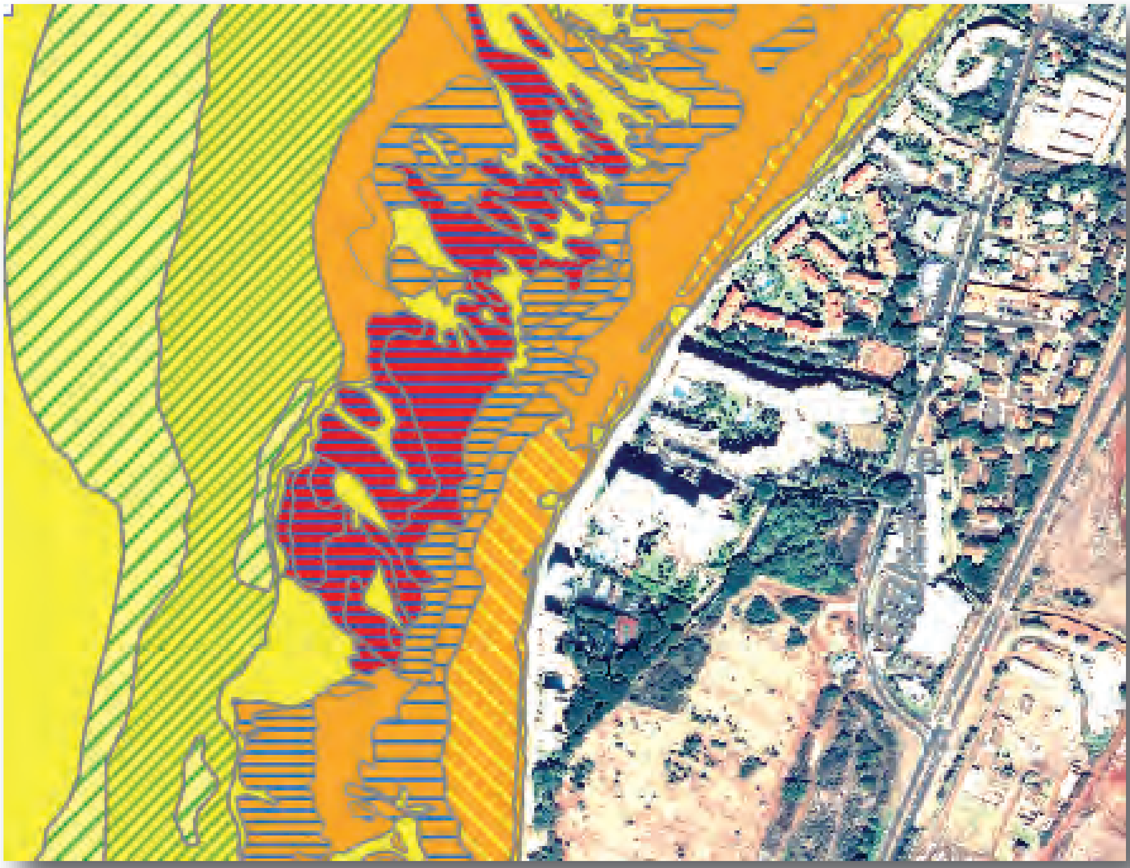
Benthic Habitat Map of the U.S. Coral Reef Task Force **Watershed Partnership Initiative Kā‘anapali Priority Study Area and the State of Hawai‘i Kahekili Herbivore Fisheries Management Area, West-Central Maui, Hawai‘i**



Open-File Report 2014–1129

U.S. Department of the Interior
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SALLY JEWELL, Secretary

U.S. Geological Survey
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Conversion Factors, Datum, and Abbreviations and Acronyms

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
square kilometer (km^2)	247.1	acre
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviations and Acronyms

DAR	Division of Aquatic Resources (Hawai‘i Department of Land and Natural Resources)
ESRI	Environmental Systems Research Institute, Inc.
GPS	global positioning system
KHFMA	Kahekili Herbivore Fisheries Management Area
MMU	minimum mapping unit
NOAA	National Oceanic and Atmospheric Administration
SHOALS	Scanning Hydrographic Operational Airborne Lidar Survey
USCRTF	U.S. Coral Reef Task Force
USGS	U.S. Geological Survey

Benthic Habitat Map of the U.S. Coral Reef Task Force Watershed Partnership Initiative Kāʻanapali Priority Study Area and the State of Hawaiʻi Kahekili Herbivore Fisheries Management Area, West-Central Maui, Hawaiʻi

By Susan A. Cochran[1], Ann E. Gibbs[1], and Darla J. White[2]

Abstract

Nearshore areas off of west-central Maui, Hawaiʻi, once dominated by abundant coral coverage, now are characterized by an increased abundance of turf algae and macroalgae. In an effort to improve the health and resilience of the coral reef system, the Kahekili Herbivore Fisheries Management Area was established by the State of Hawaiʻi, and the U.S. Coral Reef Task Force selected the Kāʻanapali region as a priority study area. To support these efforts, the U.S. Geological survey mapped nearly 5 km^2 of sea floor from the shoreline to water depths of about 30 m. Unconsolidated sediment (predominantly sand) constitutes 65 percent of the sea floor in the mapped area. Reef and other hardbottom potentially available for coral recruitments constitutes 35 percent of the mapped area. Of this potentially available hardbottom, only 51 percent is covered with a minimum of 10 percent coral, and most is found between 5 and 10 m water depth.

Introduction

Over the past two decades, there has been a notable change in seafloor-bottom type along west-central Maui, Hawaiʻi. Significant declines in coral cover (greater than 40 percent; Ross and others, 2012), reduced fish stocks (Friedlander and others, 2007; Williams and others, 2008; Walsh and others, 2010), as well as seasonal macroalgal blooms (Smith and others, 2005) and turf algal competition (Ross and others, 2012) suggesting a local nutrient imbalance, all document an ecosystem under stress and warrant further investigation. Previous studies by the U.S. Environmental Protection Agency (Wiltse, 1996), the U.S. Geological Survey (Storlazzi and others, 2006a, 2006b; Storlazzi and Field, 2008; Storlazzi and Jaffe, 2008; Hunt and Rosa, 2009; Swarzenski and others, 2012), and the University of Hawaiʻi (Dailer and others, 2008, 2010) have addressed the magnitude of change along this section of the Maui coast and have investigated the physio-chemical processes driving these changes.

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[2] State of Hawaiʻi, Department of Land and Natural Resources, Division of Aquatic Resources, Maui, Wailuku, Hawaii.

Based on a series of baseline studies, the reef at Kahekili still has the complex structure needed to support fish life and, therefore, was identified by the State of Hawaiʻi for urgent management actions to reverse a phase shift from a coral dominated habitat to an algal dominated habitat. In 2009, the Hawaiʻi Department of Land and Natural Resources, Division of Aquatic Resources (DAR), established the Kahekili Herbivore Fisheries Management Area (KHFMA) in an effort to increase the number of herbivores (plant eaters) to help reduce the overabundance of turf algae and macroalgae that outcompete the corals at the site, thus improving the health and resilience of the coral reef ecosystem. Hawaiʻi Administrative Rules, title 13, chapter 60.7 (HAR §13-60.7) states:

> The Kahekili Herbivore Fisheries Management Area, Maui is designated to control the overabundance of marine algae on and about coral reefs within this area by increasing the local abundance of certain herbivorous fishes and sea urchins by fisheries management methods. Natural controls of marine algae are intended to help the marine ecosystem in the area return to a healthy balance. (State of Hawaiʻi, 2009, p.1)

State regulations prohibit the injury, killing, possession, or removal of any rudderfish (nenue), parrotfish (uhu), or surgeonfish, as well as any sea urchin, and feeding of fish is prohibited. The protected area is offshore of the Wahikuli and Honokōwai watersheds, and the boundaries reach from the south end of Honokōwai Beach Park to Hanakaʻōʻō Beach, just south of Kekaʻa Point (also known as Black Rock; fig. 1).

The U.S. Coral Reef Task Force (USCRTF) Watershed Partnership Initiative selected the Kāʻanapali region of West-Central Maui as the site of the second national priority study area on which to focus its research and restoration efforts (U.S. Coral Reef Task Force, 2011, 2012). Driven by this national support, the Hawaiʻi Coral Reef Strategy for 2010–2020 (State of Hawaiʻi, 2010) identified the coral reef ecosystem of West Maui as a priority management area, and the West Maui Ridge to Reef Initiative published the Wahikuli-Honokōwai Watershed Management Plan. The plan provides a template framework for use in other watersheds to reduce the generation and transport of land-based pollutants (generally sedimentation, but also other nutrients), thus improving water quality and the health of West Maui coral reef ecosystems (West Maui Ridge to Reef Initiative, 2012).

In cooperation with the State of Hawaiʻi Division of Aquatic Resources, the U.S. Geological Survey Pacific Coastal and Marine Science Center initiated an effort in 2012 to produce a high-resolution map of the nearshore underwater environments along the west-central coast of Maui (fig. 1) in support of USCRTF and DAR efforts.

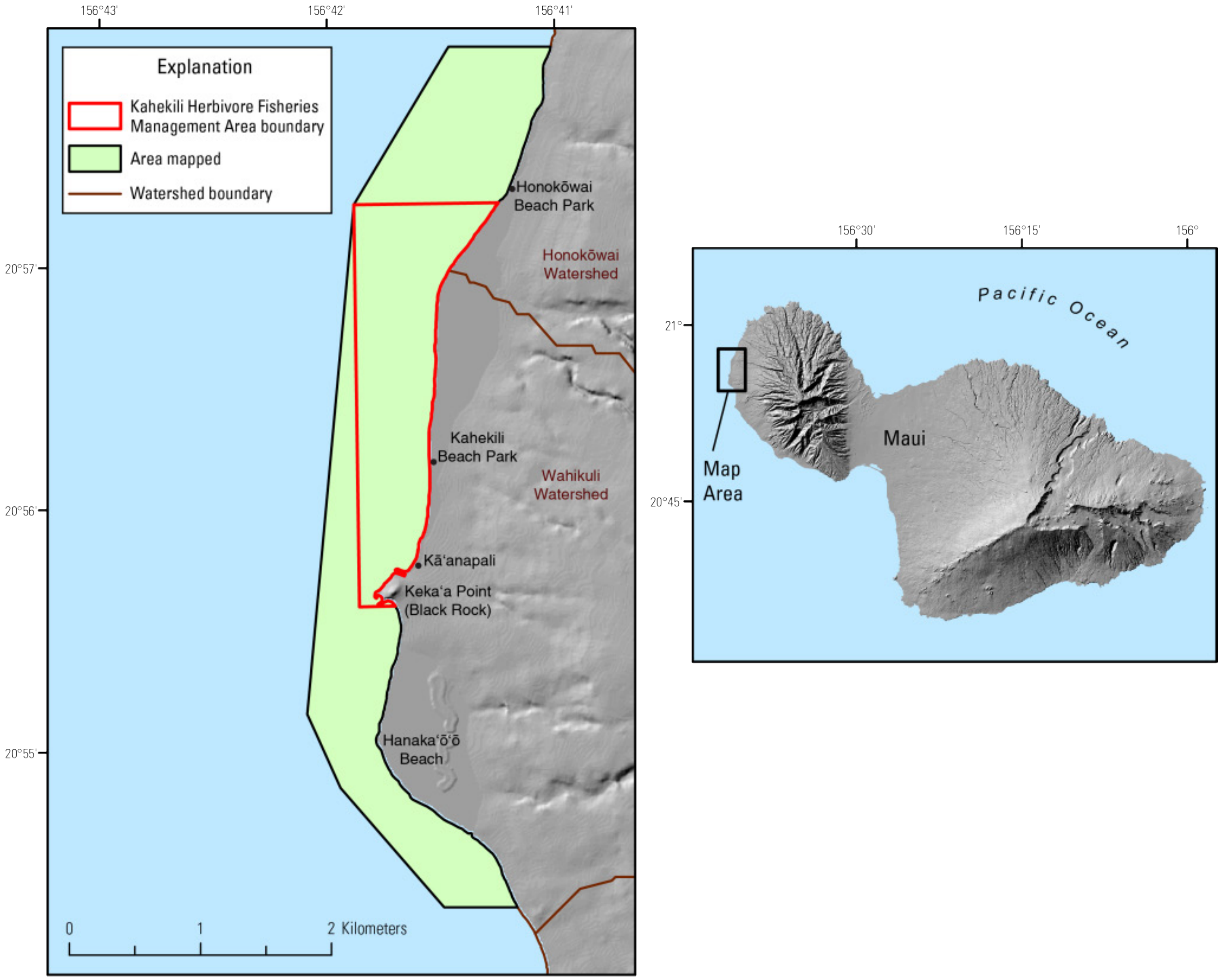

Figure 1. Map of west-central coast of Maui showing boundary of State of Hawaiʻi Kahekili Herbivore Fisheries Management Area and extent of area mapped in this report, including U.S. Coral Reef Task Force Watershed Partnership Initiative Kāʻanapali priority study area.

Data and Methods

A standard for characterization of coral-reef environments first was implemented by the National Oceanic and Atmospheric Administration (NOAA) for mapping the Florida Keys (Rohman and Monaco, 2005) and Puerto Rico and the Virgin Islands (Kendall and others, 2001). This standard for mapping coral reefs in the United States and its territories describes benthic habitats on the basis of their seafloor geomorphology, geographic zonation, and biological cover.

In this study, the benthic-habitat classification maps were created using the standards established by NOAA, but at a finer scale (minimum mapping unit of 100 m^2 compared to NOAA standards of 1 acre [4,046 m^2]) and with additional data sources, including DigitalGlobe™ satellite imagery, Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) bathymetric data, sidescan sonar data, and georeferenced underwater video. The maps were generated using ArcMap™

Geographic Information System (GIS) software by Environmental Systems Research Institute, Inc (ESRI) with a benthic habitat digitizing extension created by NOAA (National Oceanic and Atmospheric Administration, 2012), and a statistical analysis of accuracy of the resultant maps was completed. The complete methodology is shown in the flowchart in figure 2.

