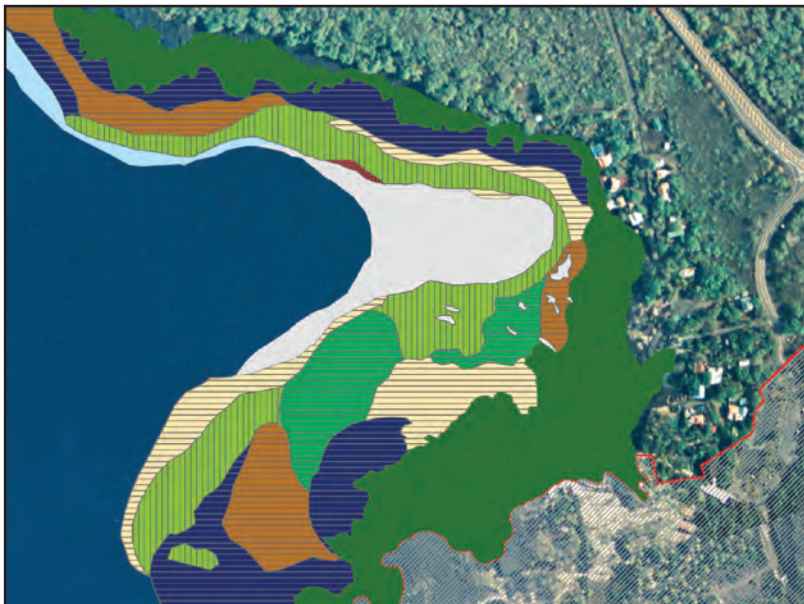
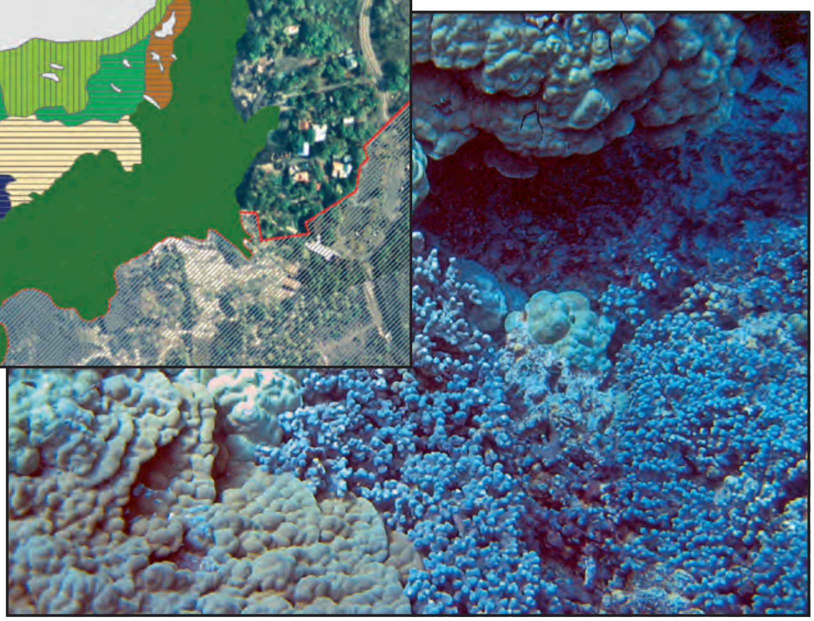
Prepared in cooperation with the U.S. National Park Service

Geologic Resource Evaluation of Pu`uhonua O Hōnaunau National Historical Park, Hawai`i

Part II: Benthic Habitat Mapping





Scientific Investigations Report 2006-5258

U.S. Department of the Interior
U.S. Geological Survey

Geologic Resource Evaluation of Pu`uhonua O Hōnaunau National Historical Park, Hawai`i

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By Susan A. Cochran, Ann E. Gibbs, and Joshua B. Logan

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Cover: Left, enlarged portion of benthic habitat map showing Hōnaunau Bay and Pu`uhonua O Hōnaunau National Historical Park shoreline. Right, underwater photograph shows example of coral reef habitat on the Kona coast of Hawai`i.

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Part II: Benthic Habitat Mapping

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Introduction

In cooperation with the U.S. National Park Service (NPS), the U.S. Geological Survey (USGS) has mapped the underwater environment in and adjacent to three parks along the Kona coast on the island of Hawai`i (fig. 1). This report is the second of two produced for the NPS on the geologic resource evaluation of of Pu`uhonua O Hōnaunau National Historical Park (PUHO) and presents the results of benthic habitat mapping of the offshore waters for PUHO. See Part I (Richmond and others, 2005) for an overview of the regional geology, local volcanics, and a detailed description of coastal landforms in the park.

Pu`uhonua O Hōnaunau National Historical Park boundaries extend only to the mean high tide line and do not officially include the marine environment. However, impacts downslope of any development in the park are of concern to management. The area mapped for this report extends from Hōnaunau Bay, around Pu`uhonua Point, to Ki`ilae Bay and the south park boundary and from the shoreline to depths of approximately 40 m (130 ft), where the shelf drops off to a sand-covered bottom.

Pu`uhonua O Hōnaunau National Historical Park lies within the nearly 850-km² Ki`ilae watershed, which begins at the crest of Mauna Loa. The Ki`ilae Watercourse runs through the southern area of the park and empties into Ki`ilae Bay, but only during periods of extreme rainfall.

The waters of Keone`ele Cove, the ancient royal canoe landing at PUHO, while not formally under NPS jurisdiction, are managed by the park under an agreement with the State of Hawai`i. This small embayment is a known haven for sea turtles, which are often found sunning themselves on the near-

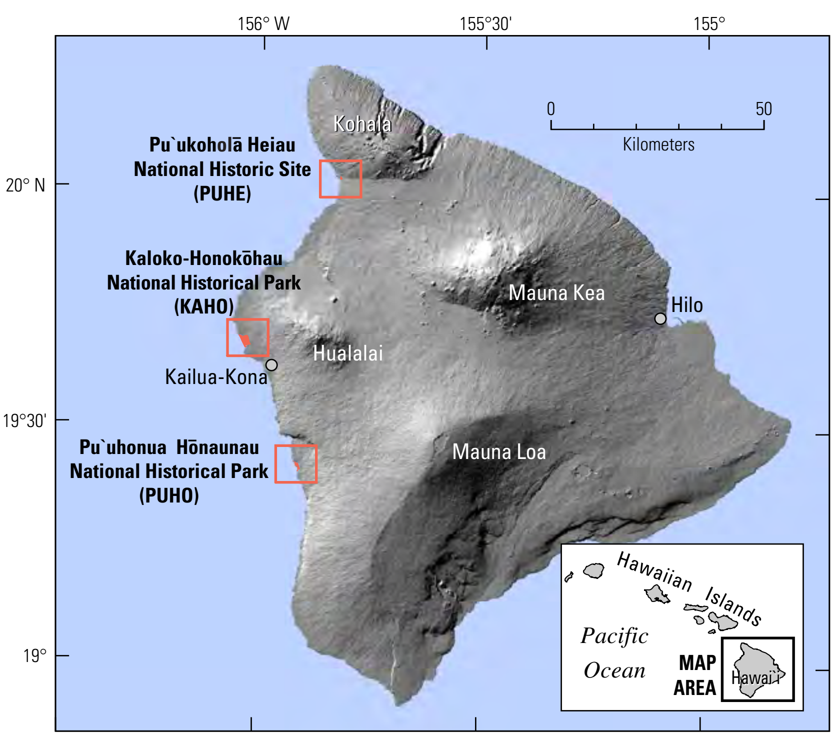

Figure 1. Index map of the Island of Hawai`i showing the location of the three National Parks along the Kona coast. Volcano names are shown in white.

shore volcanic platform. Impacts to this area include frequent visits by scuba divers and snorkelers to Hōnaunau Bay and a small boat ramp located just to the north of Keone`ele Cove.

