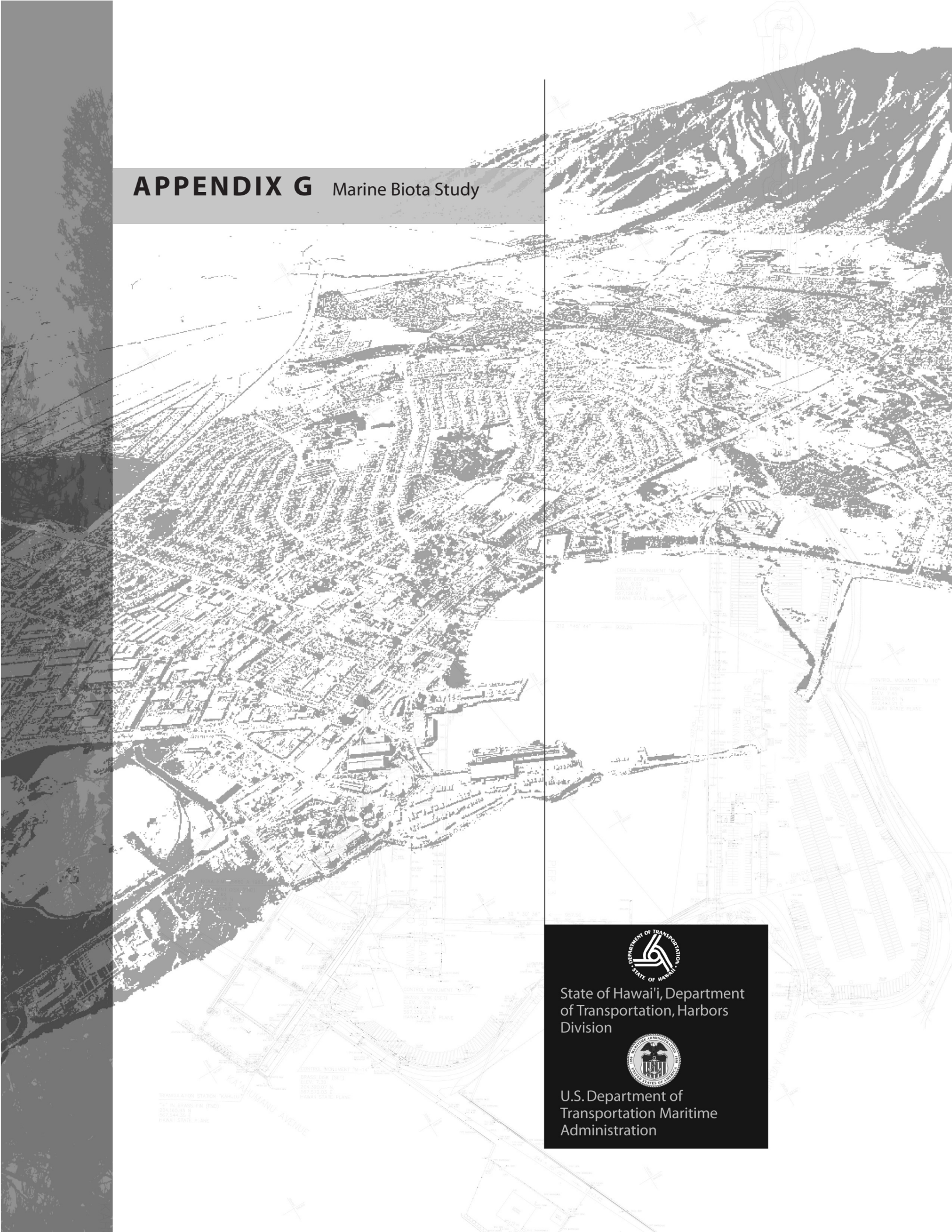
APPENDIX G Marine Biota Study



State of Hawai'i, Department of Transportation, Harbors Division

U.S. Department of Transportation Maritime Administration

RECONNAISANCE SURVEY OF THE MARINE ENVIRONMENT
KAULUI COMMERCIAL HARBOR, MAUI, HAWAII

CHARACTERIZATION OF BENTHIC HABITATS
ASSESSMENT OF IMPACTS FROM HARBOR EXPANSION

DRAFT

Prepared for:

Belt Collins Hawaii, Ltd.
2153 N. King St., Suite 200
Honolulu, HI 96819-4554

by:

Marine Research Consultants, Inc.
1039 Waakaua Pl.
Honolulu, HI 96822

June 2007

I. PURPOSE

The State of Hawaii Department of Transportation Harbors Division has developed plans for Kahului Commercial Harbor in furtherance of its mission , "to provide a safe, efficient, accessible, and inter-modal transportation system that ensures the mobility of people and goods, and enhances and/or preserves economic prosperity and the quality of life." As part of the 2030 Master Plan, several alternative plans have been developed to address future requirements for Kahului Commercial Harbor. Alternative A involves expansion of Piers 1, 2 and 4 for Cargo Operations and development of the Western Breakwater for Passenger Operations. Alternative B the western breakwater would be developed for cargo operations, and Pier 2 would accommodate the inter-island ferry and cruise ship operations. Under the "No Action Alternative" Piers 1, 2 and 3 would remain unchanged, while construction of a new Pier 4, which has already been approved, would proceed to provide additional berthing and facilities for bulk cargo, and fuels. A complete description of the scope of each proposed alternative is presented in the EISPN for Kahului Commercial Harbor Master Plan 2030.

One of the considerations for the proposed project is the effect on the marine communities that inhabit the area. To date, assessment of marine resources within, and immediately outside the Harbor have been limited to descriptive assessments of the area drawn primarily from the Maui Coastal Resource Inventory (1981). As an initial phase of the characterization of marine resources, the intent of this study is to create a benthic habitat map that characterizes the marine environment within, and immediately outside of Kahului Harbor, with particular emphasis on the regions that would most likely be affected by the proposed Alternative Actions A and B described above. The survey area encompassed approximately 1.8 million square meters [m^2] (443 acres). Of this total 867,000 m^2 (214 acres) was inside the Harbor, and 926,000 m^2 (229 acres) was outside the Harbor.

II. METHODS

"Mapping coral reef areas is the ***essential first step*** to management and can be done with a range of techniques" (emphasis added)(Hill and Wilkinson 2004). As such, the initial approach to assessment of the biotic communities within, and in the vicinity of Kahului Harbor, is development of a benthic habitat mapping scheme. It is important to note that as a first step, such habitat maps

are not meant to provide exhaustive comprehensive species lists, nor provide detailed quantitative data of small segments of the environment that would be the results of intensive survey methods that employ techniques such as quadrats and transects. If such data is required, it will be the target of future studies designed to address specific questions.

All methods utilized in this report follow standard procedures for processing coral reef remote sensing imagery (e.g., Andréfouët et al. 2003, Green et al. 2000, Mumby et al. 1998). A good discussion of the uses and techniques for mapping of coral reef habitats is presented in Hill and Wilkinson (2004). Mapping protocols similar to those employed in the present study have also been utilized by several federal agencies including the U.S. Geological Survey and U.S. National Park Service (e.g., Gibbs et al. 2007), as well as the NOAA National Center for Coastal Ocean Science, Biogeography Program, which has developed benthic habitat maps of portions of the Main Hawaiian Islands (however, these maps do not include the Kahului Harbor area).

The benthic habitat map was created based on commercially available satellite remote sensing imagery. A fully georeferenced IKONOS multispectral + panchromatic satellite image of Kahului Harbor was purchased from the Image Library at GeoEye Inc. (image data originally acquired April 9, 2002, at 1105). The image had 4 m (13 ft) ground sample distance in the spectral (color) bands and 1 m (3.2 ft) ground sample distance in the panchromatic band. The higher resolution panchromatic information was used to "sharpen" the color bands using the Gram-Schmidt Spectral Sharpening feature of ENVI (Environment for Visualizing Images, Research Systems, Inc.). The result is a set of color bands at 1 m ground sample distance. The IKONOS image was processed to highlight submerged features, which revealed areas of different bottom composition (Figure 1).

All fieldwork was carried on March 31, and May 11-12, 2007 by SCUBA divers working from an 8-m (26 ft) boat. Coral and macrobenthos abundance and substratum type were delineated using a method for ground truthing remote sensing data modified from Bainbridge and Reichelt (1988). In-water survey of the reef consisted of two steps. First, the entire area of the reef was qualitatively surveyed using a Manta tow method to determine broad-scale zonation and patterns in bottom cover. Surveys were conducted by divers traversing the reef using underwater propulsion vehicles, or by towing abreast of the boat.

In the second step, 68 individual survey points were chosen by the observers that best characterized the reef by geomorphological zone (structural composition), dominant bottom cover (both biotic and non-biotic), and water depth. The points were geo-located using a hand-held differential Garmin Model 72 GPS (reported accuracy 4-8 m (13-26 ft). Because of the capability to survey the entire subject area, survey points were not randomly selected. Rather, points were chosen to define boundaries between major habitats, as well as to identify multiple points of the same habitat at different depths. In this manner, it was assured that no gaps were left in the characterization of the reef. In addition, numerous underwater digital photographs of each reef habitat were taken and archived.