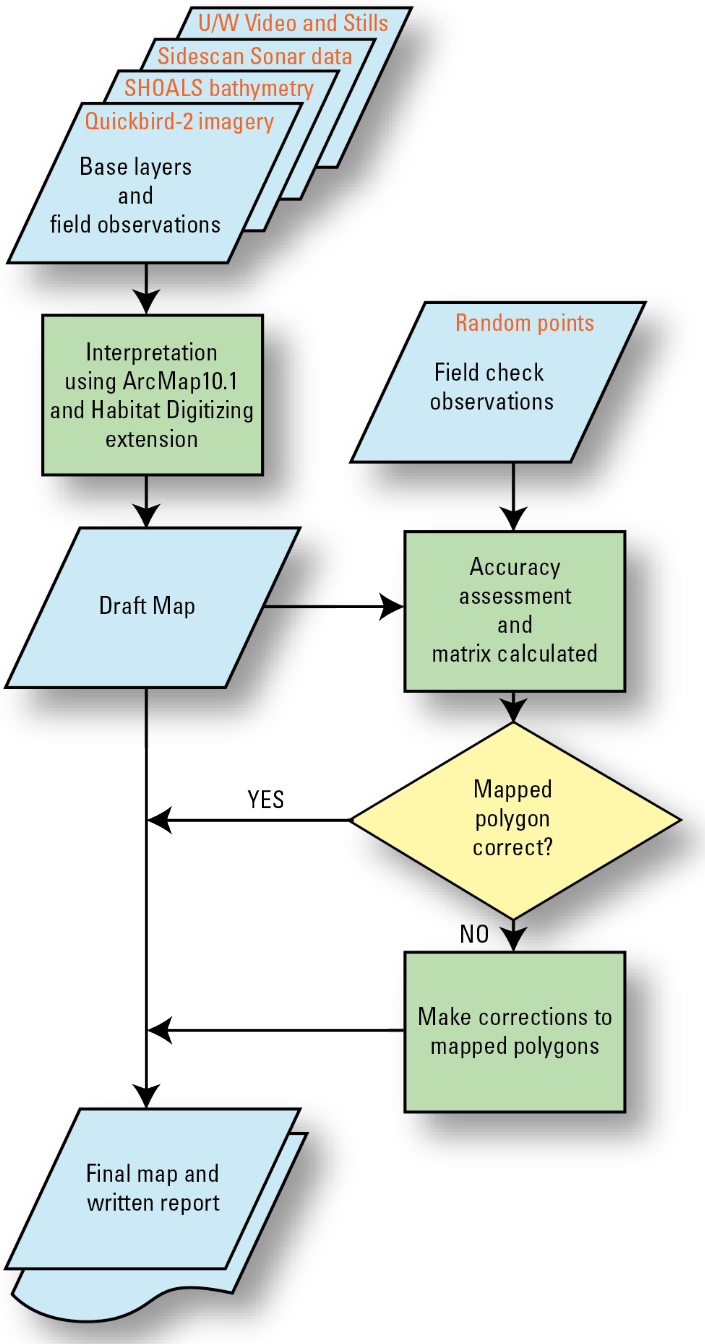

Figure 2. Flowchart showing methodology used to create benthic habitat map in this report. See text for complete description.

Background Data

QuickBird-2 Satellite Orthoimagery

Orthoimagery used as the base layer for mapping is from the DigitalGlobe™ QuickBird-2 satellite, and was obtained for research purposes through a licensing agreement with the U.S. Department of Agriculture, Natural Resources Conservation Service. The 4-band (red, green, blue, and infrared) imagery was acquired on November 20, 2005, and has a spatial resolution of 0.60 m (fig. 3). Several other satellite images of West Maui were considered for the project, including imagery with an acquisition date as recent as 2012, but were deemed unsuitable for this project because of excessive waves, sunglint, or cloud cover in the area of interest.

SHOALS Bathymetry

High-resolution SHOALS bathymetric point data collected in 2000 by the U.S. Army Corps of Engineers were interpolated to a raster surface using ESRI Arc/INFO™ GRID software. The bathymetric data have an average horizontal point spacing of 4 m ± about 3 m and a vertical resolution of ± 0.15 m, with a maximum water penetration of about 37 m (121 ft) in the study area. There are data gaps in the offshore part of the map area that are caused by a lack of signal penetration at greater water depths, non-overlapping flight lines, or holidays (gaps) in the data coverage. SHOALS bathymetric data overlying the Quickbird-2 satellite imagery is shown in figure 4, and the same data-enhanced imagery, zoomed in to the KHFMA boundary, is shown in figure 5. Contour lines, hillshades, and slope maps were derived from this dataset using standard ArcMap functions. Merging the hillshade derived from the SHOALS data with the Quickbird-2 satellite imagery (fig. 6) shows shaded relief, as well as color differences visible in the satellite imagery (for instance, lighter-colored sand patches against darker-colored reef areas), and aids in the interpretation of benthic habitats.

Acoustic Backscatter Imagery

Sidescan-sonar data were collected with a Humminbird® 898C SI system along 12 survey lines covering an area of 0.92 km^2. The data were processed using Chesapeake Technology's SonarWiz software, and an acoustic backscatter image was produced (see fig. 6 in Swarzenski and others, 2012). The acoustic backscatter image shows soft substrate (for example, sand) as brighter hues and harder substrates (for example, pavement) as darker hues (fig. 7).

Underwater Video

Underwater video footage used in the interpretation of habitats was collected along 8 towed-camera transect lines and from 145 drop-camera stations during three cruises in 2002, 2003, and 2011 (fig. 8). More than 1,350 still images were extracted from these videos, including still frames extracted every 10 seconds along transect lines, and still frames showing an overview and a near-bottom view from the drop-camera stations. A complete description of the methodology used to collect the underwater video footage, the techniques and software used to convert the analog video tapes to digital data in order to extract the still-frame grabs, and online links to the actual video and images are available in Gibbs and others (2013).

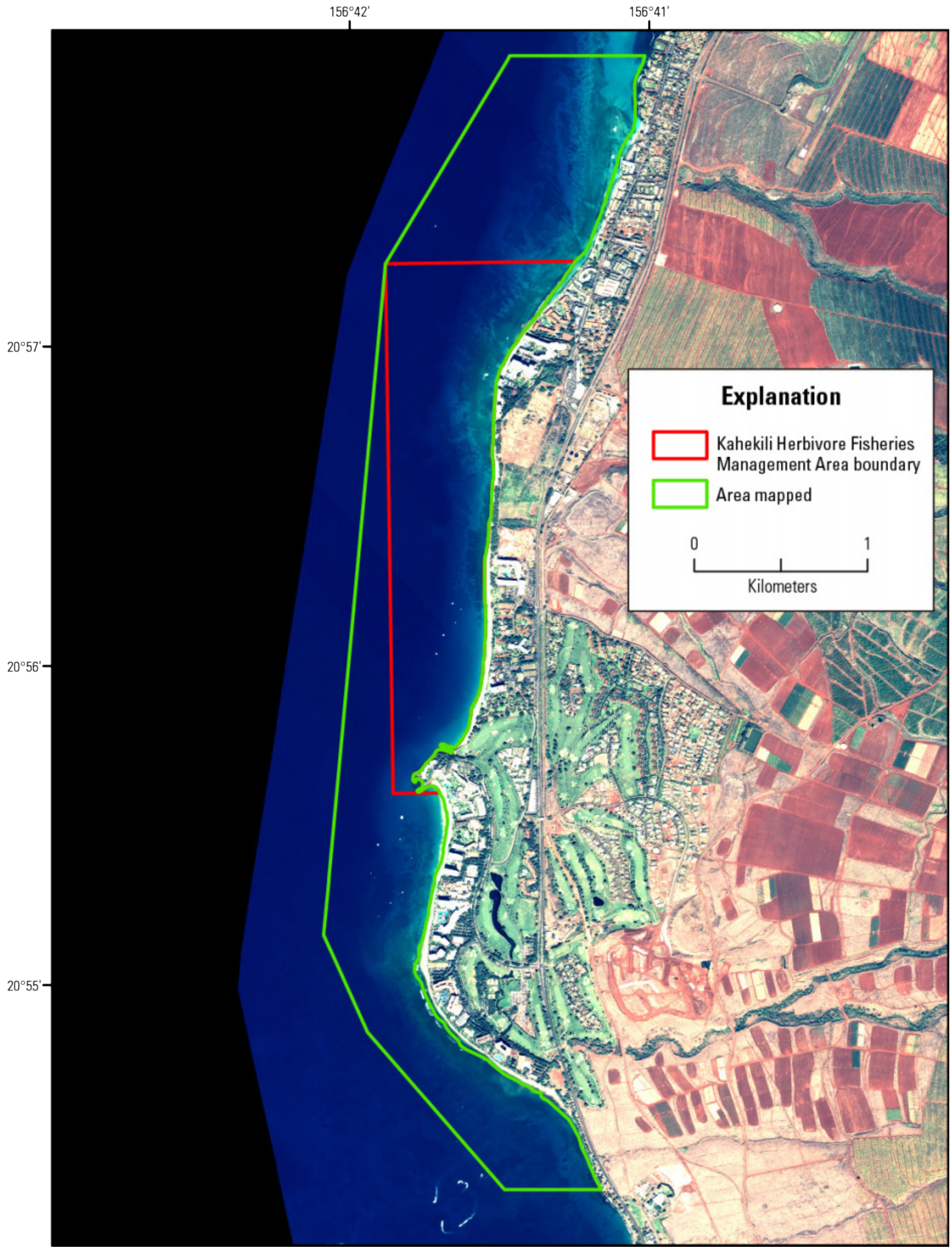

Figure 3. DigitalGlobe™ QuickBird-2 satellite imagery from 2005 showing study area, west-central Maui, Hawai‘i.

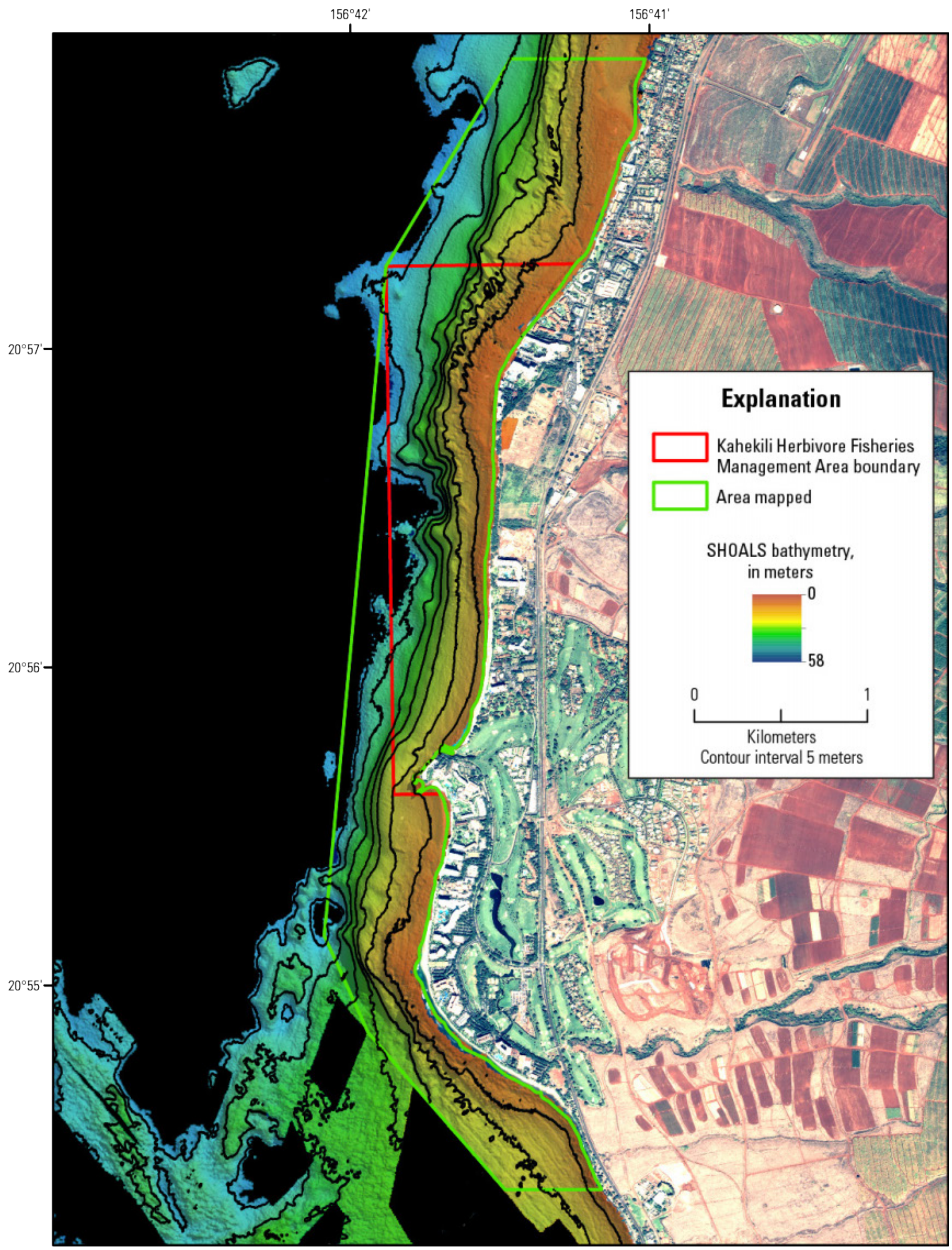

Figure 4. Hillshaded Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) bathymetric data overlaid on DigitalGlobe™ QuickBird-2 satellite imagery showing study area, west-central Maui, Hawai‘i.