Data and Methods

A standard for characterization of coral-reef environments was first 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 sea-floor 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 versus 1 acre) and with additional data sources, including existing color aerial photography, Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) bathymetric data, georeferenced underwater video, and still photography. The maps were generated using both ArcView and ArcMap Geographic Information System (GIS) software by ESRI (http://www.esri.com), and a statistical analysis of accuracy of the resultant maps was performed. The flowchart in figure 2 illustrates the complete methodology.

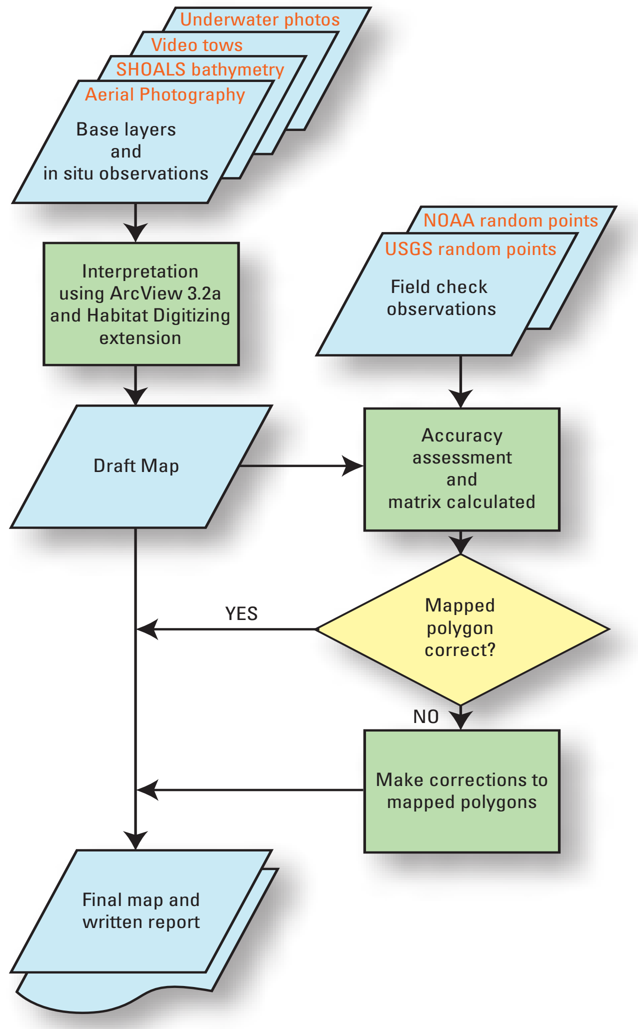

Figure 2. Flowchart illustrating methodology used to create Acquired Data habitat map. See text for complete description.

Background Data

Aerial Photography

The National Park Service provided the aerial imagery used as a base layer in this mapping effort. True-color aerial photographs were collected in June 2000 by NOAA. These images were geometrically registered to true map coordinates and mosaicked by the Pacific Disaster Center, resulting in an orthorectified digital mosaic with a resolution of 1 meter per pixel (fig. 3). For further details on NOAA aerial photography for Hawai`i see http://ccma.nos.noaa.gov/products/biogeography/hawaii_cd/htm/mosaic.htm.

SHOALS Lidar Bathymetry

High-resolution SHOALS bathymetry point data collected in 2000 by the U.S. Army Corps of Engineers (USACE) were obtained and converted to a raster surface using ESRI's 'GRID' function. The bathymetric data have an average horizontal point spacing of 4 m (± ~3 m) and a vertical resolution of ± 0.15 m, with a maximum depth penetration of about 38 m in the study area. Sparse data near the coastline and throughout the central part of the study area around Pu`uhonua Point were filled in by interpolating between the coastline and shoreward edge of the SHOALS bathymetry. However, there is still a data gap in Alahaka Bay (fig. 4). Isobaths, hillshades, and slope maps were derived from this dataset using standard ArcMap functions and used to assist in the interpretation. For further details regarding SHOALS data, see http://shoals.sam.usace.army.mil.

Acquired Data

Underwater Video and Still Photography

More than 6 trackline kilometers of underwater video footage (29 towed lines plus 1 snorkel), and more than 100 still-camera photographs and video-camera point drops were collected during two field surveys between April 2004 and August 2004 to assist in interpretation of the aerial photography and lidar bathymetry (fig. 5). Navigation and other information regarding these surveys are available online at http://walrus.wr.usgs.gov/infobank/a/a204hw/html/a-2-04-hw.meta.html, and http://walrus.wr.usgs.gov/infobank/a/a604hw/html/