In the lab, survey points were located on the georeferenced satellite multispectral image which served as the basis for statistical image classification. "Training classes" (defined as the dominant 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. Because the same class could occur at different depths, the final classes could exhibit several different multispectral patterns. Thus, it was often necessary to merge several independent training classes to the same final class label. After the merging procedure, all training classes with the same spectral label were used to create the map showing the distribution of bottom cover over the reef (Figure 2).

III. RESULTS

A. General Physical Overview

Kahului Harbor is located on the south side of Kahului Bay on the north coast of the Island of Maui. The Harbor is fan-shaped; two rubble-mound breakwaters that angle toward the channel mouth form a semi-enclosed basin with an area of approximately 200 acres (0.8 km^2). The 600-foot (183 m) wide opening between the seaward ends of the breakwaters forms the channel entrance (Figure 1).

Figure 3, produced from USACE Hydrographic survey data and SHOALS LiDAR data, shows the bathymetric structure of the Harbor and surrounding area.

The eastern side of the Harbor is dredged to a depth of greater than 10 m (33 ft) and contains the commercial port facilities, while the western side of the Harbor consists primarily of a shallow, un-dredged reef platform less than 4 m (13 ft) in depth. A small boat channel has been dredged through the reef platform leading from the small boat launching ramp located at the westernmost corner of the Harbor. The shoreline of the inner Harbor is composed of sand and rubble beaches with several boulder groins.

The ocean floor in the Harbor channel, and the immediately surrounding areas, consists of sand. However, off the outer sides of both the east and west breakwaters, shallow reefs occur. While no depth contour data was available for reef area outside of the western breakwater, it can be seen in Figure 3 that the reefs off the eastern breakwater are relatively shallow at depths of approximately 4 m (13 ft). The areas evaluated in this report include the reefs immediately adjacent to the inner and outer faces of the east and west breakwater, as well as the Harbor basin.

B. Benthic Classification

1. Reef Zone Classification and Boundaries

Owing to the physical and biotic structure of Kahului Harbor, as well as the locations of the proposed alterations of separate areas of the Harbor under the various alternatives listed above, results are divided into five separate classes or zones. These classes are referred to as: 1. Outside East Breakwater; 2. Inside East Breakwater; 3. Outside West Breakwater; 4; Inside West Breakwater; and Harbor Basin (Figure 4).

a. Outside East Breakwater

The region outside the Harbor basin fronting the East Breakwater is an extremely diverse area in terms of both physical structure and biotic community assemblages. The seaward portion of the reef is characterized by substantial vertical relief, consisting of a series of narrow “finger reefs” that have nearly vertical sides and flat upper surfaces. The finger reefs are composed of accreted limestone from growth of corals and other calcifying organisms. These fingers are clearly visible in Figure 1at coordinates of approximately 20°54' N, 156°28'07". Coral cover on the steeply sloping sides of the fingers is uniformly close to 100%, composed exclusively of overlapping plates of various species of

the genus *Montipora* (Figure 5). The tops of the fingers are colonized with a variety of coral species which occur primarily in flat encrusting or plating growth forms including *Porites lobata, Montipora patula, M. flabellata, M. capitata*, as well as the sturdy branching coral *Pocillopora meandrina* (Figures 5 and 6). Also abundant on the tops of the finger reefs was the soft-bodied colonial zoanthid *Palythoa tuberculosa*. Total coral cover on the tops of the finger reefs was on the order of 25-50%. While calcareous encrusting algae was common on the finger reefs, fleshy macroalgae was relatively rare. Motile macro-invertebrates were limited to rarely occurring sea urchins *Echinothrix diadema* and the boring urchin *Echinometra mathaei*.

Inland from the finger reefs, the reef on the outside of the East Breakwater has less vertical relief with the absence of the vertical walls. Rather, the geomorphology of the reef is a raised limestone platform that is bisected by several large sand channels (Figures 1-3). Coral cover is less on the reef platform than on the more seaward zone, and is far patchier in occurrence. Dominant coral species were *Pocillopora meandrina* and *Montipora* spp. Scattered over the reef platform were large patches of short-fingered *Porites compressa*. The primary difference between the seaward finger reefs and the inner reef platform is the preponderance of fleshy macroalgae that occurred along with corals on the latter. The most noticeable alga was the fluorescent blue species *Martensia fragilis* which was very abundant throughout the area (Figure 7.) The most dominant alga was *Acanthophora specifera*, which covered large expanses of the reef surface (Figure 7). Other conspicuous algae were *Halymenia formosa* and *Amansia glomerata*. While these species were the most abundant and conspicuous, a multitude of other species were also observed over the reef platform. Total cover of macro-algae on the reef platform was on the order of at least 50%. With decreasing distance from shore, algal abundance increased and coral abundance decreased.

The most abundant motile macro-invertebrates were the sea cucumbers *Holothuria atra* and *Actinopyga mauritiana*. Sea urchins were conspicuously absent across the reef platform.

The reef platform outside the eastern breakwater contained the highest abundance and diversity of fish of any of the areas around Kahului Harbor, largely based on the greatest degree of habitat relief. As is typical on many Hawaiian reefs, the most common fishes were the damselfishes (*Chromis agilis*, *C. hanui, Abudefduf abdominalis*), as well as a variety of surgeonfishes

(*Acanthurus nigroris, A. nigrofuscans, A. olivaceus, Naso lituratus*) and *butterflyfishes Chaetodon miliaris, C. multicinctus, C. quadrimaculatus,* and *C. auriga)*. Hawkfishes *(Parracirrhites arcatus, P. forsteri,* and *Cirrhitops fasciatus)* were common sitting on the upper branch tips of colonies of Pocilloporid corals. Common wrasses *included Bodianus bilunulatus* and *Thallosoma duperrey*. Numerous squirrelfish *(Myripristes spp.)* were observed under ledges cut in the reef platform. Several small jacks (*Caranx melampygus*) were observed swimming between the reef top and the channels between the reef fingers. On the sand flats that bisected the reef platform, the blue-lined snapper (*Lutjanus kasmira*) as well as several goatfishes (*Mulloidichthys* spp.) were observed.

In general, the marine habitats on the outside of the Eastern Breakwater were remarkable in the diversity of physical structure and biotic composition.

b. Outside West Breakwater

The reef habitats outside of the west breakwater are substantially different than off the east breakwater. Most of the bottom cover off the east breakwater consists of sand, with the exception of an area of raised hard-bottom that is visible in Figure 1 at coordinates of approximately 20°54'05"N and 156°28'35"W. Benthic cover of the platform consist almost exclusively of the soft bodied zooanthids *Palythoa* spp. and *Zooanthus* spp. (Figure 8). While these "soft corals" are very abundant in the area comprising up to 90% of bottom cover, stony corals comprised 5-10% of bottom cover, consisting primarily of the species *Porites lobata, Pocillopora meandrina, Montipora patula* and *M. capitata*. The dominant algae in the area were various encrusting red calcareous species including *Pneophyllum* sp., and *Hydrolithon* spp.

As off the outer eastern breakwater, macro-invertebrates were very sparse in the area, limited to rarely occurring *Echinometra mathaei*.

c. Inside East Breakwater

The East Breakwater seaward of Pier 1 is constructed of tubular concrete "dolos" that extend from to the sand/mud floor of the Harbor basin. These submerged concrete structures are designed to provide a maximum amount of surface area, and as a result provide an ideal habitat for settlement of coral inside the wave-sheltered Harbor. In addition, the spaces created in between the concrete structures provides sheltered habitat for fish and invertebrates (e.g. spiny

lobsters *Panulirus* spp.). The dominant coral colonizing the concrete structure is *Montipora capitata*, which is well-adapted to colonize the concrete pillars as flat overlapping plates (Figure 9). As is often observed in other Hawaiian settings, *Montipora capitata* is a very sediment-tolerant species, and many of the colonies on the concrete structures inside the Harbor were partially covered by a coating of fine-grained sediment (Figure 9). Other corals that were observed include small colonies of *Pocillopora meandrina, as well as colonies of Porites lobata and P. compressa*. While present, these species comprised only a minor component of the coral community that consisted primarily of *Montipora*. Frondose macroalgae were rare along the inner eastern breakwater, limited to several large *Halymenia formosa* attached to the concrete structures. Sea urchins were not observed on the concrete structures.