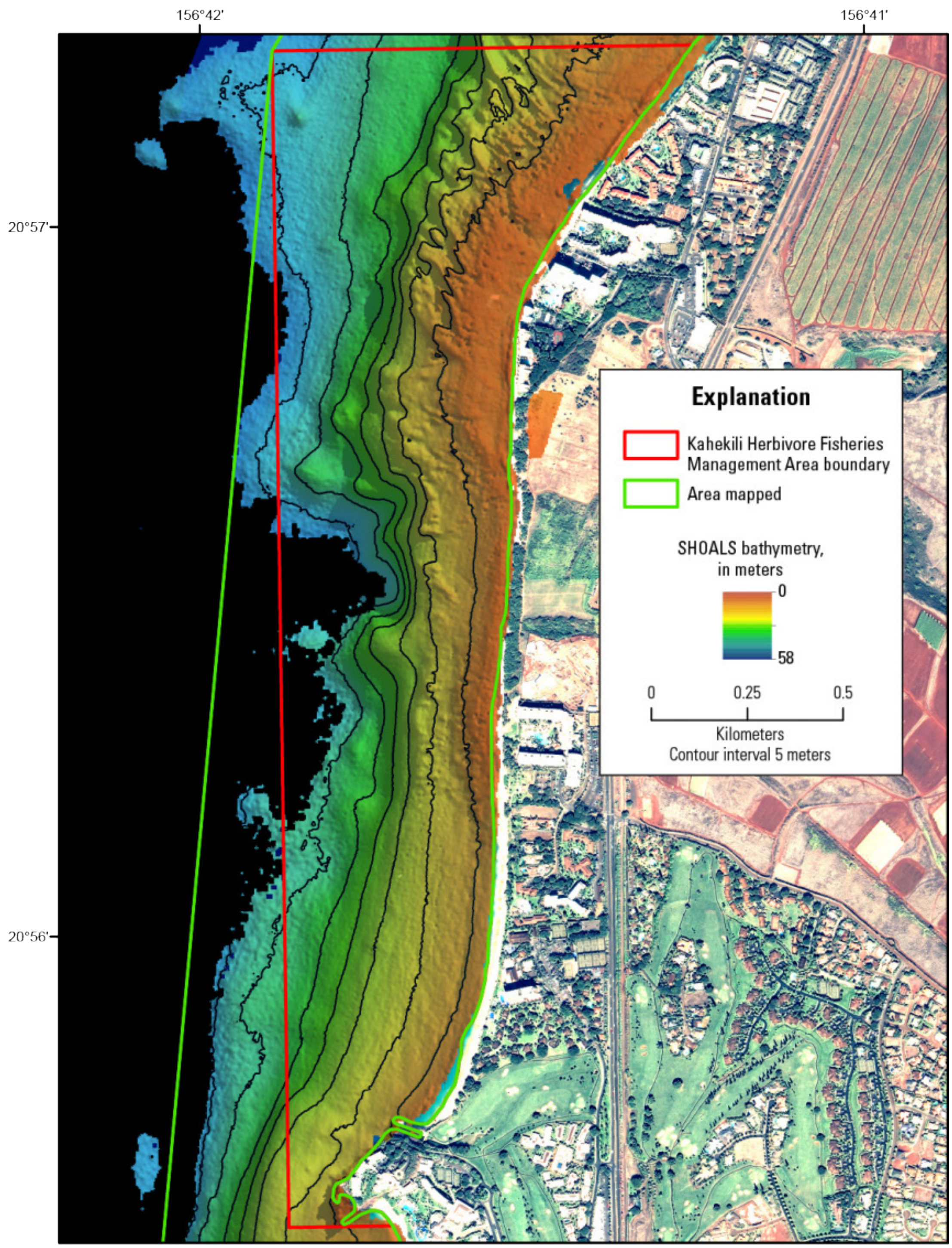

Figure 5. Zoomed-in view of Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) bathymetric data overlaid on DigitalGlobe™ QuickBird-2 satellite imagery showing Kahekili Herbivore Fisheries Management Area, west-central Maui, Hawai‘i.

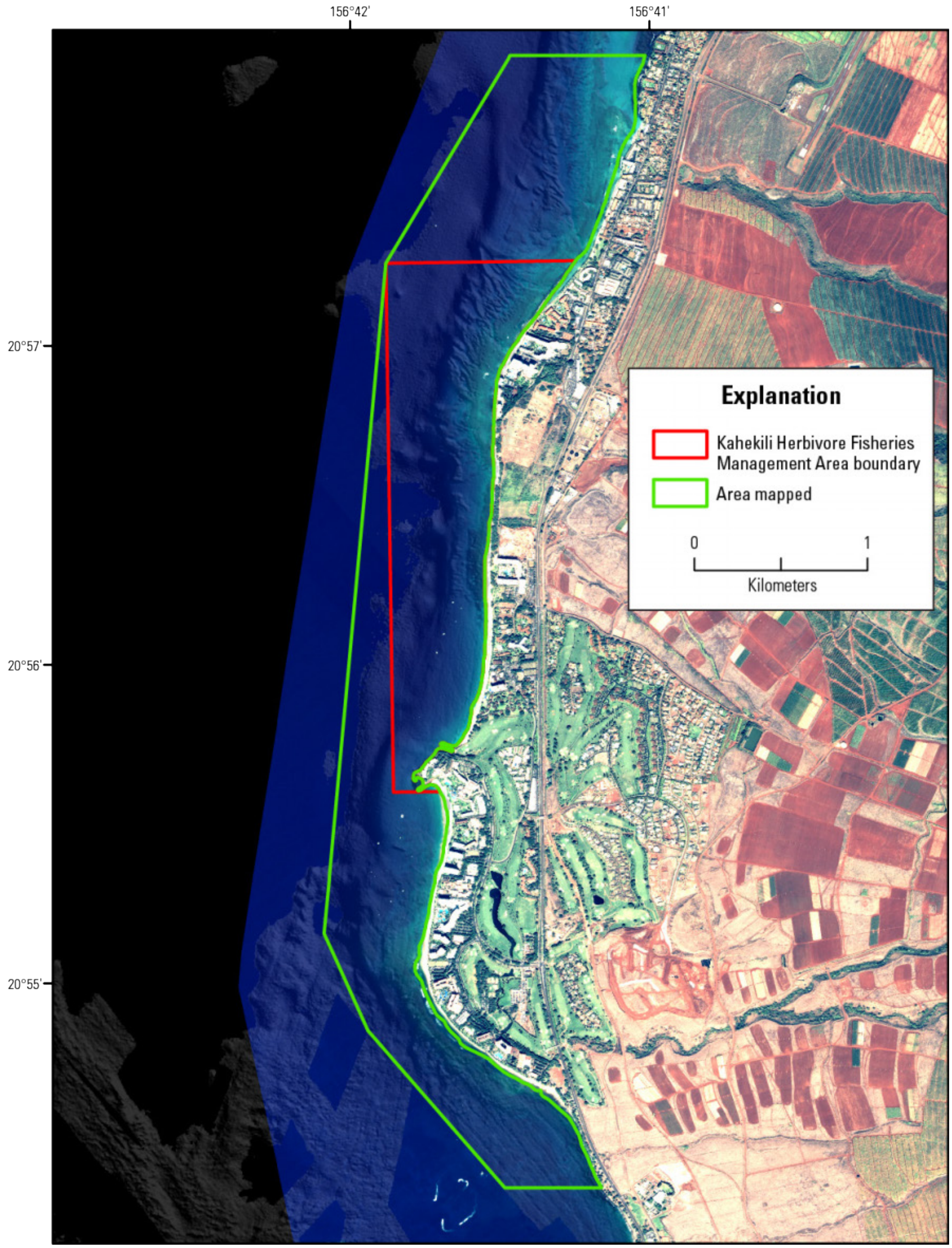

Figure 6. DigitalGlobe™ QuickBird-2 satellite imagery showing study area overlaid on hillshaded Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) bathymetric data, west-central Maui, Hawai'i.

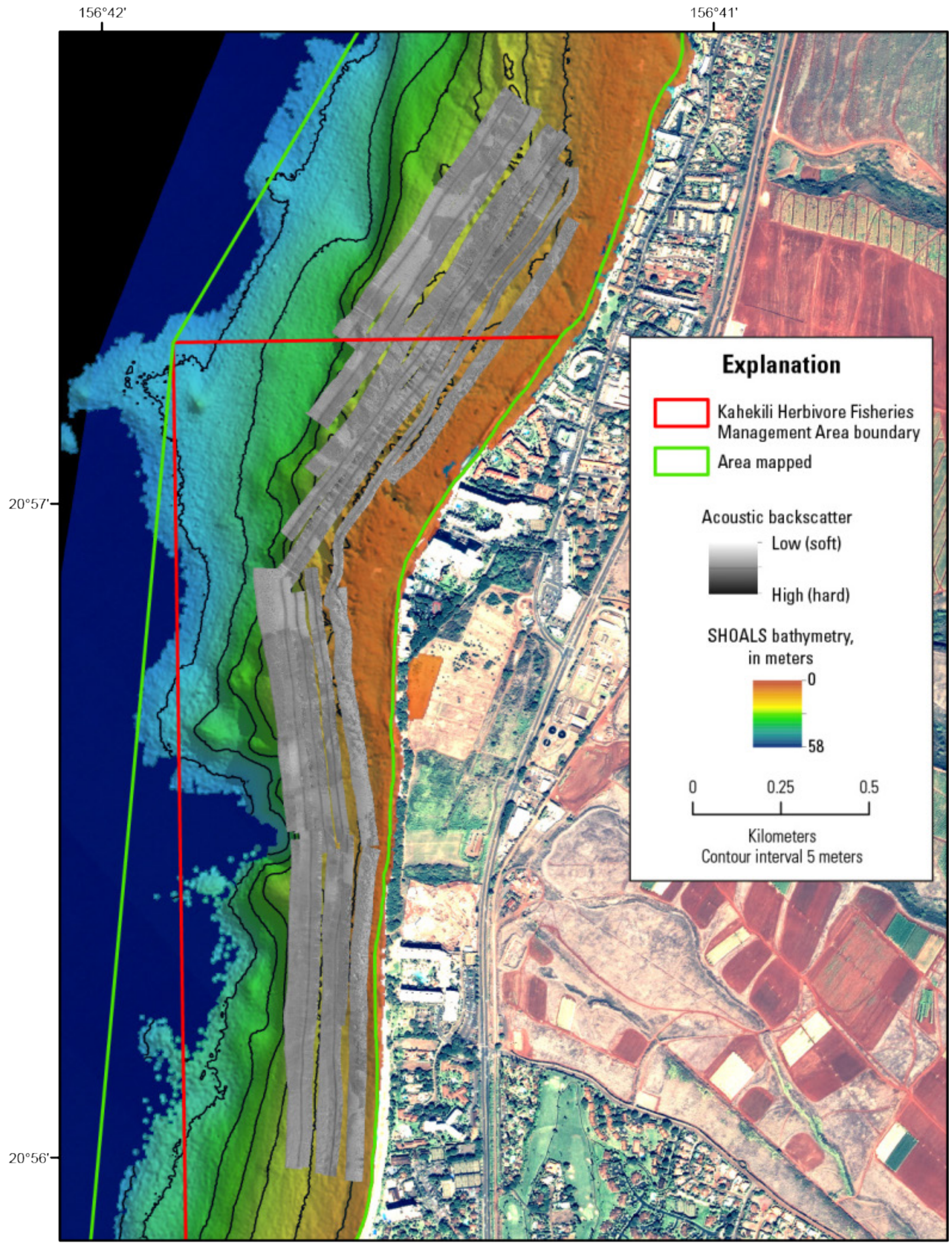

Figure 7. Acoustic-backscatter imagery from sidescan-sonar data overlaid on hillshaded, color-coded Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) bathymetric data and DigitalGlobe™ QuickBird-2 satellite imagery showing a portion of the study area, west-central Maui, Hawai'i. Acoustic backscatter image shows soft substrate (for example, sand) as brighter hues and harder substrates (for example, pavement) as darker hues.

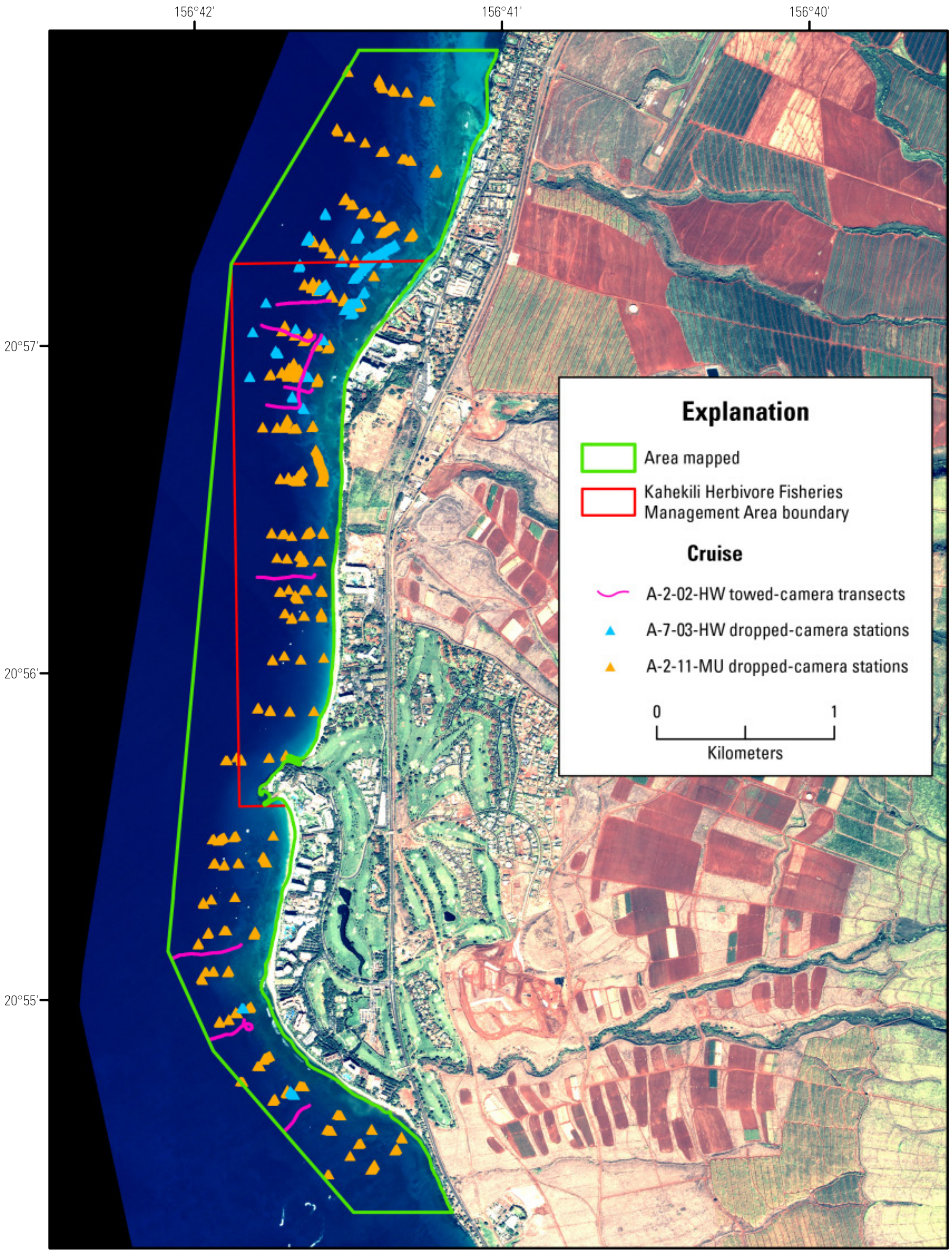

Figure 8. Locations of towed-camera transects and drop-camera stations used for interpretation of benthic habitats overlaid on DigitalGlobe™ QuickBird-2 satellite imagery, west-central Maui, Hawai'i.