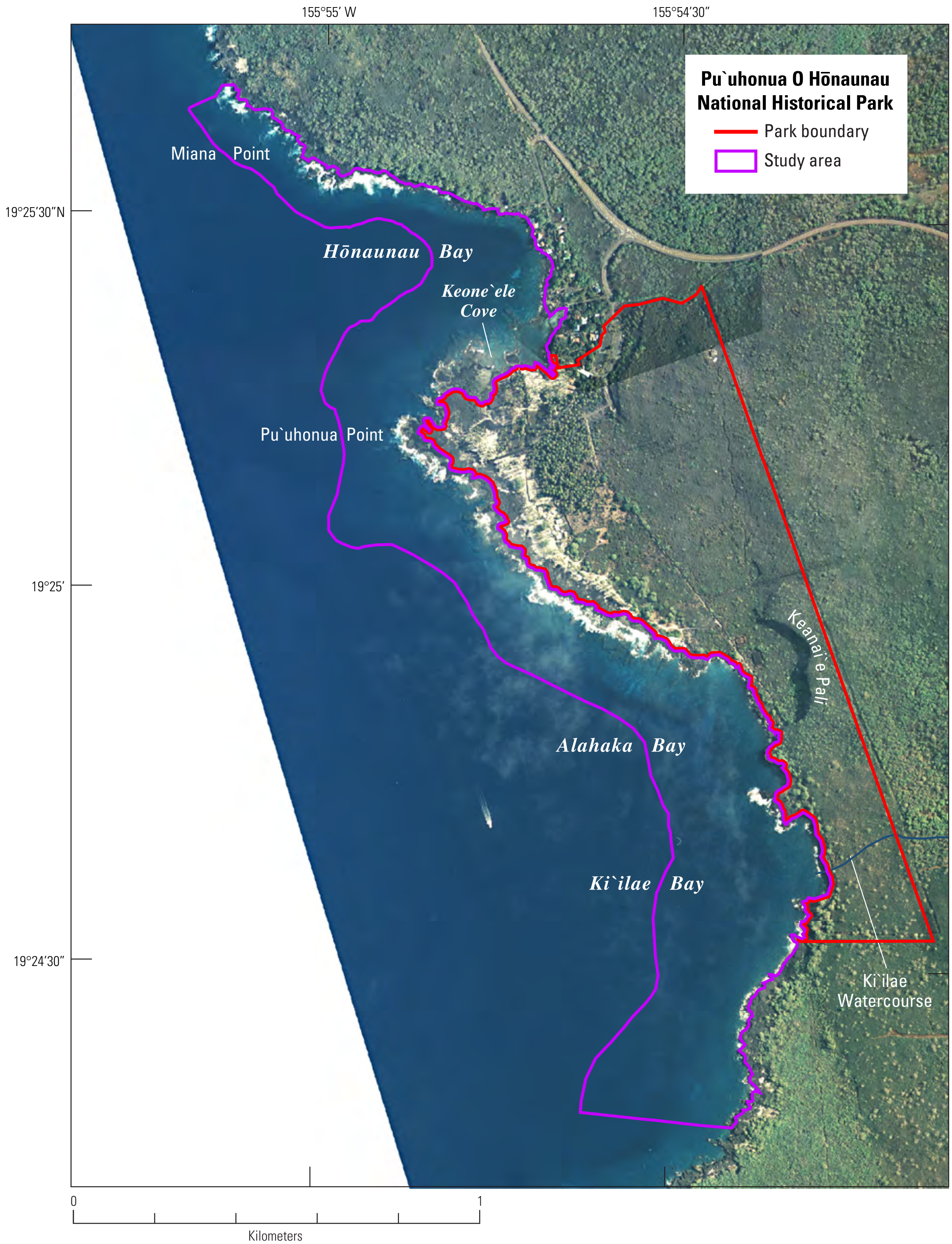

Figure 3. Aerial photomosaic showing PUHO park boundary, study area, and place names mentioned in text.

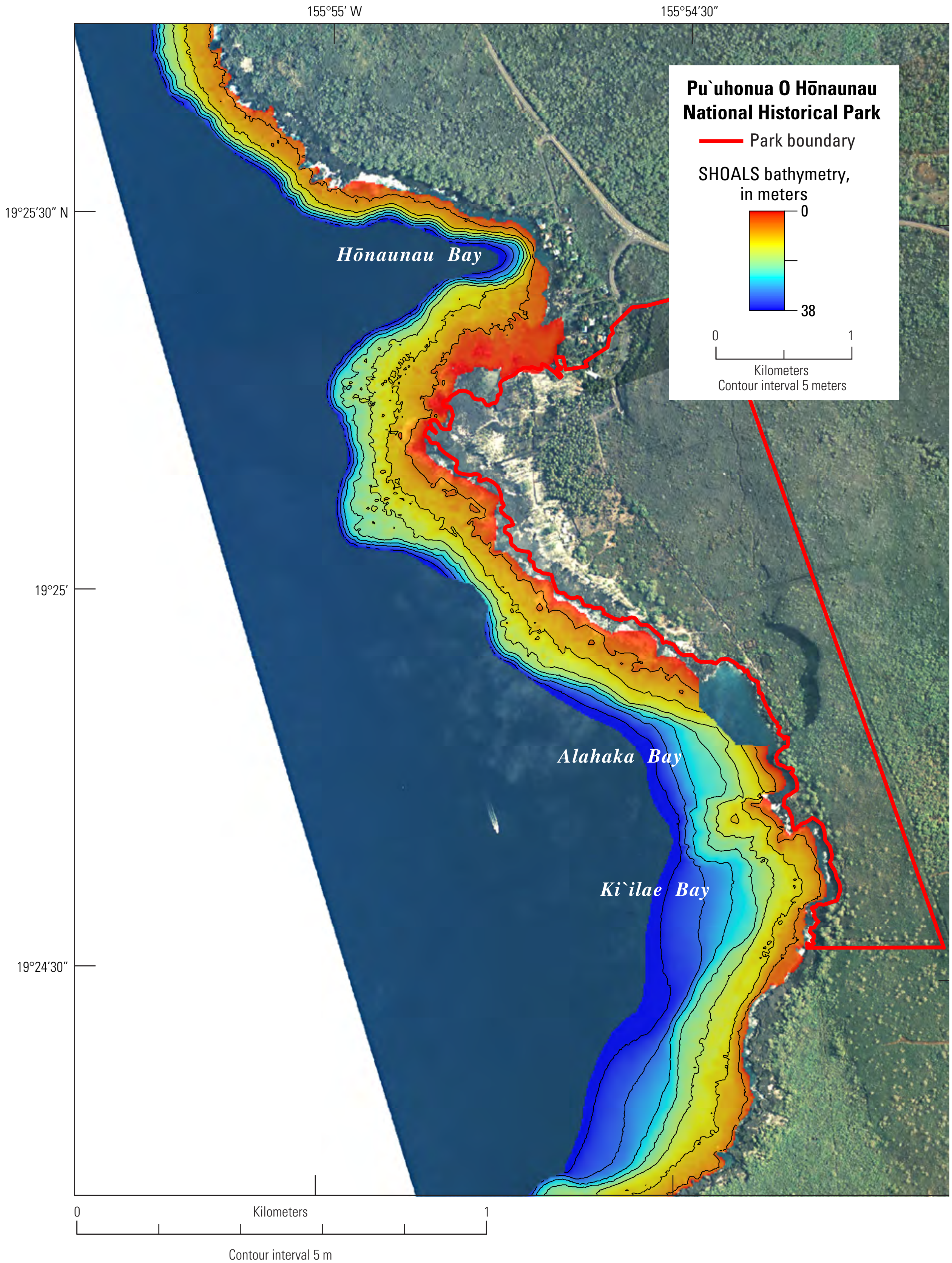

Figure 4. Aerial photomosaic of PUHO area overlaid with SHOALS bathymetry coverage.