The most abundant fish species included a variety of squirrelfishes (Holocentridae) in the interstitial spaces created by the dolos. Small jacks (*Caranx melampygus*) and a variety of surgeonfish (Acanthuridae) were also observed, as was a single sailfin tang (*Zebrasoma veliferum*).

d. Inside West Breakwater

The western breakwater is composed of basaltic boulders that extend to the shallow, un-dredged Harbor floor. Within the intertidal range, the boulders are covered with calcareous encrusting algae as well as the patches of the red alga *Hypnea* sp. and the green alga *Chaetomorpha antennina* (Figure 10). Contrary to the inner western breakwater, where man-made structures are nearly completely colonized by coral, the submerged boulder surfaces on the inner side of the western breakwater are relatively barren. The predominant colonizers are isolated heads of the hemispherical branching coral *Pocillopora damicornis* and *P. meandrina*, small plates of *Montipora* spp., as well as soft zooanthids *Palythoa* and *Zooanthus* (Figure 10). Sea urchins, particularly *Echinothrix diadema* and *Tripneustes gratilla* were common on the boulder surfaces of the inner western breakwater (Figure 10).

e. Harbor Basin

The Harbor basin, extending from the entrance channel between the ends of the east and west breakwaters to the shoreline is comprised of a variety of habitats. Most of the Harbor floor that has been previously dredged is composed of sand or mud. Bottom areas close to the western breakwater consisted primarily of

coarse sands with substantial shell fragments, while most of the central Harbor floor and eastern basin between Piers 1 and 2 were muddy sands containing numerous burrows from benthic infauna (likely a varied community including crabs, shrimps and worms) (Figure 11).

A section of the inner Harbor basin that extends from approximately the midway point of the fill area comprising the western shoreline of the Harbor basin to the innermost part of Harbor of Hoaloha Beach does not appear to have been extensively dredged in the past. As a result, the substratum is predominantly hard bottom consisting of a limestone reef platform. The most prevalent biota on the reef are the soft zooanthids *Palythoa* and *Zooanthus*, which constitute near complete bottom cover over large areas (Figure 12). On sections of the reef platform with steep vertical relief, overlapping plates of *Montipora capitata* are prevalent (Figure 13). Other corals occurring on the reef platform were *Pocillopora meandrina, P. damicornis*, and occasional large heads of *Pavona duerdeni* (Figure 13). Also common on the reef platform were a variety of macroinvertebrates including the urchins *Echinothrix diadema* and *Tripnestes gratilla*, the sea cucumbers *Holothuria atra* and *Actinopyga mauritiana*. Numerous "feather-duster" sabellid worms were also observed across the reef face, particularly in areas covered with zooanthids.

The dominant alga in the inner Harbor basin was *Bryopsis hypnoides*, which occurred as green tuft-like plants throughout the area. Fish were rarely observed within the inner Harbor basin during the current study, also the species *Mugil cephalus, Selar crumenophthalmus Decapterus macarellus, Acanthurus triostegus, Etrumeus micropus, Kuhlia sandvicensis, Caranx ignobilis* and *Chanos chanos* have been reported as common within the Harbor (Ziemann 2003).

C. Benthic Habitat Map

Figure 2 shows the benthic habitat map produced by the supervised classification scheme described above. Spectral resolution of the image allowed for distinction of four bottom classifications dominated by biotic cover, including dense coral (>50% bottom cover); moderate coral cover (20-50% bottom cover); dense macroalgae (>50% bottom cover), and moderate macroalgae (20-50% bottom cover). Two additional abiotic bottom cover classes were also mapped, which included pavement (hard bottom) and soft sediment (sand and mud).

Examination of the habitat map reveals several important points. First, while there are gradations between zones, in general the reef zonation pattern is fairly distinct, and allows good distinction of dominant biotic assemblages throughout the area of interest. A second aspect that is apparent is that while Kahului Harbor is "man-made" the habitats inside and directly outside the Harbor structures are comprised of healthy and diverse reef communities. Other than the dredged portions of the Harbor basin were there areas that it was evident that the Harbor structures had resulted in any impairment or damage to reef community structure. Rather, structures that formed the Harbor breakwater provided ideal substrata for settlement of corals.

Table 1 shows results of classification of the reef in terms of area coverage of each reef zone and bottom type of the area surveyed within and outside of the Harbor Basin. Of the total 1,793,360 m^2 (442 acres) surveyed, about 48% (867,328 m^2 [214 acres]) was inside the Harbor, while 52% (926,032 m^2 [229 acres]) was outside the Harbor. Soft sediment comprised the highest percentage of habitat cover overall (58%), as well as both inside (69%) and outside (47%) the Harbor. Coral cover greater than 20% accounted for a total of about 22% of total area coverage, and 16% inside the Harbor, and 27% outside the Harbor. About 12% of the entire survey area was covered with algae that comprised more than 20% bottom cover, while 6% of the Harbor basin and 18% of the outer reefs had algal cover of at least this amount

D. Protected and Endangered Species

The only protected or endangered species encountered during fieldwork was the green sea turtle *(Chelonia mydas*). Several turtles were observed swimming near the reef surface outside of the eastern breakwater of Kahului Harbor. Green sea turtles have become increasingly common since attaining federal protection status in the 1970's and are routinely observed throughout Hawaiian nearshore waters. Other protected and endangered species that might occur in the area are marine mammals, particularly the Humpback Whale (*Megaptera novaeangliae*) and Hawaiian Monk Seal (*Monachus schauinslandi*). While neither of these species is known to frequent Kahului Harbor, it is possible that they could occur in the immediate area.

SUMMARY and CONCLUSIONS

Comprehensive field surveys of the marine habitats inside and directly outside of Kahului Harbor in the vicinity of areas of proposed expansion of Harbor Facilities were carried out in early 2007. Results of the surveys provided ground-truth data to produce a benthic habitat map of the area utilizing the multispectral properties of available satellite remote sensing imagery. The map provides an accurate large-scale classification of benthic habitats. The extent of major bottom covers, particularly coral reef community resources, are delineated to a degree that can be of value for both evaluation of potential impacts and potential mitigation of reef area altered by modification of Kahului Harbor. Should future remote sensing data become available, particularly low altitude hyperspectral imagery, a second generation of map products with higher resolution could be created to enhance the existing product.

Results of field surveys indicate that while soft sediment (mud and sand) comprise the highest single class of bottom cover, extensive coral reef resources exist both inside and outside the Harbor. The richest and most diverse coral communities occur outside of the east breakwater where the physical habitat consists of a fossil reef platform with areas of substantial vertical relief. Inside of the eastern breakwater, coral growth covers large portions of the concrete structures that form the breakwater. Both outside the western breakwater, and on the un-dredged reef flat inside the western sector of the Harbor, bottom cover is dominated by soft-bodied zooanthids. Such zooanthid reefs are relatively uncommon in other reef areas of Hawaii.

Expansion Alternative A would include development of the West Breakwater, dredging of the existing basin to widen by approximately 800 feet, extension of the inner west breakwater and an extension of the eastern breakwater. In addition, Pier 1 would be lengthened from the existing 1,760 feet to 2,400 feet, and Pier 2 would be lengthened from 870 to 1,200 feet. Expansion Alternative B would include similar breakwater extensions and basin enlargement dredging as Alternative A. However, Alternative B does not include the elongation of Pier 1 that is part of Alternative A. The No Action Alternative would include the same extension of Pier 1 as in Alternative A.

With respect to benthic habitats, expansion alternatives will include both "direct" effects, which are defined as physical removal of the physical habitat by dredging or build-over, and "indirect" effects which include impacts brought about by changes in physical or chemical changes of the water column as a result of construction activities (e.g. changes caused by excessive dredge-induced sedimentation). Direct effects of Expansion Alternative A would include loss of most of the existing coral growing on the dolos on the inner side of the east breakwater, and most of the shallow reef habitat that presently occurs on the shallow un-dredged reef on the inner west side of the Harbor. Construction of extensions of both the east and west breakwaters would have minimal direct effects to hard bottom communities at either location, as the underlying habitats are soft sediment. Similarly, expansion activities in the inner eastern Harbor in the area of Piers 2, 3, and 4 would have minimal direct effects as the entire area is characterized by soft bottom. Alternative B would have the same direct effects on the western side of the Harbor in the proposed dredge area. However, as there would be no changes to the existing structure of Pier 1, the present coral communities on the existing concrete structures would not be affected. The No Action alternative would have the same direct effect of loss of the existing corals on the dolos on the inner side of the East Breakwater as with Alternative A.

Indirect effects to marine communities are more difficult to estimate than direct effects owing to uncertainties of the magnitude of alteration of the water column from the construction activities, as well as the physiological resilience of the existing communities. More exact estimates of sedimentation arising from the construction activities would probably require modeling of the sediment plumes and deposition rates, which goes beyond the scope of the present report. However, periodic high loads of resuspended sediment frequently occur as a result of maneuvering of large ships in the Harbor. As a result, the existing Harbor communities are pre-adapted to sediment stress, and may not be affected further by similar loads created during construction activities. In addition, if sediment plumes did exit the Harbor through the entrance channel, it is likely that such plumes would be sufficiently dispersed by waves and currents before they could reach the areas with substantial reef structure.

In summary, all three proposed Alternatives for expansion of Kahului Harbor will result in removal of some existing reef communities. The most extensive loss will occur under Alternatives A and B to the communities on the shallow reef flat in the western sector of the Harbor as a result of dredging to expand the size of

the navigable basin. Loss of much of the existing corals that have colonized the concrete structures forming the East Breakwater will also occur under Alternative A and the No Action Alternative. Reef communities within the Harbor likely experience regular episodes of high sediment as a result of ship activities, and as a result benthic communities are largely pre-adapted to any temporary sedimentation that might result from dredging. It is also unlikely that reefs outside the Harbor will be affected by the proposed expansion as they are not within the construction footprints, and sediments exiting the Harbor would be dispersed by prevailing oceanographic condition to levels that would not exceed the natural envelop of variability. The most likely potential effects to protected and endangered species would occur if sea turtles entered the Harbor during construction activities. Under such circumstances, Best Management Practices would be in place to halt construction activities until turtles have left the area.