Benthic Habitat Mapping Using GIS

Digital benthic habitat maps were created using ESRI ArcGIS™ v.10.1 software with a habitat-digitizing extension created by NOAA (National Oceanic and Atmospheric Administration, 2012). The habitat-digitizing extension allows users to delineate habitat areas and to assign attributes to the habitat polygons based on a predetermined classification scheme using a point-and-click menu system.

We digitally delineated nearly 400 polygons, covering nearly 5 km^2 in the USCRTF Watershed Partnership Initiative Kāʻanapali priority study area and the State of Hawaiʻi KHFMA of West Maui, Hawaiʻi. A minimum mapping unit (MMU) of 100 m^2 was used; however, select smaller features were mapped if they carried unique habitat significance (for example, an individual coral colony 2 m in diameter in an otherwise uncolonized area), or when caused by subdividing a habitat polygon that traversed more than one geographic zone.

Classification Scheme

The classification scheme used here is based on a scheme established by the NOAA biogeography benthic habitat mapping program (Coyne and others, 2003) for the main eight Hawaiian Islands, and subsequently revised in 2004 (National Oceanic and Atmospheric Administration National Centers for Coastal Ocean Science, 2005). Developed with input from coral reef scientists, managers, and local experts, the hierarchal scheme allows users to expand or collapse the level of thematic detail as necessary. The NOAA definition of benthic habitats and their classification scheme is used as a starting point to provide continuity to the coral reef scientific community. However, additional modifications have been made to the classification scheme to best reflect the benthic habitats and geologic substrates present along the West Maui coast.

The classification scheme uses five basic attributes to describe each polygon on the benthic habitat map: (1) the major structure or underlying substrate, (2) the dominant structure, (3) the major biologic cover found on the substrate, (4) the percentage of major biologic cover, and (5) the geographic zone indicating the location of the habitat. The structure combination with the overlying biologic cover is referred to as a “habitat.” At the mapping scale used (100 m^2 MMU), if a polygon includes two or more substrate or coverage types, the polygon is identified with the dominant type.

Four major structure (substrate) types are subdivided further into 15 dominant structures (table 1). Ten major biologic cover types also are modified by the percentage of coverage (tables 2 and 3). The classification scheme allows for any biologic cover to be found on any structure (substrate), although many combinations are unlikely (for example, coral on sand, or emergent vegetation on spur-and-groove). Less than 10 percent cover of any type is equivalent to 90–100 percent uncolonized; therefore, 0–10 percent cover is not used. Each polygon is coded with a 4-digit UNIQUEID attribute that represents the combination of the individual habitat components (major structure, dominant structure, major biologic cover, and percent cover).

The fifth attribute, zone, refers only to the location of a habitat community in the coral reef ecosystem and does not indicate the substrate or biologic cover type (fig. 9). Eleven zones correspond to typical reef geomorphology found in coral reef literature (table 4). Detailed descriptions of habitats and zones, including example photographs, are available in appendix A.

Table 1. Major structure (substrate) types with dominant structure subdivisions.

[Numbers in bold represent UNIQUEID identifier]

Major structure	Dominant structure
1 Unconsolidated sediment	**1** Mud
	2 Sand
2 Reef and hardbottom	**1** Aggregate reef
	2 Spur-and-groove
	3 Individual patch reef
	4 Aggregated patch reef
	5 Volcanic pavement with 10-50% Rocks/Boulders
	6 Volcanic pavement
	7 Volcanic pavement with >50% Rocks/Boulders
	8 Volcanic pavement with sand channels
	9 Reef rubble
3 Other	**0** Unknown
	1 Land
	2 Artificial
	3 Artificial/historical
9 Unknown	**0** Unknown

Table 2. Major biologic cover attributes.

[Numbers in bold represent UNIQUEID identifier]

Major biologic cover
0 Unknown
1 Uncolonized
2 Macroalgae
3 Seagrass
4 Coralline algae
5 Coral
6 Turf
7 Emergent vegetation
8 Mangrove
9 Octocoral

Table 3. Percent cover attributes.

[Numbers in bold represent UNIQUEID identifier.]

Percent cover
0 Unknown
2 10-<50%
3 50-90%
4 90-100%

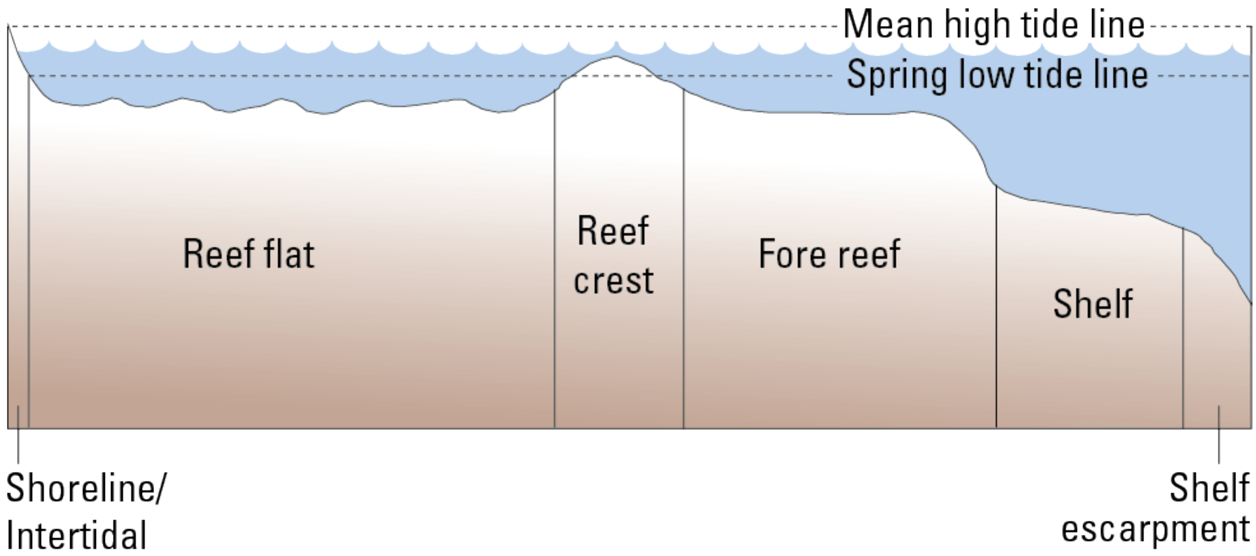

Figure 9. Schematic diagram showing generalized cross-shelf coral-reef zonation. Not shown: land, channel, dredged, or vertical wall (modified from Kendall and others, 2004).

Table 4. Geomorphic zones of coral reef ecosystems.

Zone
Land
Shoreline/intertidal
Vertical wall
Lagoon
Back reef (with lagoon)
Reef flat (without lagoon)
Reef crest
Fore reef
Bank/shelf
Bank/shelf escarpment
Channel
Dredged

Accuracy Assessment

The validity and usefulness of any classification or interpretation may be determined with an accuracy assessment, which compares the interpretation with what actually found in the field. In this project, the overall accuracy of the benthic habitat map and its accuracy from the points of view of the producer and user are determined.

Overall accuracy indicates which points on the map are classified correctly according to a field check (Lillesand and Keifer, 1994). Producer accuracy indicates how well the map producer classified the different cover types (that is, the number of points on the map labeled correctly). User accuracy indicates the probability that a point in a given class is actually represented by that class in the field (that is, which mapped areas are actually what the map says they are).

For the accuracy assessment, 100 randomly generated waypoints within the mapped area were ground-truth surveyed in 2013 by taking underwater photographs of the benthic habitat. The shallow, nearshore waypoints were surveyed by snorkel using a global positioning system (GPS) attached to a torpedo float with a dive flag. Snorkel teams swam to the designated coordinates and took vertical photographs of the habitat, as well as oblique photographs around the site to get a more comprehensive view of the area. A new GPS waypoint was recorded at the exact location where the photographs were taken. Deeper, offshore waypoints were surveyed using a drop-camera system from a small boat. A GoPro® Hero 3+ Black Edition camera, set to automatically take a photograph every five seconds, was mounted on a SeaView SeaMaster Offshore Underwater Video System (fig. 10). A 2-pound lead diving weight was attached to a line suspended 1 m below the video camera lens to hold it straight down in the current and to provide a safety buffer for the camera. A 150-ft cable provided a live video feed to a color monitor onboard the boat to visually assess when the camera reached the substrate. Once on site, the camera was lowered slowly by hand until the lead weight touched the seafloor (fig. 11), and then was held for several seconds to ensure that a sufficient number of photographs were acquired at depth. A new GPS waypoint was recorded when the weight reached the bottom. The video cable and hand line were labeled every 0.5 m to provide a depth measurement. The camera system then was slowly raised back up to the boat. This methodology yielded numerous high-resolution photographs of the sites, at the seafloor and from the overlying water column, to give an overall view of the habitat for classification assessment.

Once the accuracy assessment calculations were completed, any misinterpreted polygons identified were corrected, thereby increasing the accuracy of the final map.

Figure 10. Photograph showing GoPro® camera mounted on SeaView SeaMaster Offshore Underwater Video System was used to collect photographs for accuracy assessment.

Figure 11. Photograph showing Edward Wine (Hawai‘i Department of Land and Natural Resources, Division of Aquatic Resources) preparing to lower camera system over side of boat to collect photographs for accuracy assessment.

Results

Benthic Habitats

Nearly 400 polygons, covering about 5 km^2 of sea floor, were mapped in the USCRTF Watershed Partnership Initiative Kāʻanapali priority study area and the State of Hawaiʻi KHFMA of West Maui, Hawaiʻi (figs. 12 and 13). Unconsolidated sediment (for example, mud and sand) makes up 3.11 km^2 (65 percent) of the substrate in the mapped area; reef and hardbottom (for example, aggregate reef, patch reefs, pavement, reef rubble, and spur-and-groove) makes up 1.69 km^2 (35 percent); and other substrates (for example, artificial) make up less than 0.01 km^2 (<1 percent). The areal extent and percentage of total area mapped for each of the dominant structure attributes shown on the map in figure 14 are indicated in table 5. Of the 1.69 km^2 of hardbottom potentially available for coral habitat, 0.85 km^2 (51 percent) is covered with a minimum of 10 percent coral (table 6; figs. 15 and 16). Most coral is present in water depths between 5 and 10 m (fig. 17). No polygons were mapped as coral in water depths greater than 15–20 m.

Uncolonized sand covers the most area (1.47 km^2) in the overall study area, followed by sand with 10-<50% macroalgae (0.84 km^2), and sand with 50-<90% macroalgae (also 0.84 km^2) (fig. 18). Macroalgae is predominantly *Halimeda kanaloana*, which is indigenous to Hawaiʻi. A similar pattern is found within the boundaries of the KHFMA with uncolonized sand covering the most area (0.52 km^2), followed by sand with 10-<50% macroalgae (0.39 km^2), and sand with 50-<90% macroalgae (0.39 km^2).

For comparison purposes, the entire mapping area was divided into three geographic zones: (1) North, which includes the mapped area north of the northernmost boundary of the KHMFA; (2) Middle, which includes the KHMFA, and the area from the westernmost boundary of the KHFMA offshore to the westernmost limit of the mapped area; and (3) South, which includes the mapped area to the south of the southernmost boundary of the KHFMA (fig. 12). Spur-and-groove formations are present in the Middle/KHFMA geographic zone, whereas pavement dominates the South geographic zone (fig. 19*A*). The major biologic covers are found across all geographic zones, with the exception of Artificial (an outlet pipe near the shoreline), which is present in a very small amount only in the South geographic zone (fig. 19*B*).

Accuracy of Map

Accuracy assessments were completed for the dominant structure (table 7), major biologic cover (table 8), and percentage of major biologic cover (table 9) attributes using 100 randomly selected points. The assessments show overall accuracies of 91 percent (with a 95% confidence interval of ± 5.6%), 86 percent (with a 95% confidence interval of ± 6.8%), and 82 percent (with a 95% confidence interval of ± 7.5%), respectively, for each attribute, and indicate which points on the map were classified correctly according to the field check. Producer's accuracy is an indication of how well pixels were correctly identified for each attribute (for example, for the dominant structure attribute, spur-and-groove = 100 percent and pavement = 93 percent). User's accuracy is the probability that, for a classified pixel on the map, the map user will actually find that attribute in the field (for example, for the major biologic cover attributes, macroalgae = 97 percent, uncolonized = 81 percent). Tau coefficients for the accuracy assessments of the dominant structure, major biologic cover, and percentage of major biologic cover were calculated as described by Ma and Redmond (1995), and indicate that 89.71 percent, 84.00 percent, and 79.43 percent more points were classified correctly in each respective attribute than would be expected solely by chance.