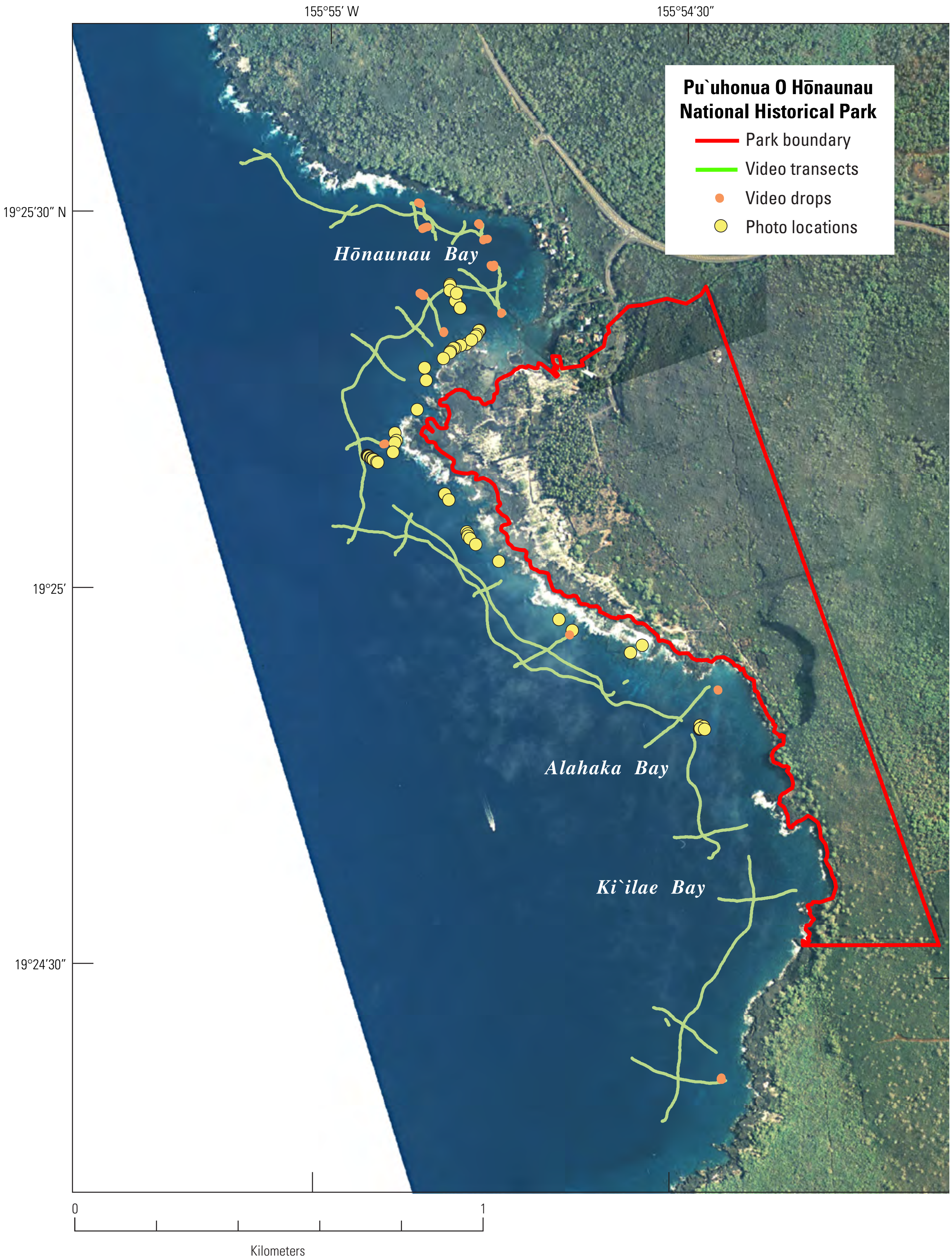

Figure 5. Aerial photomosaic of PUHO area overlaid with locations of video transects, video point drops, and still camera photographs.

a-6-04-hw.meta.html. Several types of camera systems and collection methods were used. During diving and snorkeling, still images were collected using a hand-held digital camera (Sony DSC-P5 or Canon PowerShot S-400).

Video imagery was also obtained by towing a camera off the *Alyce C*, a 32-ft vessel operated by Capt. Joe Reich of Moloka`i (fig. 6), and a 13-ft motorboat owned by the NPS. The camera system used was a watertight video camera illuminated with a light-emitting diode (LED) ring designed by SeaViewer Underwater Video Systems (http://www.seaviewer.com). The camera was mounted in a small aluminum hand-held frame with a rear-mounted plastic fin (fig. 7). Live video was viewed in a shipboard laboratory on a standard CRT monitor and recorded directly to miniDV tape. Time, date, location, and ship speed were overlaid on the video using the Sea-Trak global positioning system (GPS) method, also developed by the SeaViewer company.

Simultaneous navigation, recording of ship position, and feature annotation were conducted in real time using Red Hen Systems' (http://www.redhensystems.com) VMS200 hardware and MediaMapper software on a PC laptop (fig. 8). Location data were recorded using a hand-held, WAAS-enabled, Garmin (http://www.garmin.com) GPS76 receiver. The stated horizontal accuracy of the Garmin GPS76 is better than 3 m when receiving WAAS corrections. The VMS200 transmitted NMEA-formatted GPS data at two second intervals to the first audio channel of the video tape. A database was simultaneously created by MediaMapper to cross-reference the GPS locations and video time codes. This technique allowed for navigation and video to be viewed real-time and the location of features of interest and comments (for example, start/end of lines, substrate types) to be added to the database during data collection. Back in the lab, this technique allowed rapid random access to the original video by selecting locations along the navigation trackline within MediaMapper and GeoVideo (an extension developed by Red Hen Systems for integration with the ESRI ArcMap platform) software packages. Video could be interactively queried and geographically referenced feature annotations added to the database.

Benthic Habitat Mapping using GIS

Digital benthic habitat maps were created using ESRI's ArcViewGIS v.3.2 software with a habitat digitizing extension created by NOAA (to download the extension see http://ccma.nos.noaa.gov/products/biogeography/hawaii_cd/htm/digitize.htm). The habitat digitizing extension allows users to delineate habitat areas and assign attributes to the habitat polygons based on a predetermined classification scheme using a point-and-click menu system.

We digitally delineated more than 70 polygons, covering nearly 1 km^2, by interpreting features seen in both the aerial photographs and SHOALS bathymetry layers, with additional input from other data. A minimum mapping unit (MMU) of 100 m^2 was used; however, smaller features were mapped if

Figure 6. Photograph of the *Alyce C* of Moloka'i heading out of Mā'alaea Harbor, Maui.

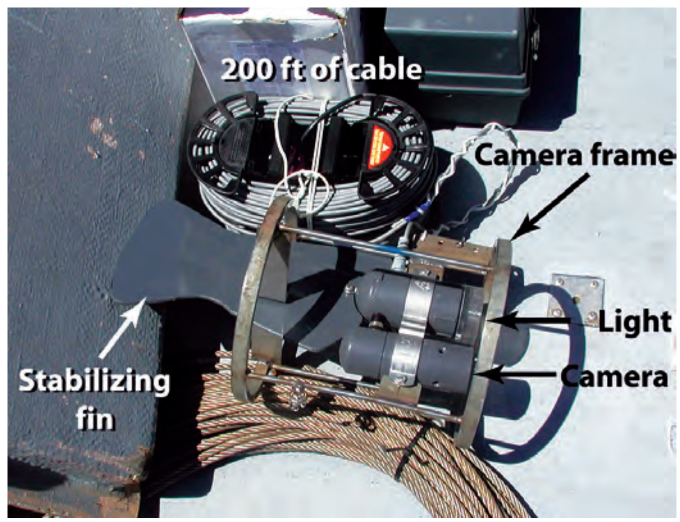

Figure 7. Photograph of SEAVIEWER camera system rigged to collect towed video.

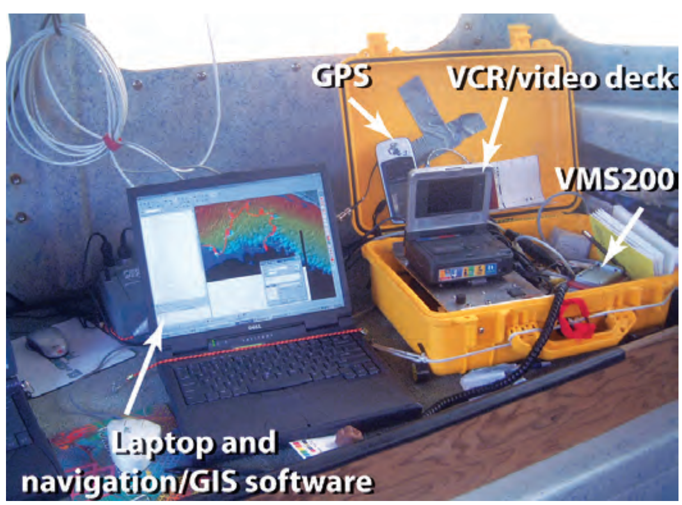

Figure 8. Photograph of shipboard system for navigation, recording of ship's position, and feature annotation.

they carried habitat significance (for example, an individual coral colony 2 m in diameter located in an otherwise uncolonized area).