References Cited

AECOS, Inc. 1981. Maui Coastal Resource Inventory. Prepared for U.S. Army corps of Engineers. Pacific Ocean Division, Fort Shafter, HI. 552 pp.

Andréfouët S., P. Kramer, D. Torres-Pulliza, K.E. Joyce, E.J. Hochberg, R. Garza-Perez, P.J. Mumby, B. Riegl, H. Yamano, W.H. White, M. Zubia, J.C. Brock, S.R. Phinn, A. Naseer, B.G. Hatcher and F.E. Muller-Karger. 2003. Multi-site evaluation of IKONOS data for classification of tropical coral reef environments. Remote Sensing of the Environment 88: 128-143.

Bainbridge, S. J. and R. E. Reicheldt. 1988. An assessment of ground truth methods for coral reef remote sensing data. 6th International Coral Reef Symposium. Townsville Australia. P. 439-444.

Gibbs, A.E., S. A. Cochran, J. B. Logan, and E. E. Grossman. 2007. Benthic habitats and offshore geological resources of Kaloko-Honokohau National Historical park, Hawaii. U.S. Geological Survey Scientific Investigations Report 2006-5256, 62 p.

Green E.P., P.J. Mumby, A.J. Edwards and C.D. Clark. 2000. Remote Sensing Handbook for Tropical Coastal Management. UNESCO, Paris. 316 p.

Hill, J. and C. Wilkinson. 2004. Methods for ecological monitoring of coral reefs. Version 1. Aust. Inst. Mar. Sci. Townsville Australia. 123 p.

Mumby, P. J., E. P. Green, C.D.Clark and A.J. Edwards. 1998. Digital analysis of multispectral airborne imagery of coral reefs. Coral Reefs 17: 59-69

Ziemann, D. A. 2003. Kahului Commercial Harbor 2025 Master Plan Environmental Assessment; Water Quality, Marine Biological and Natural Resources Impacts Assessment. Prepared for: E.K. Noda and Associates. Honolulu HI.

FIGURE 1. Georeferenced Ikonos satellite image of Kahului Harbor. Reef structure is clearly visible as dark colored areas, while sand and mud appears as blue area.

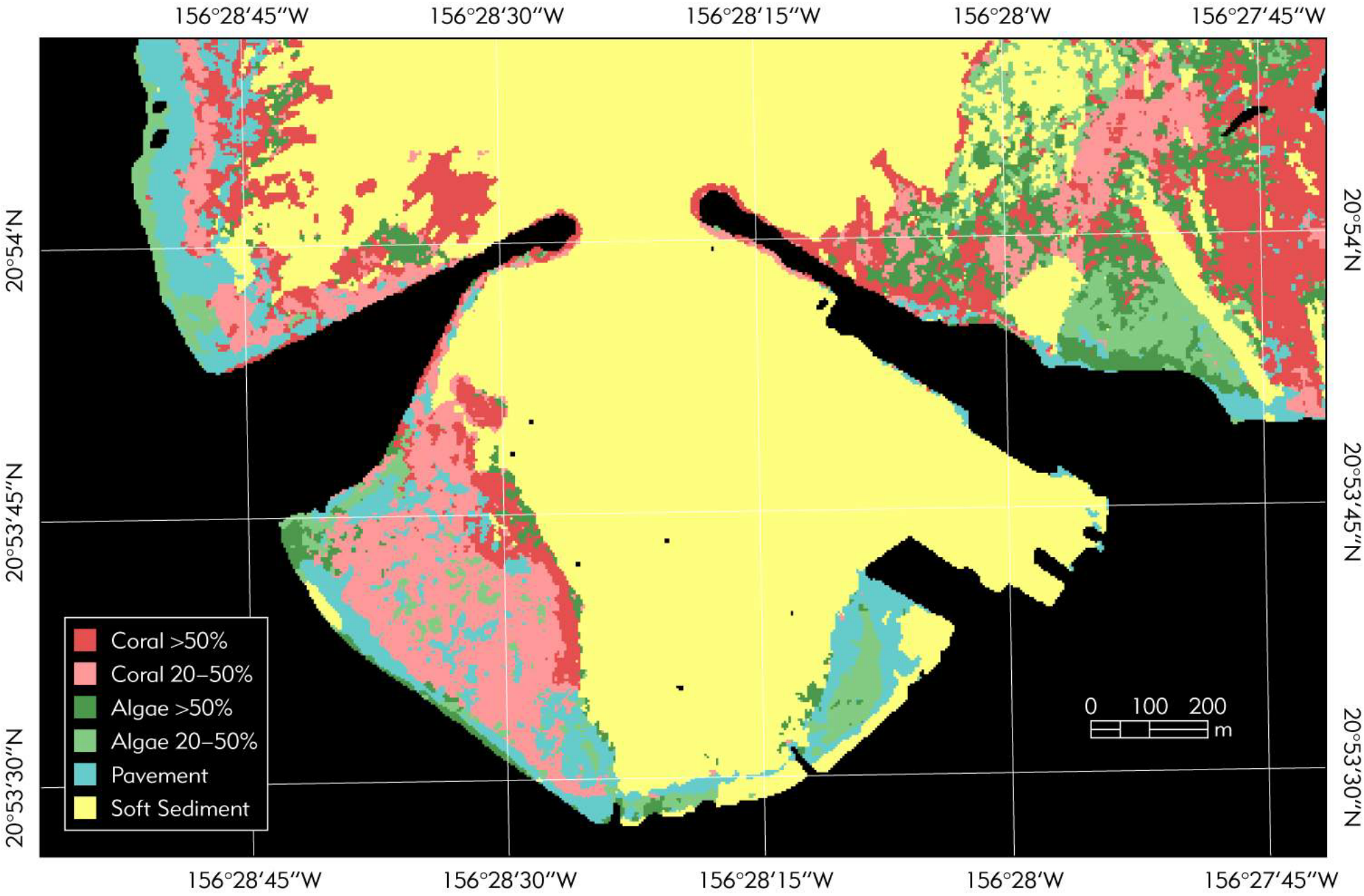


FIGURE 2. Georeferenced benthic habitat map of Kahului Harbor showing regions where coral or benthic algal cover are greater than 50% or between 20% and 50%. Soft sediment is defined as either sand or mud. Map was created using multispectral images from Ikonos satellite image shown in Figure 1 acquired on April 9, 2002. See Table 1 for area coverage of each component of habitat classification.