After accuracy assessment calculations were completed, any misinterpreted polygons were corrected using the field check data, thereby increasing the overall accuracy of the final map.

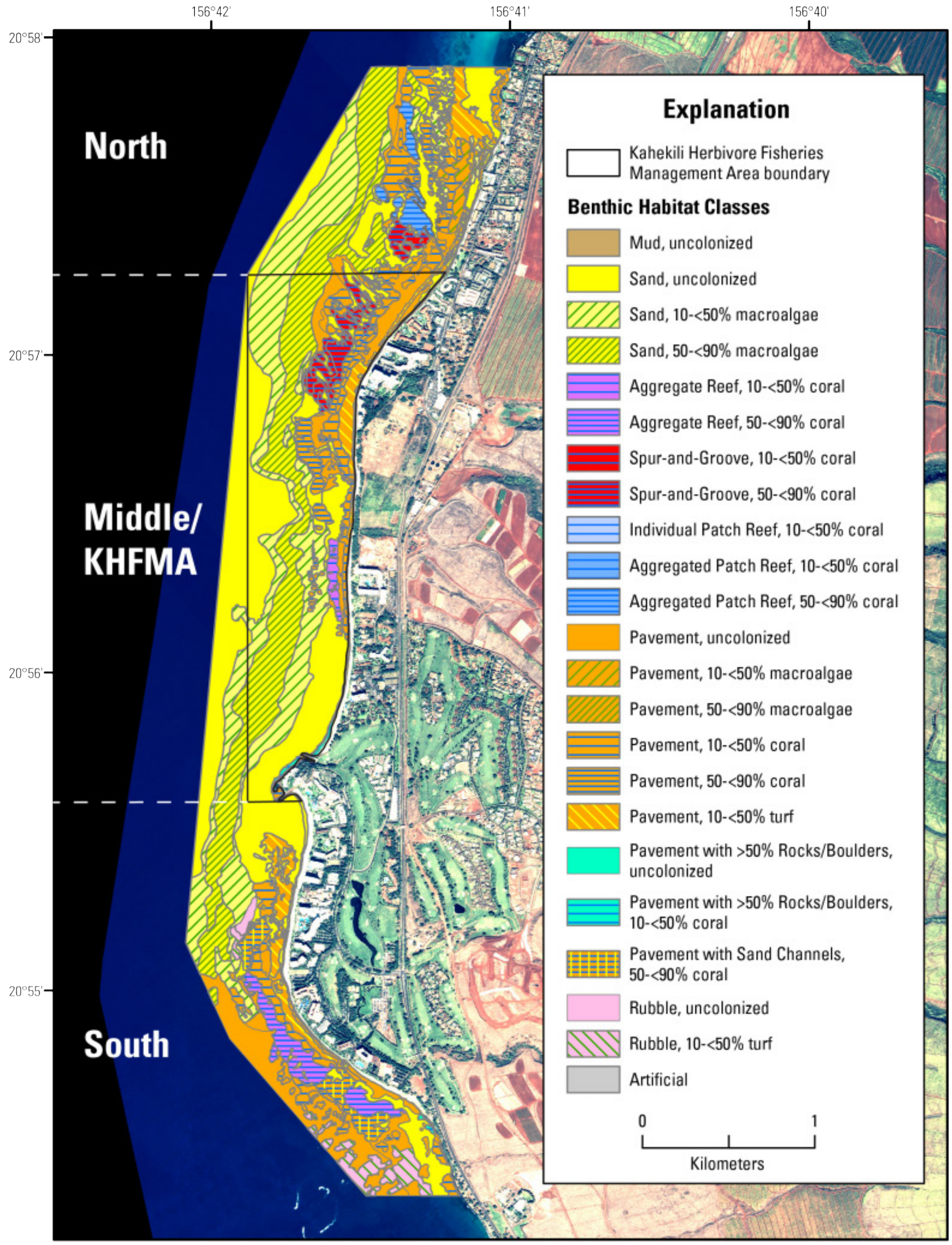

Figure 12. Benthic habitat map showing U.S. Coral Reef Task Force Watershed Partnership Initiative Kāʻanapali priority study area and State of Hawaiʻi Kahekili Herbivore Fisheries Management Area overlaid on DigitalGlobe™ QuickBird-2 satellite imagery, west-central Maui, Hawaiʻi. See text for discussion of North, Middle, and South geographic areas.

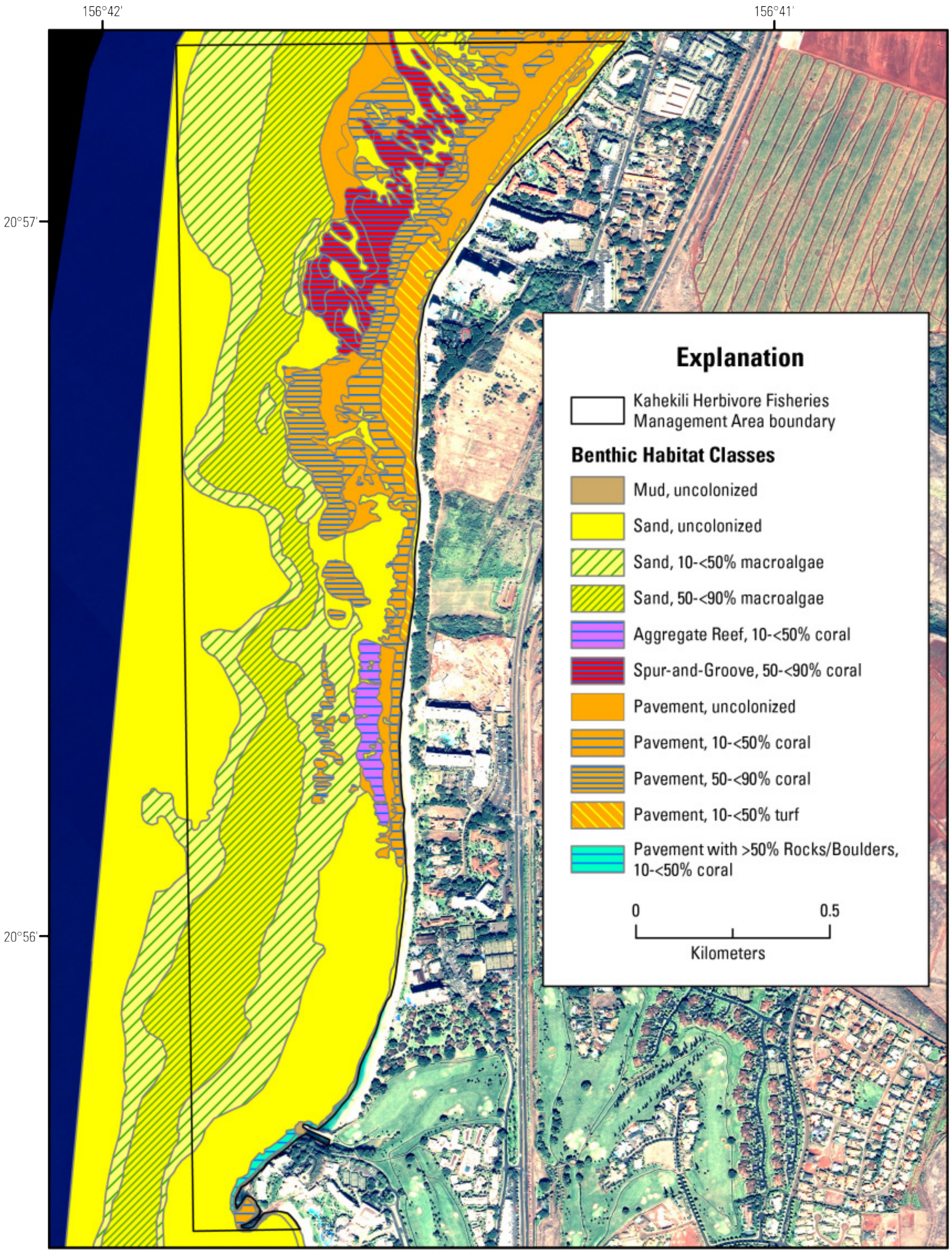

Figure 13. Zoomed-in benthic habitat map showing State of Hawai'i Kahekili Herbivore Fisheries Management Area overlaid on DigitalGlobe™ QuickBird-2 satellite imagery, west-central Maui, Hawai'i.

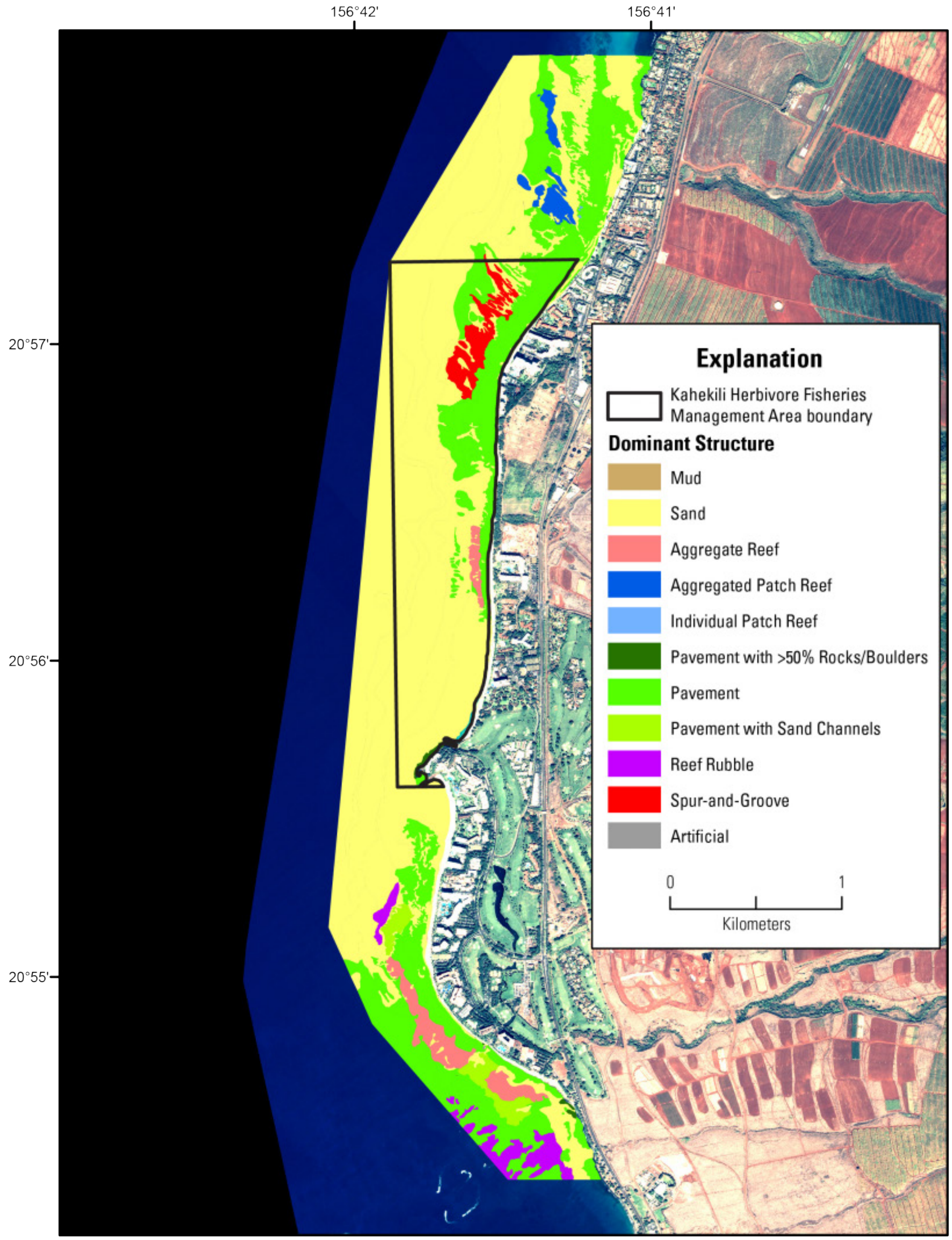

Figure 14. Map showing dominant structures (substrates) in U.S. Coral Reef Task Force Watershed Partnership Initiative Kāʻanapali priority study area and State of Hawaiʻi Kahekili Herbivore Fisheries Management Area overlaid on DigitalGlobe™ QuickBird-2 satellite imagery, west-central Maui, Hawaiʻi.

Table 5. Breakdown of area mapped for each dominant structure (substrate) attribute and percentage of total area mapped.

Dominant structure	Mapped area (km^2)	Percentage of total area mapped
Mud	<0.01	<0.01
Sand	3.11	64.85
Aggregate reef	0.13	2.70
Aggregated patch reef	0.06	1.20
Individual patch reef	0.01	0.01
Pavement with >50 percent rocks/boulders	0.01	0.14
Pavement	1.22	25.57
Pavement with sand channels	0.07	1.53
Reef rubble	0.10	2.07
Spur-and-groove	0.09	1.93
Artificial	<0.01	<0.01

Table 6. Breakdown of area mapped for each major biologic cover attribute and percentage of total area mapped.