Classification Scheme

The classification scheme is based on a scheme established by NOAA's biogeography benthic habitat mapping program in 2002 (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, local experts, and others, the hierarchal scheme allows users to expand or collapse the level of thematic detail as necessary. As stated above, we are using NOAA's definition of benthic habitats and their classification scheme as a starting point to provide continuity to the coral reef scientific community. However, we have made additional modifications to the classification scheme to better reflect the benthic habitats and geologic substrates found along the Kona 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 biological 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." Majority rules — if a polygon includes two or more substrate or coverage types, the polygon is identified with the dominant one.

Four major structure types are further subdivided into fifteen dominant structures (table 1). Ten major biologic cover types are also modified by the percent 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 reflects the combination of the individual habitat components (major structure, dominant structure, major biologic cover, and percent cover).

The fifth attribute, zone, refers only to a habitat community's location within the coral reef ecosystem and does not indicate the substrate or biological cover type (fig. 9). Eleven zones correspond to typical reef geomorphology found in current literature (table 4). An additional dredged zone has been added to include those areas where anthropogenic change has occurred (for example, harbors and manmade channels). Detailed descriptions of habitats and zones, including example photographs, may be found in the appendix.

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

[Numbers 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 classes.

[Numbers represent UNIQUEID identifier.]

Major Biological 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 classes

[Numbers represent UNIQUEID identifier.]

Percent Cover
0 Unknown
2 10–<50%
3 50–<90%
4 90–100%

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

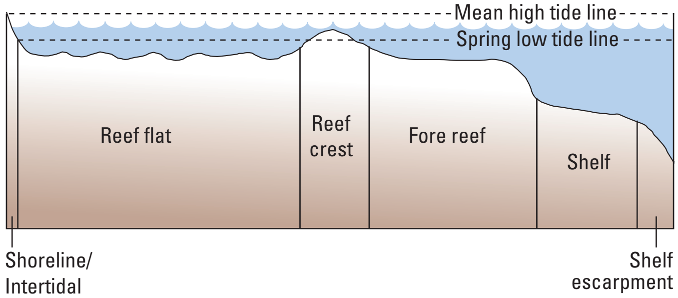

Figure 9. Schematic diagram showing the generalized cross-shelf coral reef zonation. Not shown: land, channel, dredged, or vertical wall (modified from Kendall and others, 2004). Detailed descriptions of the zones are given in the appendix.

Accuracy Assessment

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

This mapping project was performed concurrently with similar projects at two other National Parks along the Kona coast, Kaloko-Honokōhau National Historical Park (KAHO) and Pu`ukoholā Heiau National Historic Site (PUHE). A combination of field check data from all three parks was used to measure the accuracy of the PUHE benthic habitat map. Nearly 190 randomly generated sample points were visited by third-party coral reef research biologists from the University of Hawai`i who are highly familiar with the classification scheme. In addition, more than 50 sampling points from the NOAA database (http://ccma.nos.noaa.gov/products/biogeography/hawaii_cd/htm/aap.htm) were used in the accuracy assessment.

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

Data Archive

Underwater video footage, photographs, and associated shapefiles have been transferred to DVD. One complete set will be held in the USGS archives (see http://walrus.wr.usgs.gov/infobank/a/a204hw/html/a-2-04-hw.meta.html and http://walrus.wr.usgs.gov/infobank/a/a604hw/html/a-6-04-hw.meta.html to view list of analog holdings) and the other will be presented to the National Park Service to accompany this report. This report and project shapefiles are also available online (http://pubs.usgs.gov/sir/2006/5258).

Results

The reef zonation off Pu`uhonua O Hōnaunau National Historical Park (PUHO) is simple in the sense that it consists solely of a sloping volcanic shelf platform that begins at the shoreline and descends out to a sand-covered bottom towards the deep ocean (fig. 10). There is no reef crest separating a back reef from a fore reef, and no spur-and-groove structures.

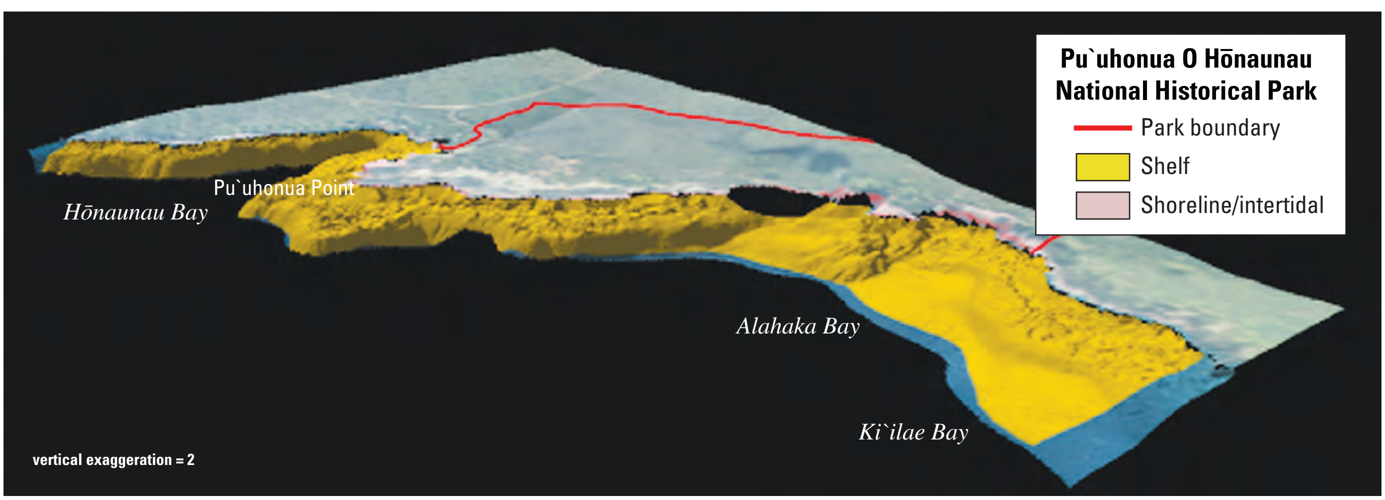

Figure 10. Three-dimensional perspective view of area of study, including Pu`uhonua O Hōnaunau National Historical Park, Hōnaunau Bay, Pu`uhonua Point, and Alahaka and Ki`ilae Bays, showing geographic reef zonation. Areas of black on reef shelf indicate lack of bathymetric data. View is to the northeast. Approximate distance along the bottom of the figure is 2.5 km.