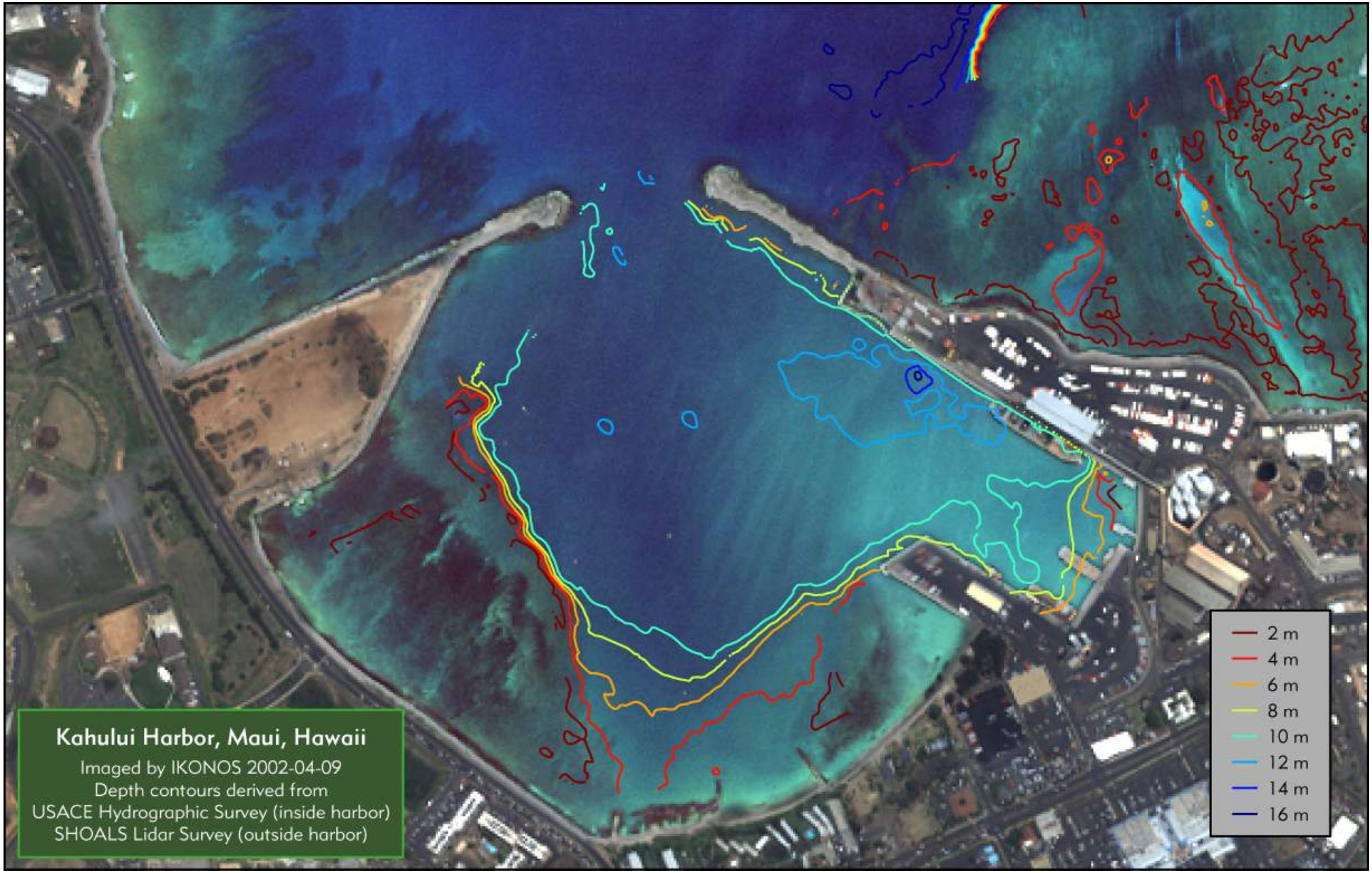


FIGURE 3. Depth contours within Kahului Harbor showing extent of dredged inner harbor basin and shallow reef platform on eastern side of harbor. Depth contouring data was not available for area off the inner and outer western breakwater.

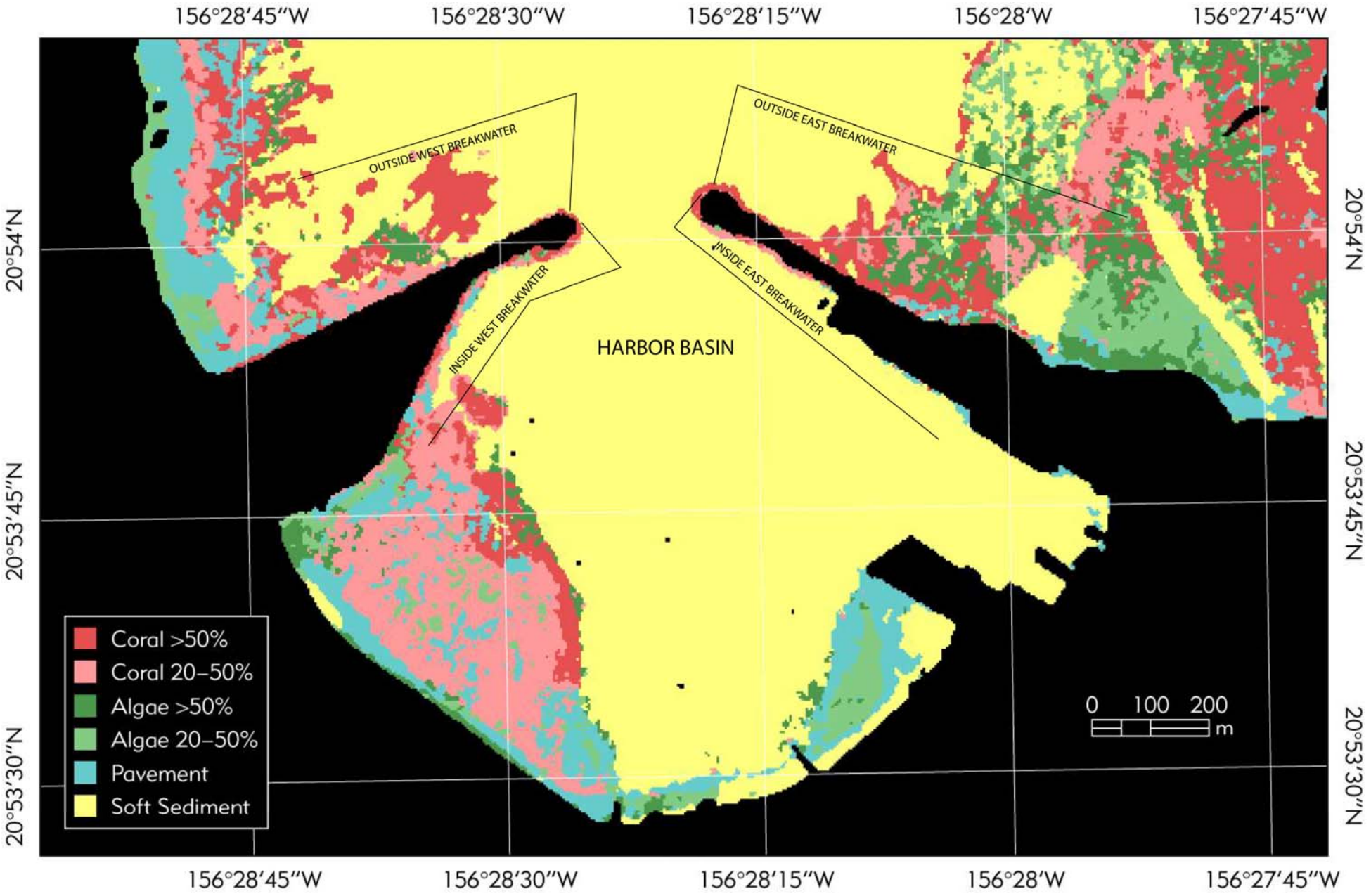


FIGURE 4. Benthic habitat map of Kahului Harbor showing delineation of sectors discussed in text.

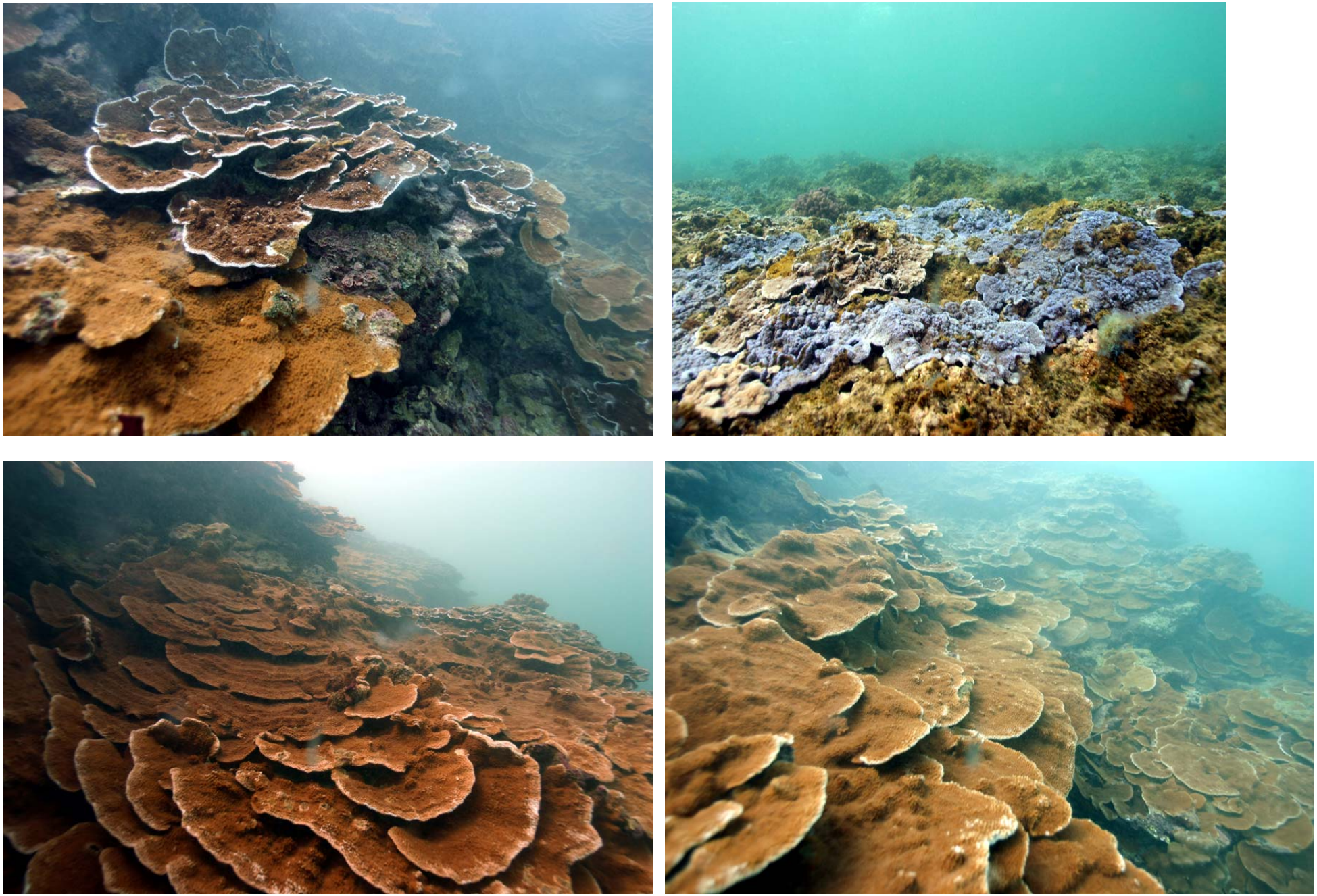


FIGURE 5. Various species and growth forms of the coral genus *Montipora* on finger reefs outside of the east breakwater of Kahului Harbor. The overlapping plating growth forms are *M. patula* and *M. capitata*, which effectively cover the entire sloping edges of the finger reefs. The blue encrusting coral in the photo at upper right is *M. flabellata*. Water depth in all photos is 6-8 m.