Major biologic cover	Mapped area (km^2)	Percentage of total area mapped
Coral	0.85	17.79
Macroalgae	1.73	36.09
Turf	0.30	6.28
Uncolonized	1.91	39.84
Unknown	<0.01	<0.01

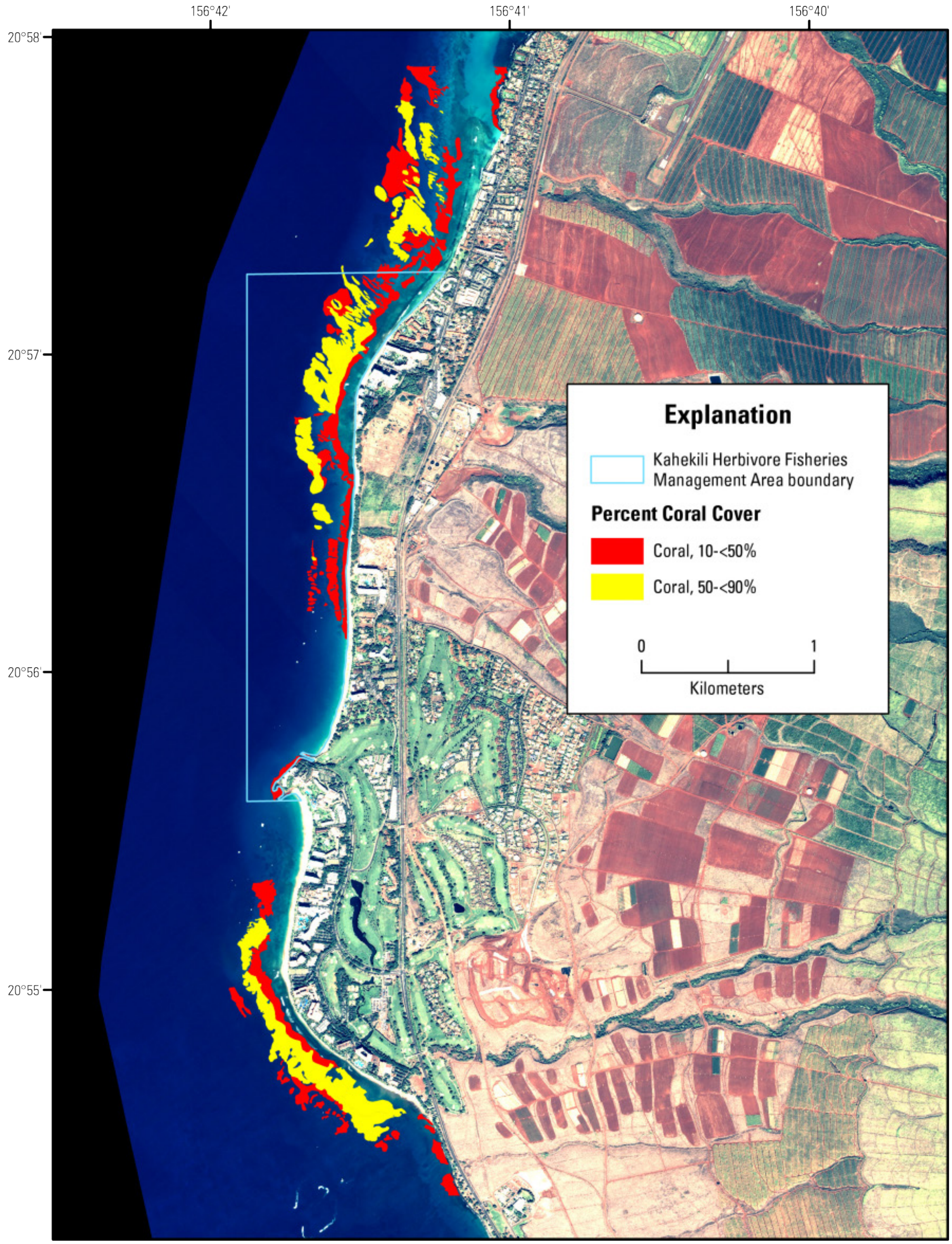

Figure 15. Map showing distribution of percentage of coral cover in U.S. Coral Reef Task Force Watershed Partnership Initiative Kāʻanapali priority study area and State of Hawaiʻi Kahekili Herbivore Fisheries Management Area overlaid on DigitalGlobe™ QuickBird-2 satellite imagery west-central Maui, Hawaiʻi.

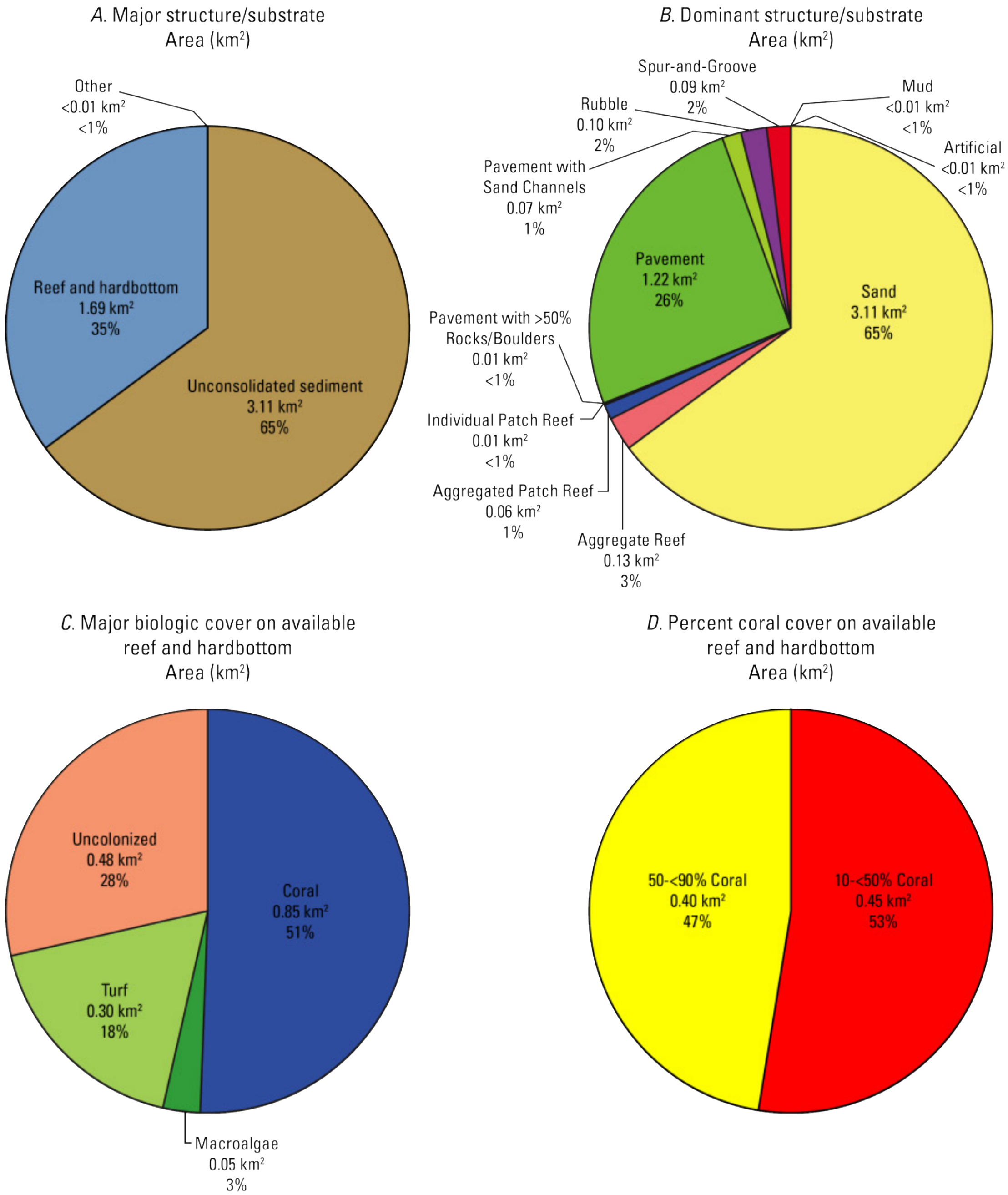

Figure 16. Relative abundance of (*A*) major and (*B*) dominant structure/substrates, (*C*) major biologic coverage on available reef and hardbottom, and (*D*) percent coral cover on available reef and hardbottom in study area. Nearly all unconsolidated sediment in study area (65 percent of study area) is sand (*A*, *B*). Remaining 35 percent of study area is reef and hardbottom available for coral habitat (*C*). Of this available hardbottom, 51 percent is covered with minimum of 10 percent coral (*C*, *D*). Most of study area is colonized with less than 50 percent live coral.

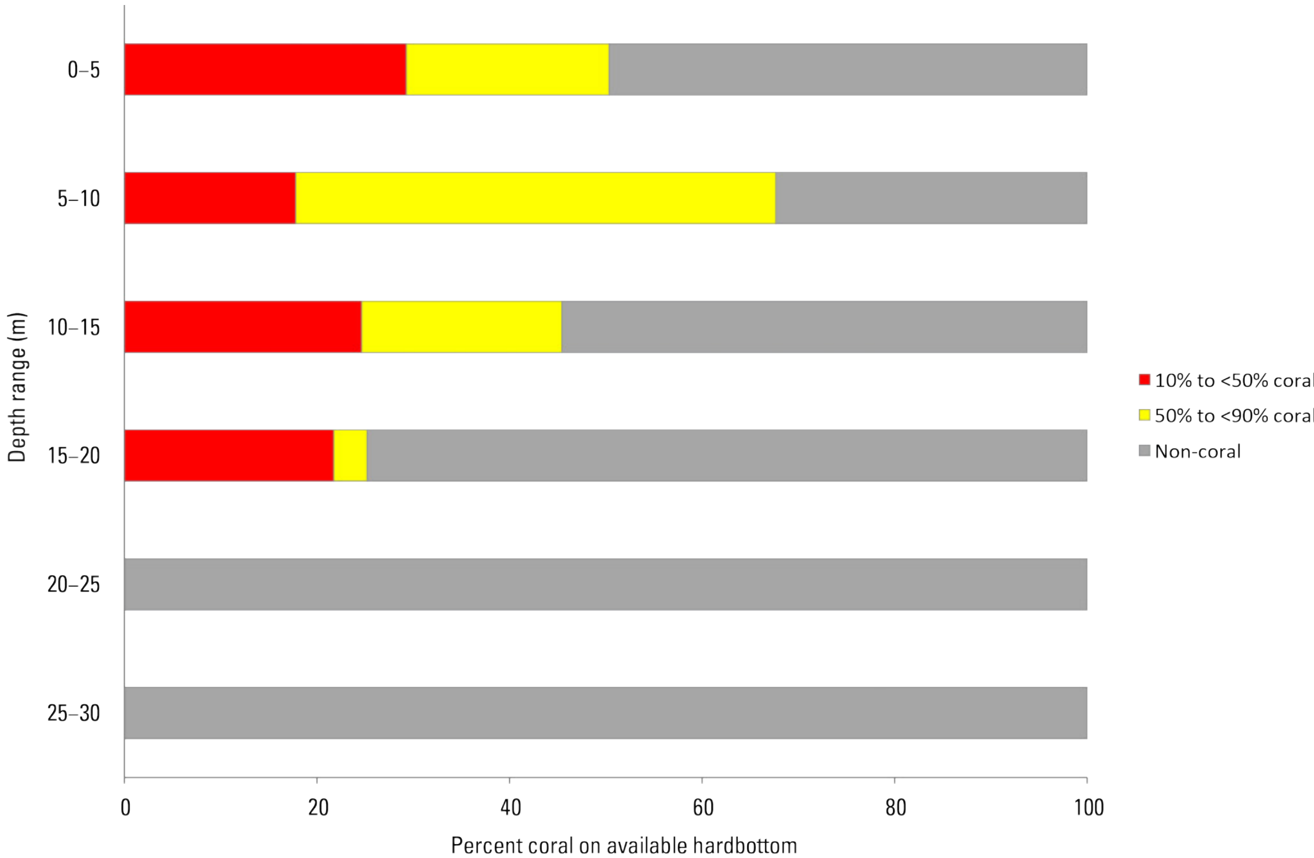

Figure 17. Bar graph showing percentage of coral on available hardbottom by depth. Most coral cover is present in water depths between 5 and 10 m. Non-coral is uncolonized hardbottom, as well as those areas of hardbottom covered with turf and (or) macroalgae.

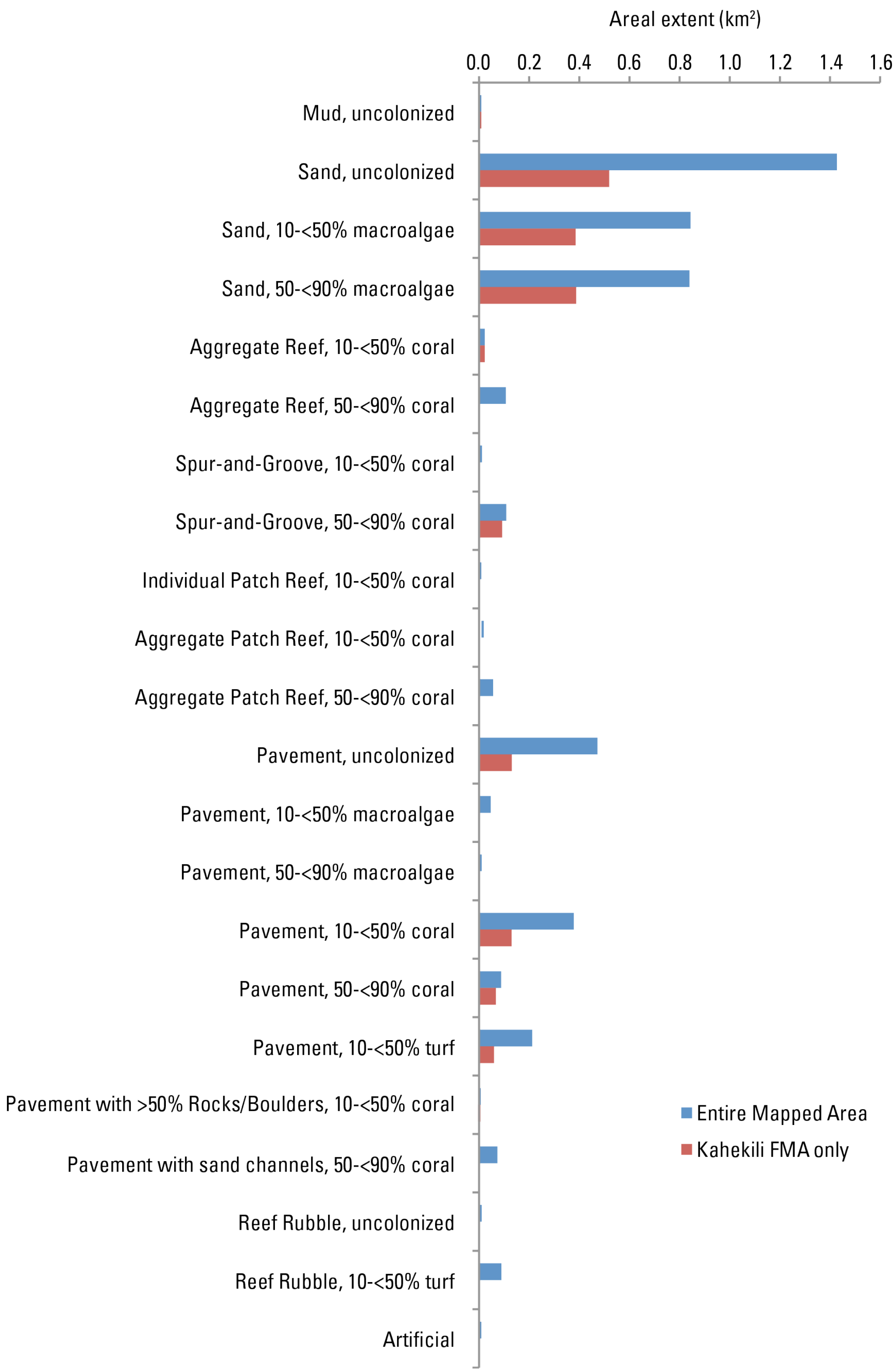

Figure 18. Bar graph comparing areal extent of benthic habitats mapped in entire study area to corresponding habitats mapped within boundaries of Kahekili Herbivore Fisheries Management Area (FMA) only, west-central Maui, Hawai'i.