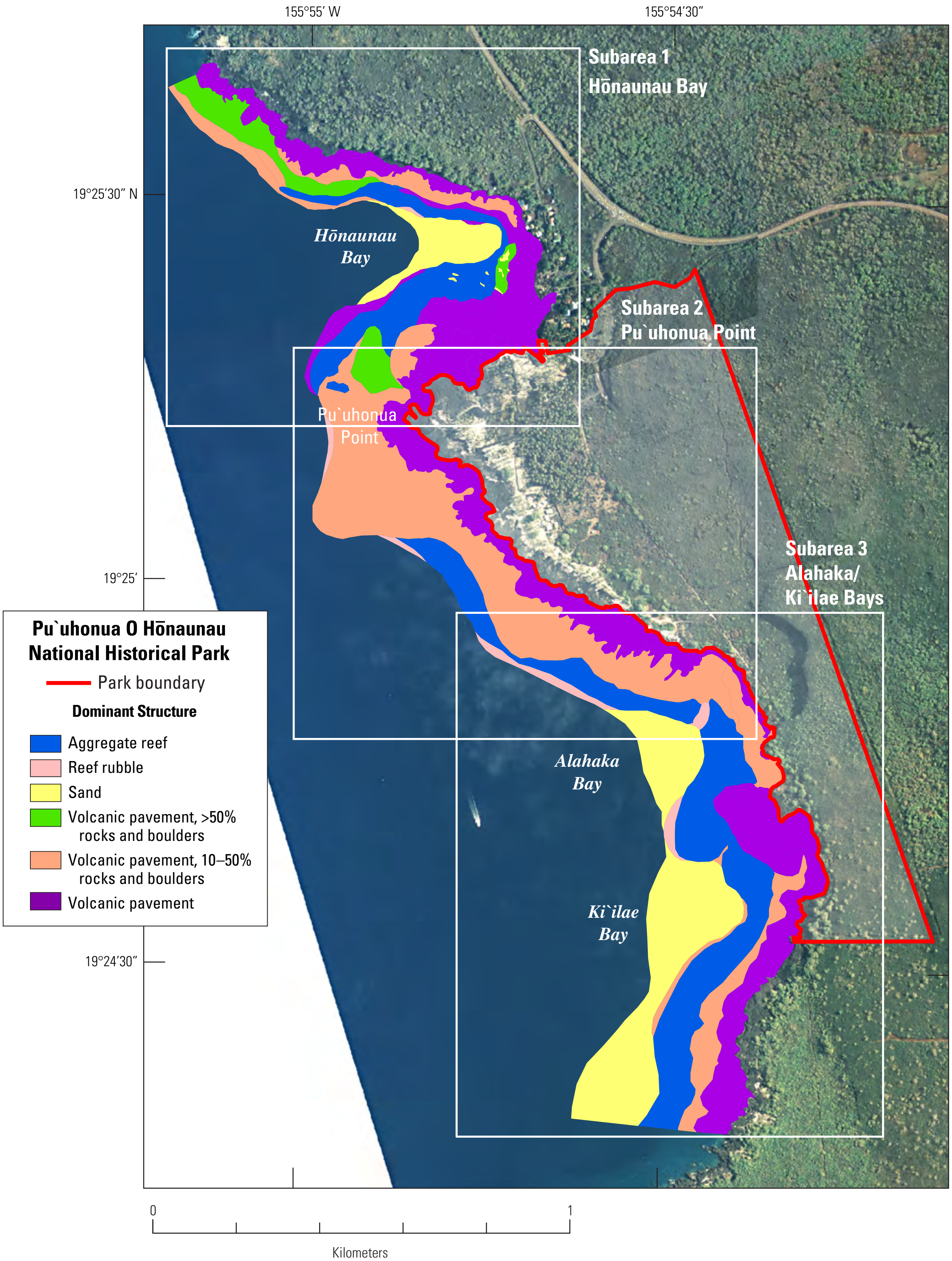

Figure 11. Classification map of Pu`uhonua O Hōnaunau National Historical Park showing dominant structure. The study area is divided into three subareas on the basis of their predominant benthic habitats and structure: (1) Hōnaunau Bay, (2) Pu`uhonua Point, and (3) Alahaka/Ki`ilae Bays. See text for detailed descriptions of each of these subareas.

The nearshore intertidal zone ranges in width from narrow rocky areas near the base of sea cliffs, to wide flat platforms around Keone`ele Cove, which are used as haul-out areas for basking sea turtles.

Although the reef zonation at PUHO is simple, the study area can be divided into three distinct subareas based upon their predominant benthic habitats and structure (fig. 11). Subarea 1 (Hōnaunau Bay), at the northern shoreline of PUHO, is a deep embayment with a well-developed coral community. Subarea 2 (Pu`uhonua Point), along the middle of the park, is exposed to high wave energy, and coral growth is limited. Subarea 3 (Alahaka and Ki`ilae Bays), at the south boundary, has variable coral cover on the volcanic pavement. Each of these subareas is described in detail below.

Hōnaunau Bay (Subarea 1)

The north boundary of PUHO lies along the south shore of Hōnaunau Bay. A well-developed coral reef environment has formed within Hōnaunau Bay (fig. 12), and easy accessibility makes it a favorite spot for recreational activities, including swimming, SCUBA diving, and snorkeling. A nearby public boat ramp allows fishermen quick access to the south Kona coastline.

The northern half of Hōnaunau Bay is characterized by a narrow (20–50 m) reef environment that abruptly drops off to the sandy bottom in the middle of the bay (fig. 13, transect *A–A*'). Near the mouth of the bay and along the southern half, the reef platform is much broader (120–150 m), yet it drops off to the bottom just as steeply (fig. 13, transect *B–B*').

A small (2–4 m high) sea cliff along the north shore of Hōnaunau Bay drops down into the shoreline zone. At the base of the sea cliff is uncolonized volcanic pavement. Around –3 m (10 ft below the surface of the water) the volcanic pavement becomes scattered with rocks and occasional large boulders and is dotted with small colonies of mostly *Pocillopora meandrina* and *Porites* sp. The volcanic pavement is relatively horizontal (~5° slope) between –3 m (–10 ft) and –15 m (–50 ft). Around –15 m the volcanic slope drops off at a 35°– 40° angle into a sand-covered bottom in the middle of the bay. This steep slope is characterized by a lush (50–<90 percent coral cover) aggregate reef that is covered predominantly with