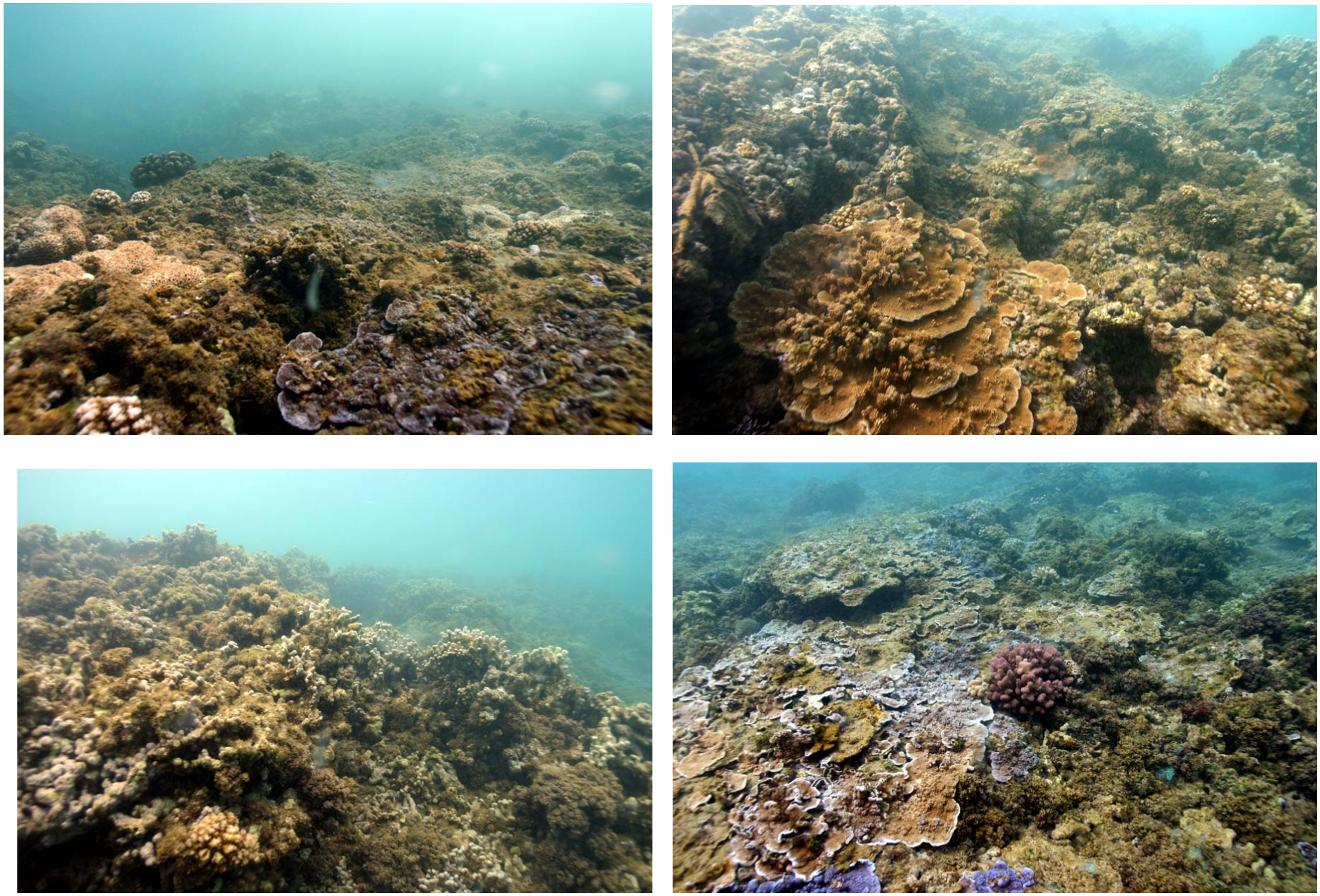


FIGURE 6. Upper surfaces of reef platform outside of east breakwater of Kahului Harbor. A variety of encrusting species of corals provide near complete coverage of reef surface. Water depth in all photos is 8-10 m.

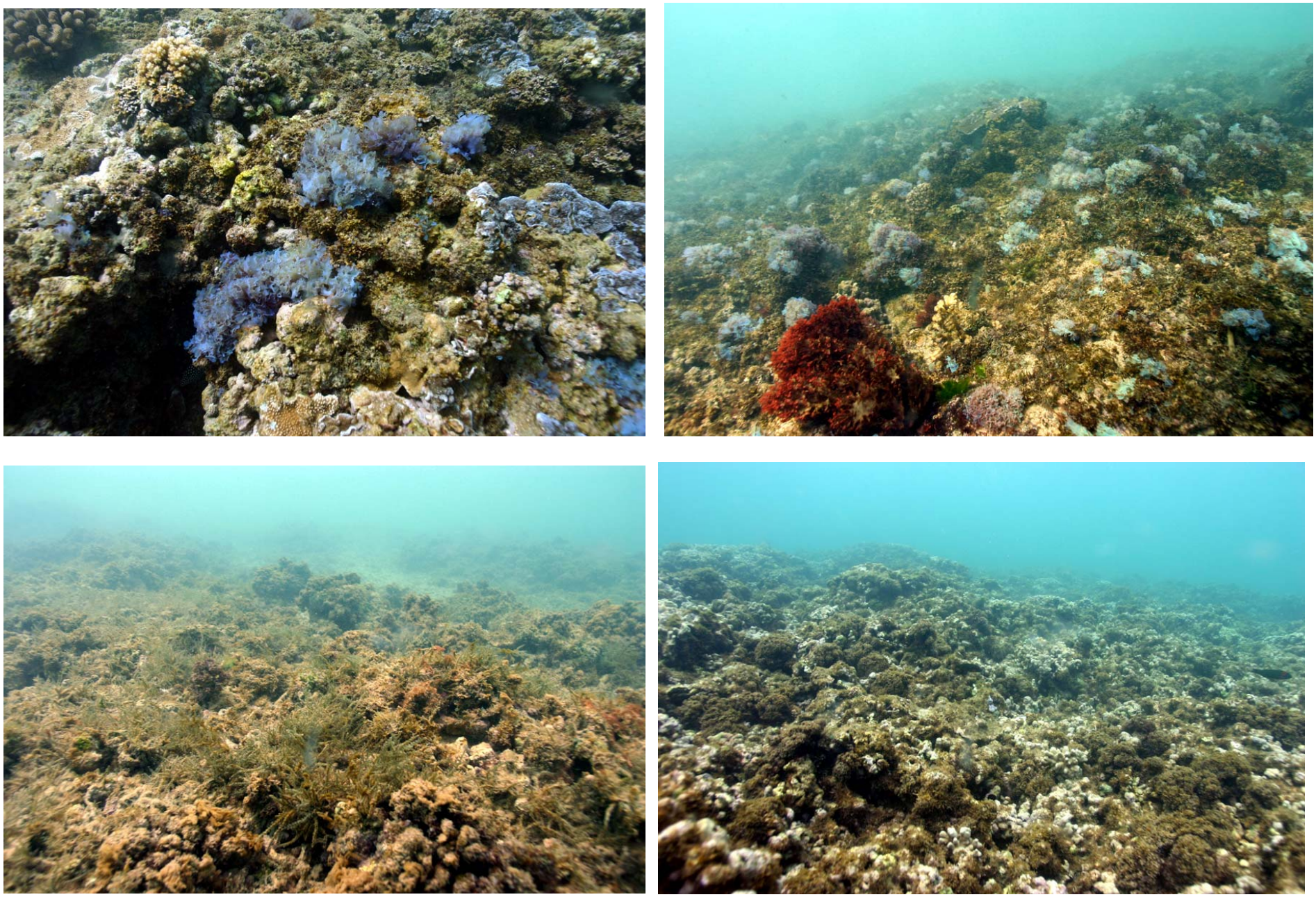


FIGURE 7. Various macro-algae on inner reef platform outside of the east breakwater of Kahului Harbor. Fluorescent blue alga in upper photos is *Martensia fragilis*. Large red plant in lower part of photo at upper right is *Halymenia formosa*. Dominant bottom cover in photo at lower left is red alga *Acanthophora specifera*, and dominant cover in photo at lower right is red alga *Amansia glomerata*.