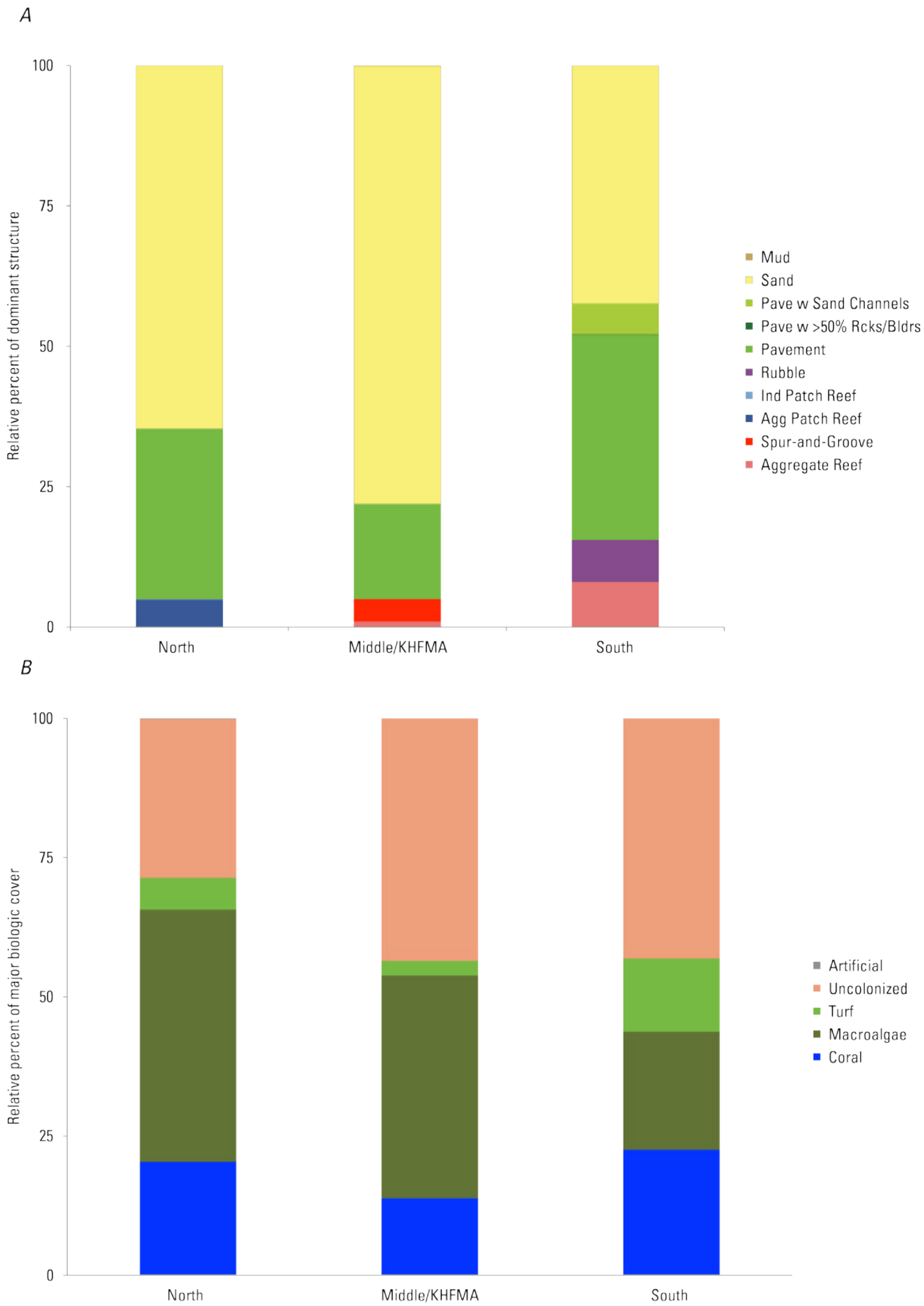

Figure 19. Bar graphs showing (*A*) relative percent of dominant structure, and (*B*) major biologic cover attributes present in North, Middle, and South geographic zones of the study area. KHFMA, Kahekili Herbivore Fisheries Management Area; Pave, Pavement; Rcks/Bldrs, Rocks/Boulders; Ind, Individual; Agg, Aggregated.

Table 7. Accuracy assessment matrix for dominant structure attributes.

[Pvmt, Pavement; rx/bldr, rocks/boulders]

		Found to be in field: Aggregate reef	Aggregated patch reef	Pavement	Pvmt w/sand channels	Pvmt w/10-50% rx/bldr	Spur-and-groove	Reef rubble	Sand	Total	User's accuracy (percent)
As mapped	Aggregate reef	2								2	100
	Aggregated patch reef		1		1					2	50
	Pavement	1		26		2			3	32	81
	Pvmt w/sand channels				1					1	100
	Pvmt w/10-50% rx/bldr					0				0	100
	Spur-and-groove						2			2	100
	Reef rubble			1				1		2	50
	Sand			1					58	59	98
Total		3	1	28	2	2	2	1	61		
Producer's accuracy (percent)		67	100	93	50	0	100	100	95		Diagonal sum = 91
											Overall accuracy = 91 T_e = 90

Table 8. Accuracy assessment matrix for major biologic cover attributes.

		Found to be in field				Total	User's accuracy (percent)
		Coral	Macroalgae	Turf algae	Uncolonized		
As mapped	Coral	18	1		4	23	78
	Macroalgae	1	36			37	97
	Turf algae		1	7	1	9	78
	Uncolonized	2	4		25	31	81
Total		21	42	7	30		
Producer's accuracy (percent)		86	86	100	83		Diagonal sum = 86
							Overall accuracy = 86 T_e = 84

Table 9. Accuracy assessment matrix for percentage of major biologic cover attributes.

		Found to be in field							Total	User's accuracy (percent)
		10-<50% Coral	50-<90% Coral	10-<50% Macroalgae	50-<90% Macroalgae	10-<50% Turf Algae	50-<90% Turf Algae	Uncolonized		
As mapped	10-<50% Coral	10		1				4	15	67
	50-<90% Coral	1	7						8	88
	10-<50% Macroalgae			15	2				17	88
	50-<90% Macroalgae		1		19				20	95
	10-<50% Turf algae			1		6	1	1	9	67
	50-<90% Turf Algae						0		0	100
	Uncolonized	1	1	3	1			25	31	81
Total		12	9	20	22	6	1	30		
Producer's accuracy (percent)		83	78	75	86	100	0	83		Diagonal sum = 82
										Overall accuracy = 81 T_e = 79

Digital Data Availability

The GIS shapefile for the benthic habitat map is available for digital download from the USGS at http://pubs.usgs.gov/of/2014/1129/.

Future Outlook

The Kahekili Herbivore Fisheries Management Area (KHFMA) was designated with the specific focus to protect herbivores—including three fish families (*Acanthuridae*, *Scaridae*, and *Kyphosidae*) and all urchins—and to impose a ban on fish feeding. This new fisheries management strategy capitalizes on the ecological services of herbivores by protecting them from harvest and allowing natural recruitment to replenish their numbers. After four years, the monitoring data (Williams, 2013) indicate no change in surgeonfish biomass. Given that surgeonfishes generally are long-lived (40–80 years), and have only been protected for a short period of time, this is not surprising. However, there is a consistent increasing trend in parrotfish biomass; specifically, more fishes are reaching older life stages (Williams, 2013). This trend is not distributed evenly over the KHFMA, and has not increased in the shallow nearshore reef area. The increase in parrotfish biomass is strongly correlated to an increase in crustose coralline algae cover (Williams, 2013), a suitable substrate for coral larvae recruits and an indicator of reef resilience (Fabricius and De'ath, 2001; Vermeij and others, 2011; Heenan and Williams, 2013). Coralline algae is present in the mapped area, but only in minor amounts. Therefore, at the scale of the mapping in this report (100 m^2 MMU), no polygons have coralline algae as the major biologic cover attribute in this report.

This map was created using satellite imagery from 2005, SHOALS bathymetry from 2000, sidescan-sonar data from 2012, and underwater video from 2002 to 2011, and reflects the benthic habitats found at those times. Repeat mapping in the future would be beneficial for change detection and can help determine if management plans are effective. The full effects of the management strategy on fishes and slow-growing corals would take many more years, but early indications are positive.

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Appendix A. Detailed Classification Scheme

The classification scheme used by the U.S. Geological Survey for benthic habitat mapping of the U.S. Coral Reef Task Force Watershed Partnership Initiative Kāʻanapali priority study area and the State of Hawaiʻi Kahekili Herbivore Fisheries Management Area, West Maui, Hawaiʻi is described in appendix A. Each of the habitats and zones is described in detail with some example photos. Many of the descriptions are from the NOAA classification scheme for the main eight Hawaiian Islands (Coyne and others, 2003), and subsequent revision (National Oceanic and Atmospheric Administration, National Centers for Coastal Ocean Science, 2005).

Habitats

Major Structure—Unconsolidated Sediment

Mud—Fine sediment often associated with stream discharge and buildup of organic material in areas sheltered from high-energy waves and currents (for example, harbors, and fishponds).

Figure A-1. Example of muddy shallow area exposed at low tide (Kawela, Molokaʻi).

Sand—Coarse sediment typically found in areas exposed to currents or high wave energy (reef-derived) or on beaches (land-derived or reef-derived).

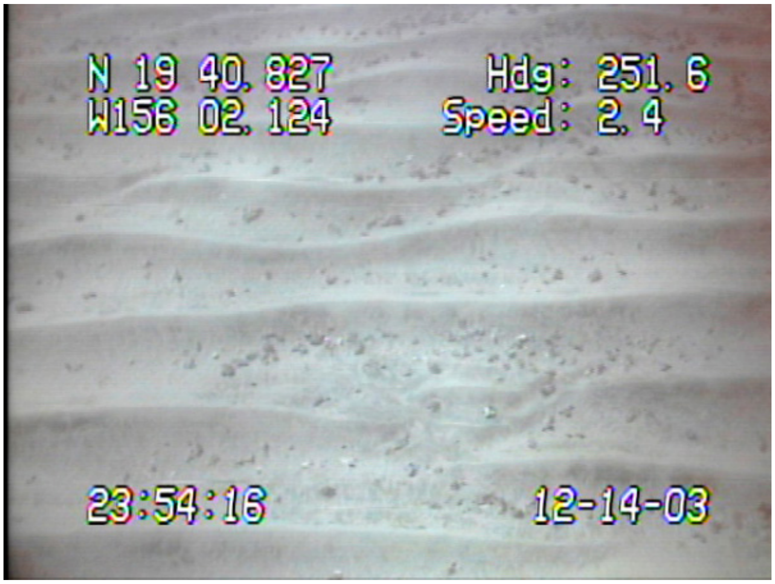

Figure A-2. Example of uncolonized sand (Kaloko-Honokōhau, Hawai'i).

Major Structure—Reef and Hardbottom

Aggregate reef—Formations with high relief and complexity, which form an extensive reef structure without sand channels (as found in spur-and-groove). Note that aggregate reef refers to the underlying hard structure and implies nothing about the nature of the biological cover, nor whether it is live or dead.

Figure A-3. Example of aggregate reef with 90–100% coral (Kawaihae Bay, Hawai'i).

Spur-and-groove—Elongate, alternating sand and coral formations that are oriented perpendicular to the shore or bank/shelf escarpment. The coral formations (spurs) of this feature typically have a high vertical relief relative to the pavement with the channels, and are separated from each other by 1–5 m of sand or bare pavement (grooves).