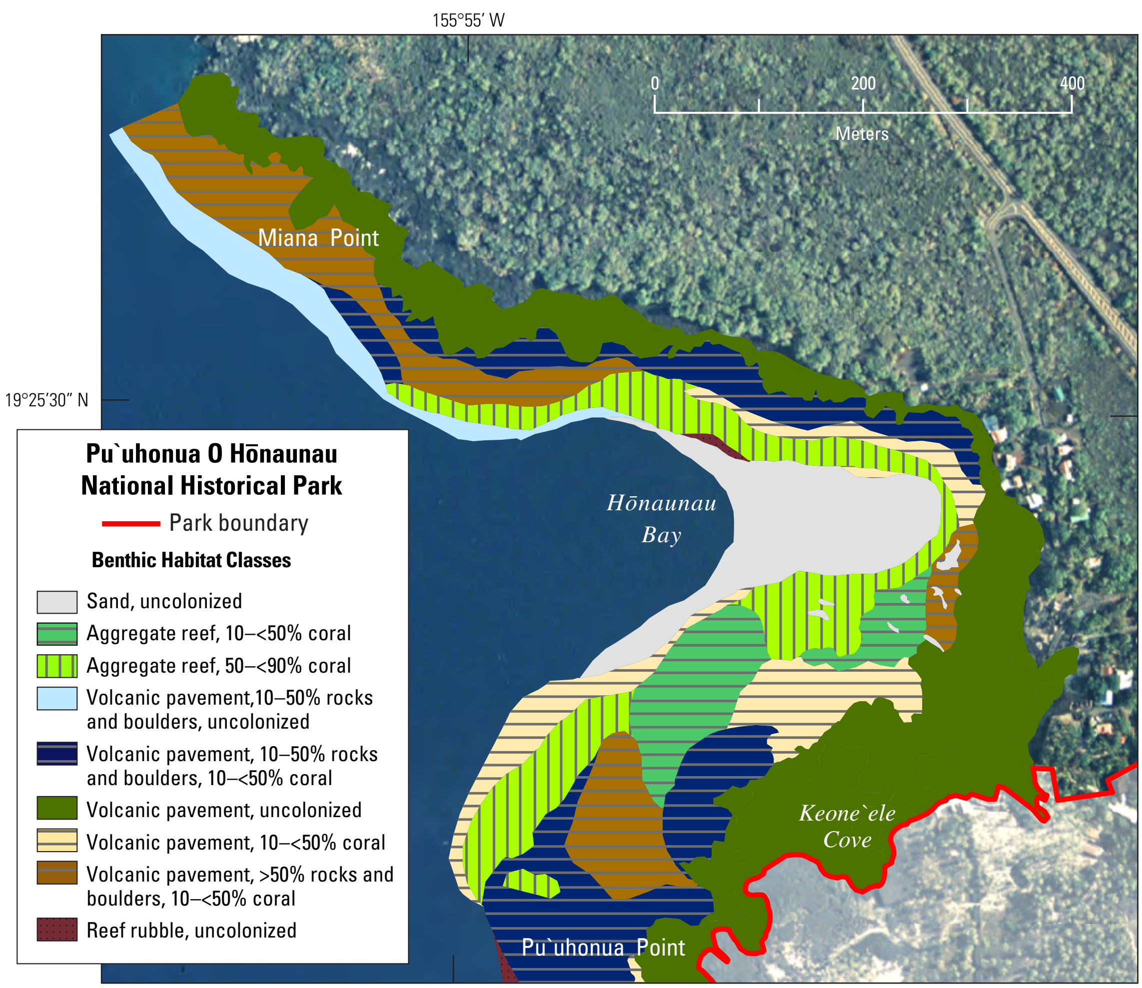

Figure 12. Aerial photomosaic of subarea 1(Hōnaunau Bay), overlaid with benthic habitat classes. See text for discussion.

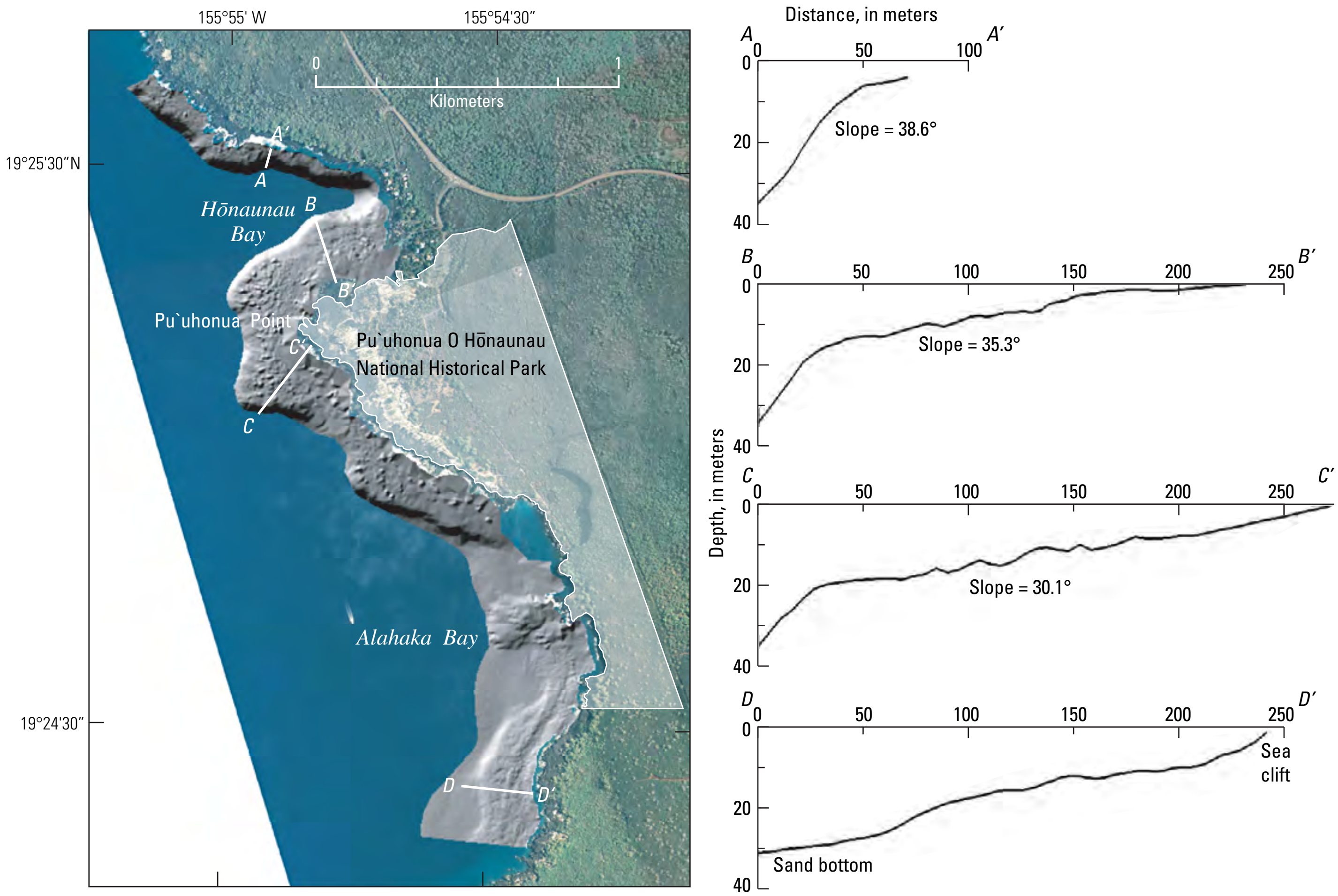

Figure 13. Aerial photomosaic of PUHO showing shaded relief bathymetry and cross-section profiles of the reef. See text for details.

Porites sp. Large, lobate colonies (for example, *Porites lobata*) are found near the upper edge, transitioning into more finger-shaped colonies (for example, *Porites compressa*) in deeper water. Farther seaward, the upper depth limit of this lush coral zone trends deeper, where it is less exposed to high wave conditions, until it terminates at Mīana Point. Outside Mīana Point, where the sloping volcanic platform is exposed to more energetic waves, there is no aggregate reef, but there are a greater number of rocks and boulders. Presumably the higher wave energy outside the point is strong enough to dislodge more rocks from the surrounding sea cliff than farther within Hōnaunau Bay. North of Mīana Point this sparsely covered rocky pavement continues to around –38 m (–125 ft), the depth limit of this survey.

The volcanic platform in the southern half of Hōnaunau Bay is much broader than in the northern half of the bay. The nearshore intertidal zone consists of a nearly horizontal uncolonized volcanic platform. The uneven surface is often exposed at low tides, leaving behind tide pools. Sea turtles often bask on the warm platform around the PUHO boundary, especially near Keone`ele Cove. Approximately 40 m from shore, the shallow intertidal volcanic platform drops off to another nearly horizontal platform around –5 m (–16 ft). Scattered corals grow directly on this part of the volcanic pavement, becoming more and more dense in deeper water. With the exception of a few sand patches, by –10 m (–33 ft) the coral is dense enough to form an aggregate reef complex, which then extends to the edge of the platform and deeper. As in the northern half of the bay, around –15 m (–50 ft) the volcanic slope drops off sharply at a 35°–40° angle. The aggregate reef follows the slope all the way to the sand-covered bottom in the middle of the bay. Rapid assessments of benthic coverage show an average coral cover of 67.0 percent in this area of Hōnaunau Bay (Rodgers and others, 2004). Farther seaward along the south edge of the bay towards Pu`uhonua Point, the upper depth limit of the reef complex lies deeper and deeper, where it is less exposed to high wave conditions. Near the point, where the upper slope and shallower platform are exposed to higher waves, the volcanic pavement is scattered with numerous rocks and boulders and occasionally dotted with smaller wave-resistant corals.