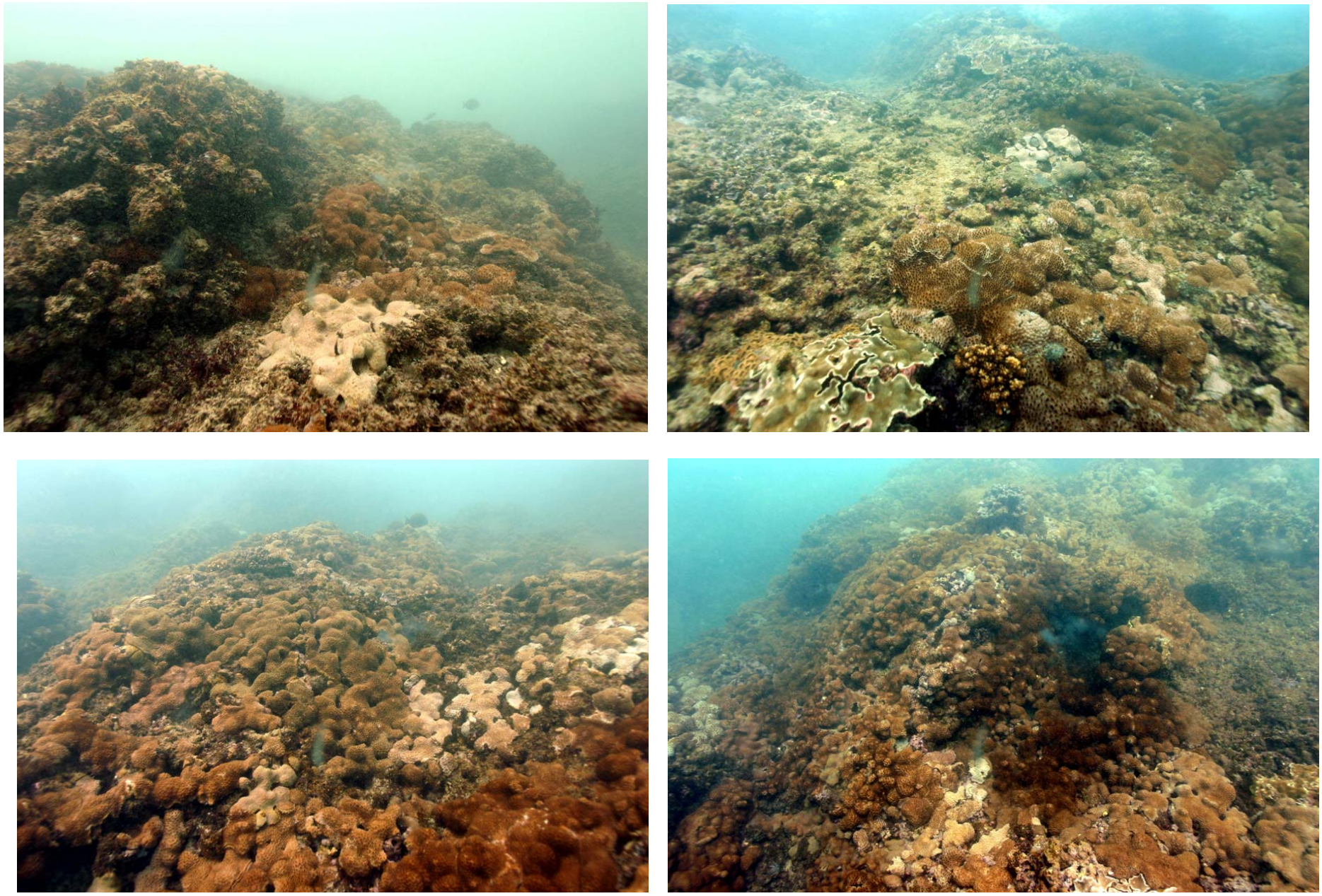
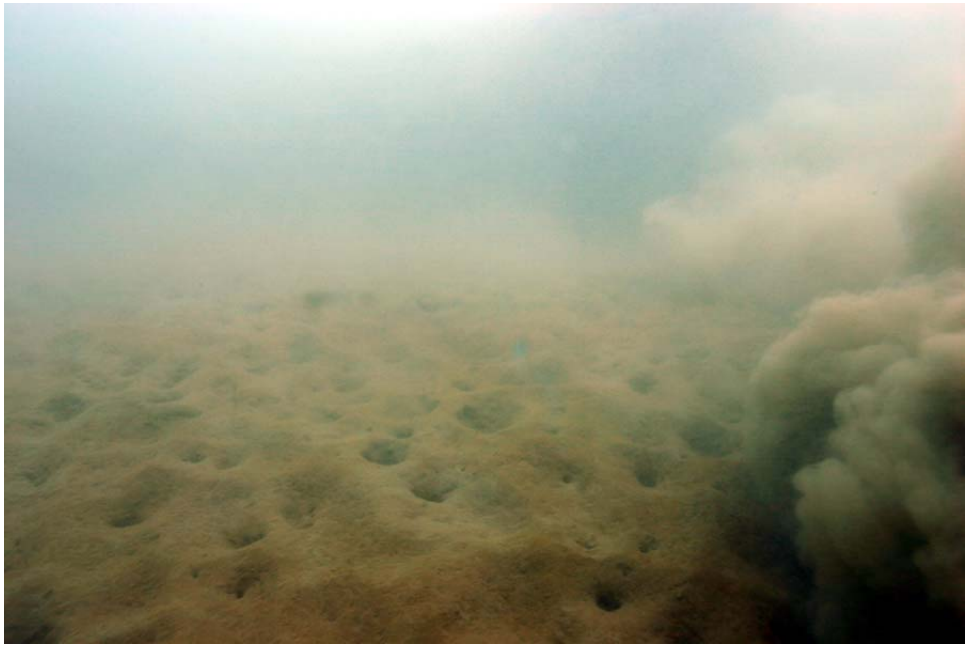


FIGURE 8. Reef surface outside of west breakwater of Kahului Harbor. Bottom cover of reef knolls consists almost entirely of the soft-bodied zooanthids *Palythoa tuberculosa* and *Zooanthus* spp. Water depth in all photos is approximately 10 m.

FIGURE 9. Colonies of *Montipora capitata* growing inside Kahului Harbor on concrete structures (dolos) that form the eastern breakwater of the harbor. Water depth is approximately 5-7 m in all photos.

FIGURE 10. Typical community assemblages on western breakwater of Kahului Harbor. Photo at upper left shows band of calcareous and frondose algae in the intertidal zone. Hemispherical corals in photo at upper right are *Pocillopora damicornis*. The sea urchin *Tripneustes gratilla* was common on the submerged breakwater (bottom left). Other common corals off the west breakwater were *Monitpora capitata* and *Pocillopora meandrina* (lower right). Water depth is three underwater photos is 1-2 m.



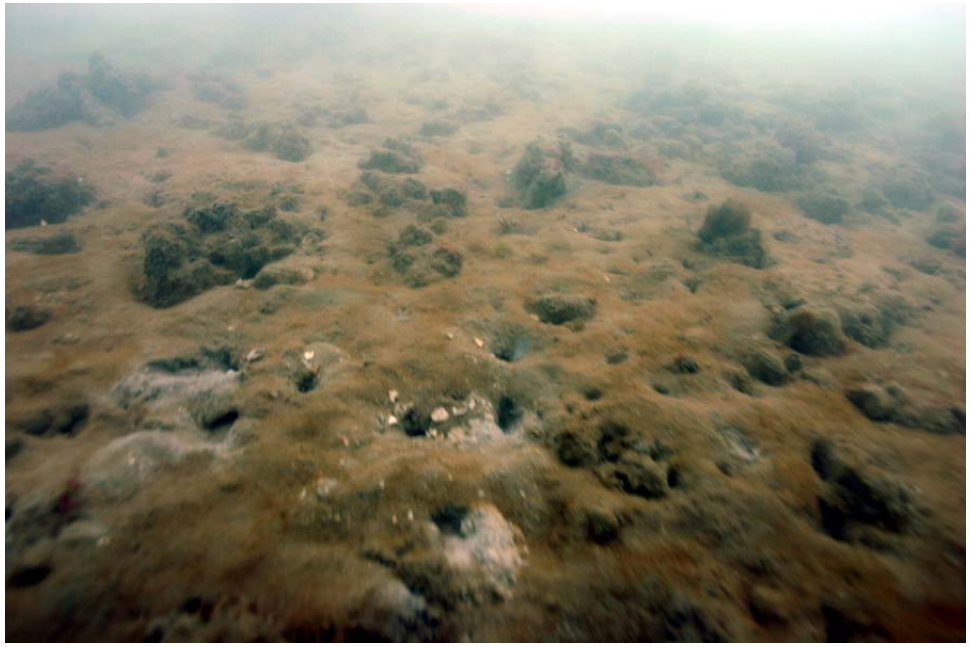


FIGURE 11. Coarse sand and gravel that is the typical bottom cover within Kahului Harbor off the western breakwater (upper left). Photos at upper right and lower left show fine-grained mud and sand that covers most of the dredged areas of inner Kahului Harbor. Numerous burrows are likely from a variety of crustaceans and worms.