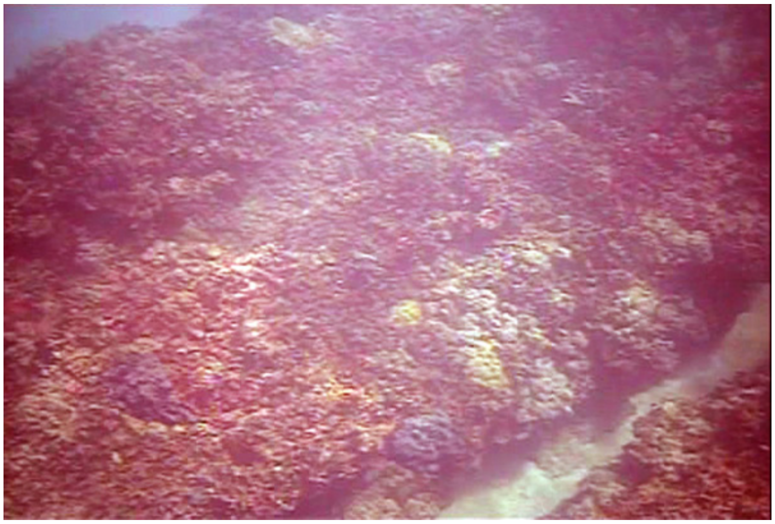

Figure A-4. Example of spur-and-groove reef system with 90–100% coral cover on spurs (Kawaihae Bay, Hawai‘i).

Individual patch reef—Coral formations, larger than or equal to the minimum mapping unit (MMU) (100 m^2 in this study), that are isolated from other coral reef formations by sand, seagrass, or other habitats and that have no organized structural axis relative to the contours of the shore or shelf edge.

Aggregated patch reef—Clustered coral formations, smaller than the MMU (100 m^2 in this study) or too close together to be mapped separately, that are isolated from other coral reef formations by sand, seagrass, or other habitats and that have no organized structural axis relative to the contours of the shore or shelf edge.

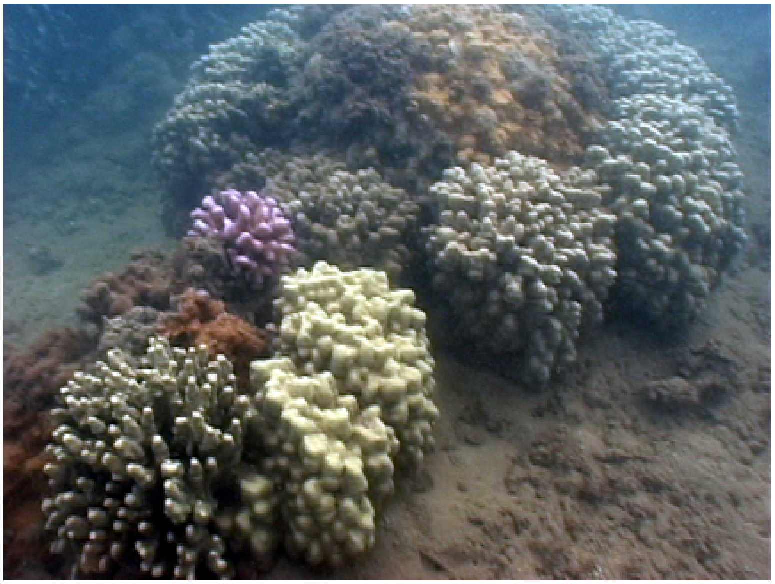

Figure A-5. Example of aggregated patch reef covered with 50-<90% coral (Moloka'i). These patch reefs are smaller than minimum mapping unit and, therefore, could not be called individual patch reefs. They would be digitized together, along with others shown in background, as aggregated patch reefs.

Volcanic pavement—Volcanic substrate with less than 10 percent loose rocks or boulders scattered on the surface. Volcanic substrate may be smooth or irregular, depending on the original lava flow and subsequent erosion patterns.

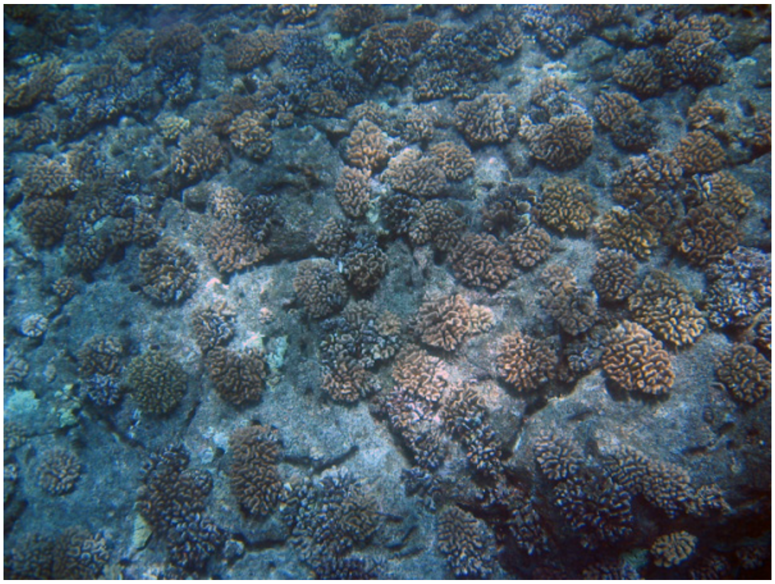

Figure A-6. Example of volcanic pavement with 50-<90% coral cover (Hōnaunau Bay, Hawai‘i).

Volcanic pavement with sand channels—Having volcanic substrate alternating with sand channels that are oriented perpendicular to the shore or bank/shelf escarpment. The sand channels have low vertical relief relative to spur-and-groove formations.

Figure A-7. Example of volcanic pavement with sand channels, with 90–100% coral cover (Kaloko-Honokōhau, Hawai‘i).

Volcanic pavement with 10-<50% rocks/boulders—Volcanic substrate with 10–<50% volcanic rocks and (or) boulders scattered on the surface. The underlying substrate may be smooth or irregular, depending on the original lava flow and subsequent erosion patterns.

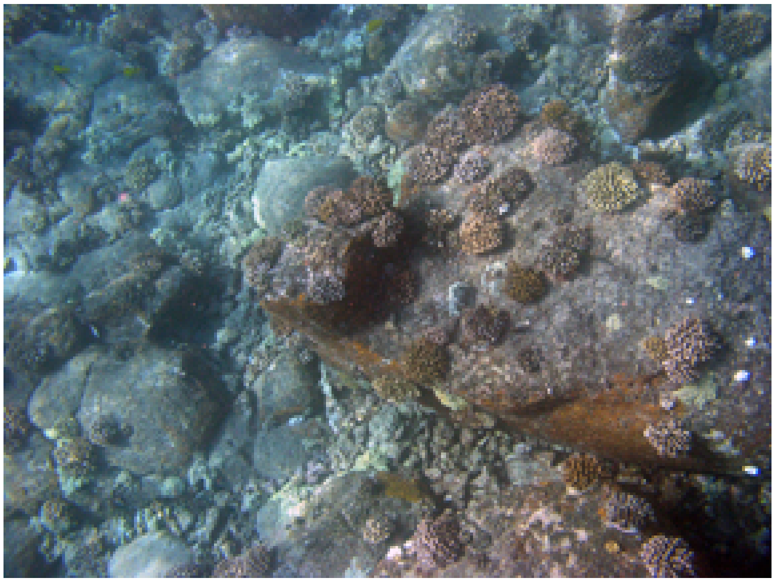

Figure A-8. Example of volcanic pavement with 10–<50% rocks/boulders, with 10–<50% coral cover (Hōnaunau Bay, Hawai'i).

Volcanic pavement with >50% rocks/boulders—Volcanic substrate with >50% volcanic rock and (or) boulders on the surface. The underlying substrate may be smooth or irregular, depending on the original lava flow and subsequent erosion patterns.

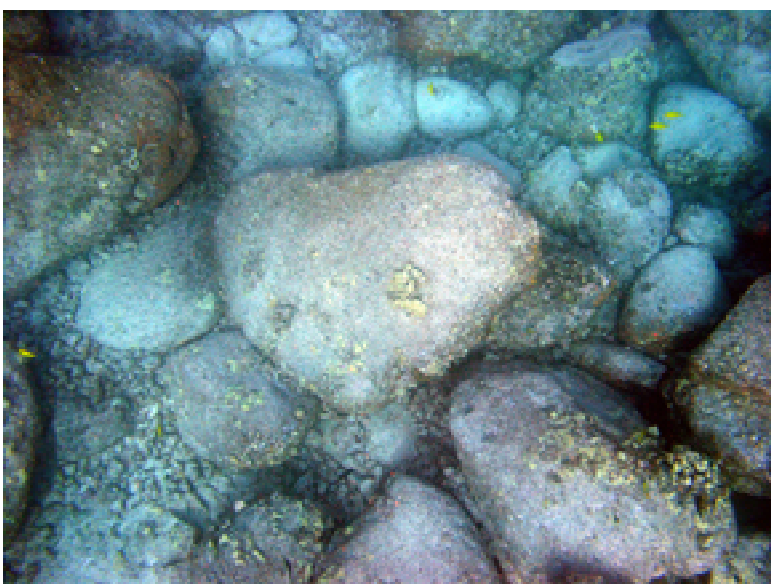

Figure A-9. Example of volcanic pavement with >50% rocks/boulders with less than 10 percent cover, and, therefore, 90–100% uncolonized (Kaloko-Honokōhau, Hawai'i).

Reef rubble—Dead, unstable coral rubble, often covered with coralline algae or filamentous or other macroalgae.

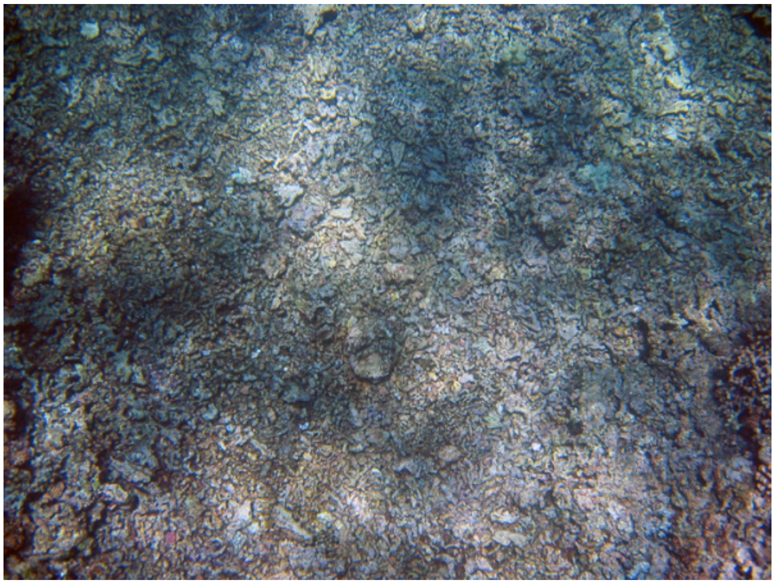

Figure A-10. Example of reef rubble with less than10 percent cover, and, therefore, 90–100% uncolonized (Kawaihae Bay, Hawai‘i).

Major Structure—Other

- *Land*—Area shoreward of the mean high water line, or landward edge of emergent vegetation, when present.
- *Artificial*—Manmade habitats such as large piers, submerged parts of riprap jetties, and shoreline areas created from dredge spoil.
- *Artificial/historical*—Manmade features of historical significance, such as active and relict fishpond walls.

Zones

- *Land*—Area shoreward of the mean high water line, or landward edge of emergent vegetation, when present.
- *Shoreline/intertidal*—Area between the mean high water line (or landward edge of emergent vegetation) and lowest spring tide level. Typical habitats include mangrove and other emergent vegetation, sand, mud, and uncolonized rock.
- *Vertical wall*—Area with near-vertical slope along channels, from shelf to shelf escarpment, or between different inner-shelf platforms. This zone typically is narrow and may not be visible in remotely sensed imagery, but is included because it is recognized as a biologically important feature. Typical habitats include coral, algae, and uncolonized rock.
- *Lagoon*—Shallow area between the shoreline/intertidal zone and the back reef zone of a barrier reef system. If no reef crest is present, there is no lagoon zone. Typical habitats include individual patch reefs, sand, seagrass, algae, and pavement.
- *Back reef (with lagoon)*—Area between the seaward edge of a lagoon floor and the landward edge of a reef crest. This zone is present only when a reef crest and lagoon also are present. Typical habitats include sand, coral rubble, seagrass, algae, and patch reefs.

- *Reef flat (without lagoon)*—Shallow, semi-exposed area between the shoreline/intertidal zone and the reef crest of a fringing reef system. This zone is protected from the high-energy waves commonly experienced on the reef crest and fore reef. The reef flat is not present if there is a lagoon. Typical habitats include sand, reef rubble, pavement, algae, mud, and patch reefs.
- *Reef crest*—Flattened, emergent (especially during low tides) or nearly emergent segment of a reef, usually where the waves break. This zone is between the back reef and fore reef zones of a barrier reef system, and between the reef flat and fore reef of a fringing system. Typical habitats include reef rubble, patch reefs, and aggregate reefs.
- *Fore reef*—Area from the seaward edge of the reef crest that slopes into deeper water to the landward edge of the bank/shelf platform. Fore reef is also defined as features not forming an emergent reef crest but still having a seaward-facing slope that is significantly greater than the slope of the bank/shelf. Typical habitats include aggregate coral reef and spur-and-groove.
- *Bank/shelf*—A deep-water platform extending offshore from the seaward edge of the fore reef to the beginning of the escarpment where the insular shelf drops off into deep, oceanic water. If no reef crest is present, the bank/shelf is the flattened platform between the shoreline/intertidal zone and deeper ocean offshore. Typical habitats include sand, patch reefs, algae, colonized and uncolonized pavement with and without sand channels, and other coral habitats.
- *Bank/shelf escarpment*—The edge of the bank/shelf where depth increases rapidly into deep, oceanic water. This zone begins in water depths of about 20–30 m, near the depth limit of features visible in aerial images. This zone captures the transition from the shelf to deep oceanic waters. Typical habitats include sand, aggregate reef, and spur-and-groove.
- *Channel*—Naturally occurring channels that often cut across several other zones. Typical habitats include sand, mud, and uncolonized pavement.
- *Dredged*—Area in which natural geomorphology is disrupted by excavation or dredging (for example, harbors and manmade channels). Typical habitats include reef rubble, sand, and mud.

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