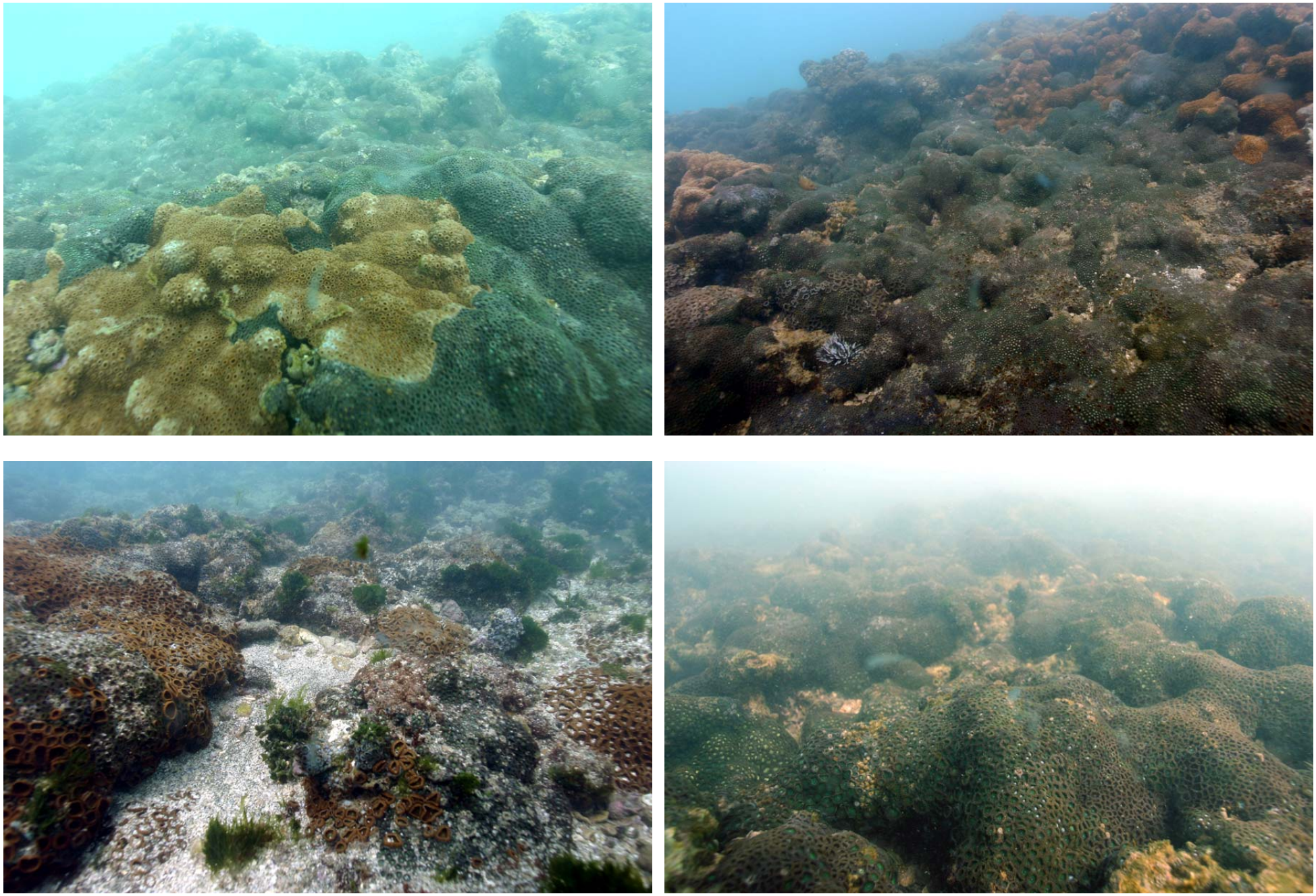


FIGURE 12. Dominant reef cover of *Palythoa tuberculosa* (light brown in photo at upper left) and *Zooanthus* spp. (green) on parts of the un-dredged reef platform in the western part of Kahului Harbor. Tufts of green algae in photo at lower left is *Bryopsis hypnoides*. Water depth in all photos is 1-3 m.

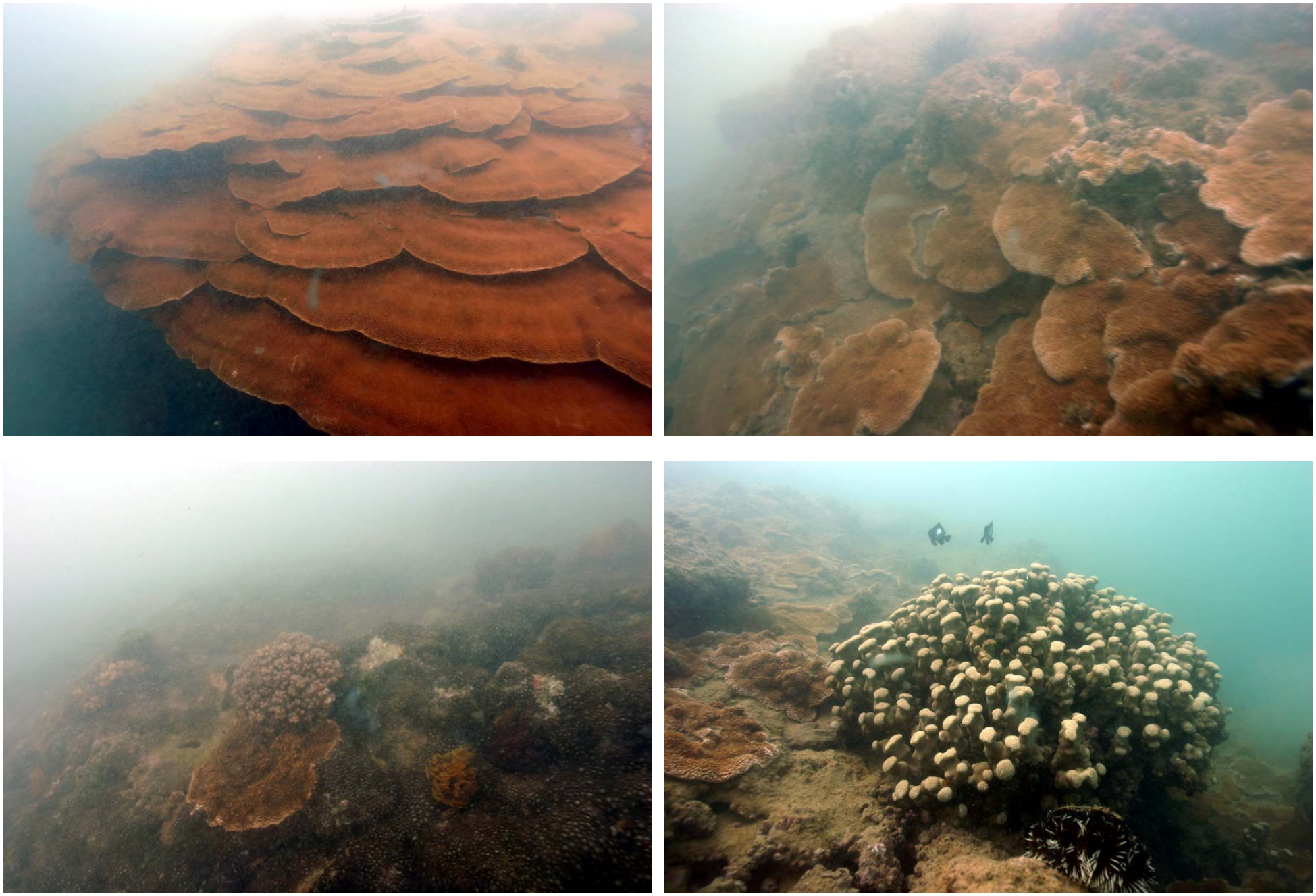


FIGURE 13. Four views of corals growing on un-dredged reef platform on west side of inner Kahului Harbor. Overlapping plating corals in upper photos is *Montipora capitata*. Large branching colony at lower right is *Pavona duerdeni*. Water depth in all photos is 2-3 m.

TABLE 1. Area coverage in square meters (m^2) of each reef zone in survey areas inside and outside of Kahului Harbor. See Figure 3 for habitat map showing various zones.

AREA (m^2)	Total	Inside Harbor	Outside Harbor
Coral >50%	200,480	28,160	172,320
Coral 20-50%	190,784	110,400	80,384
Algae >50%	112,288	18,848	93,440
Algae 20-50%	106,944	32,096	74,848
Pavement	141,536	74,992	66,544
Soft Sediment	1,041,328	602,832	438,496
TOTAL	1,793,360	867,328	926,032

% of Total	Total	Inside Harbor	Outside Harbor
Coral >50%	11.2	3.2	18.6
Coral 20-50%	10.6	12.7	8.7
Algae >50%	6.3	2.2	10.1
Algae 20-50%	6.0	3.7	8.1
Pavement	7.9	8.6	7.2
Soft Sediment	58.1	69.5	47.4
TOTAL	100.0	100.0	100.0