We observed numerous ground-water seeps along the entire shoreline of Hōnaunau Bay. These were apparent during snorkel surveys by the distortion in the water and by changes in water temperature. Although no quantitative measurements

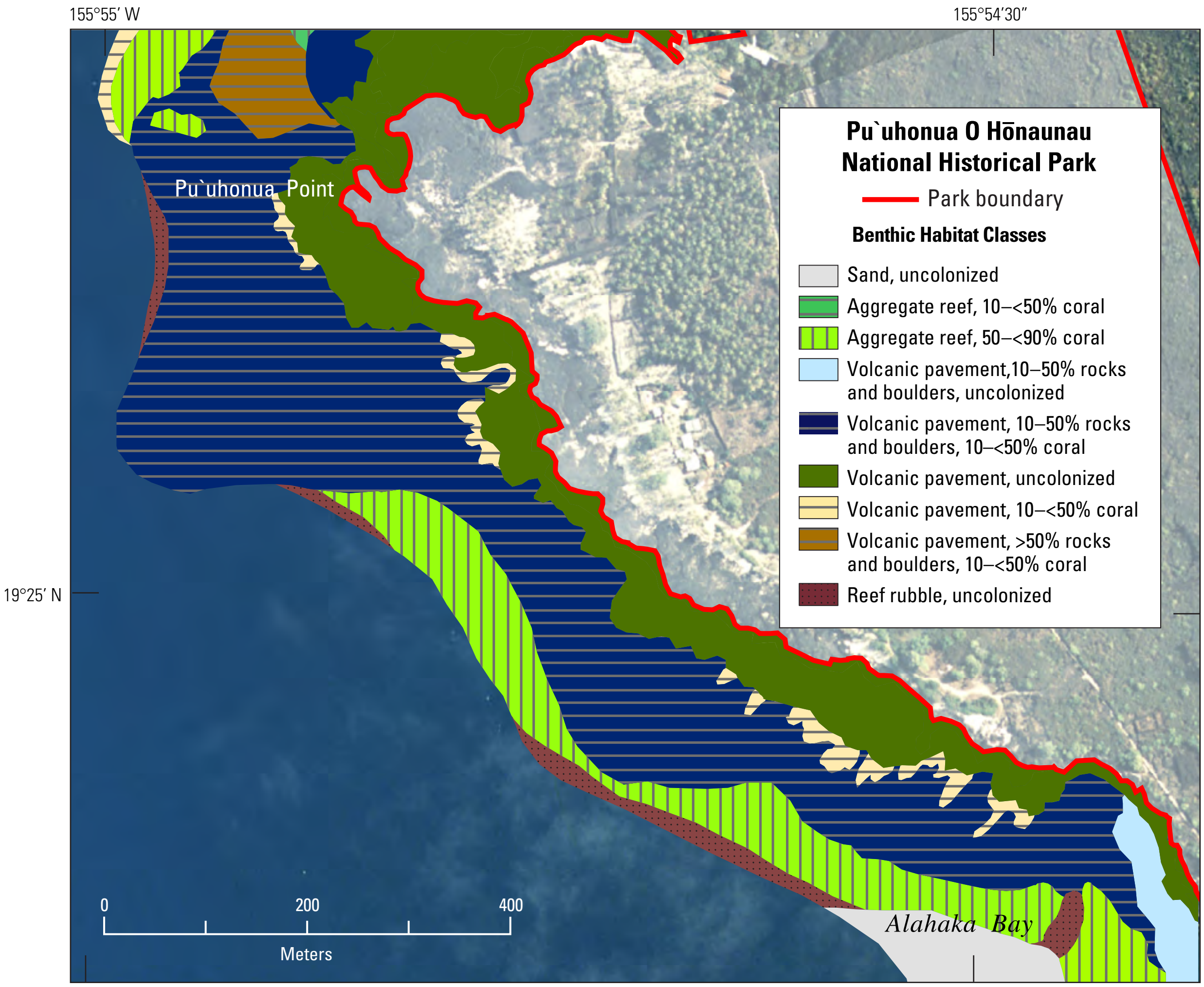

Figure 14. Aerial photomosaic of subarea 2 (Pu`uhonua Point), overlaid with benthic habitat classes. See text for discussion.

were taken along the shoreline, data were collected with a CTD (conductivity/temperature/depth) recorder from a boat in the deeper waters of the bay. These measurements were collected as part of a greater study by the USGS regarding groundwater flux along the Kona coast (Grossman and others, 2006).

Pu`uhonua Point (Subarea 2)

Pu`uhonua Point, a broad volcanic platform formed by flows from Mauna Loa, composes the central part of PUHO National Historical Park. The submerged part of this volcanic platform extends offshore approximately 100–300 m at its widest point (fig. 13, transect *C*–*C*′). Between the shoreline and –15 m (–50 ft), the platform slopes gently (5°–10°) seaward. At approximately –15 m, the platform drops off sharply at a 30°–35° slope to the offshore sandy bottom. The point is exposed to high wave energy, and is covered with scattered rocks and boulders, sparse coral cover, and many bare or sand-covered patches (fig. 14). Rapid assessments of benthic coverage, performed concurrently by marine biologists from the University of Hawai`i, show an average coral cover of 21.4 percent in this area (Rodgers and others, 2004). The shoreline/intertidal zone, where the wave energy is most extreme, is uncolonized volcanic pavement. In the leeward, southern part of Pu`uhonua Point, where there is less wave energy, a shore-parallel band of aggregate reef (mostly *Porites* sp.) is found between –10 and –20 m (–33 and –66 ft) on the sloping platform.

Alahaka and Ki`ilae Bays (Subarea 3)

The southern shoreline of PUHO lies along Alahaka and Ki`ilae Bays, which are separated by the southernmost extension of the crescent-shaped Keanae`e Pali. The narrow shoreline/intertidal zone of Alahaka Bay is uncolonized volcanic pavement (fig. 15). From the shoreline to approximately –10 m (–33 ft) the volcanic pavement is strewn with rocks and boulders, both uncolonized and sparsely covered with coral. By contrast, Ki`ilae Bay consists of uncolonized volcanic pavement near the shoreline at the base of a small (5 m) sea cliff, and lacks the rocks and boulders. A shore-parallel band of aggregate reef covered with 50–<90 percent coral (mostly *Porites* sp.) is found offshore of both bays between –12 and -30 m (–40 and –100 ft) before the volcanic slope drops off into a sandy bottom. Rapid assessments of benthic coverage show an average coral cover of 48.9 percent in Alahaka Bay (Rodgers and others, 2004).

As in subarea 1 (Hōnaunau Bay), we observed some ground-water seeps in the shallow areas of Alahaka and Ki`ilae Bays. Again, no quantitative measurements were taken along the shoreline during our snorkel surveys, yet data were collected with a CTD (conductivity/temperature/depth) recorder from a boat offshore. See Grossman and others (2006) for results of ground-water mapping.

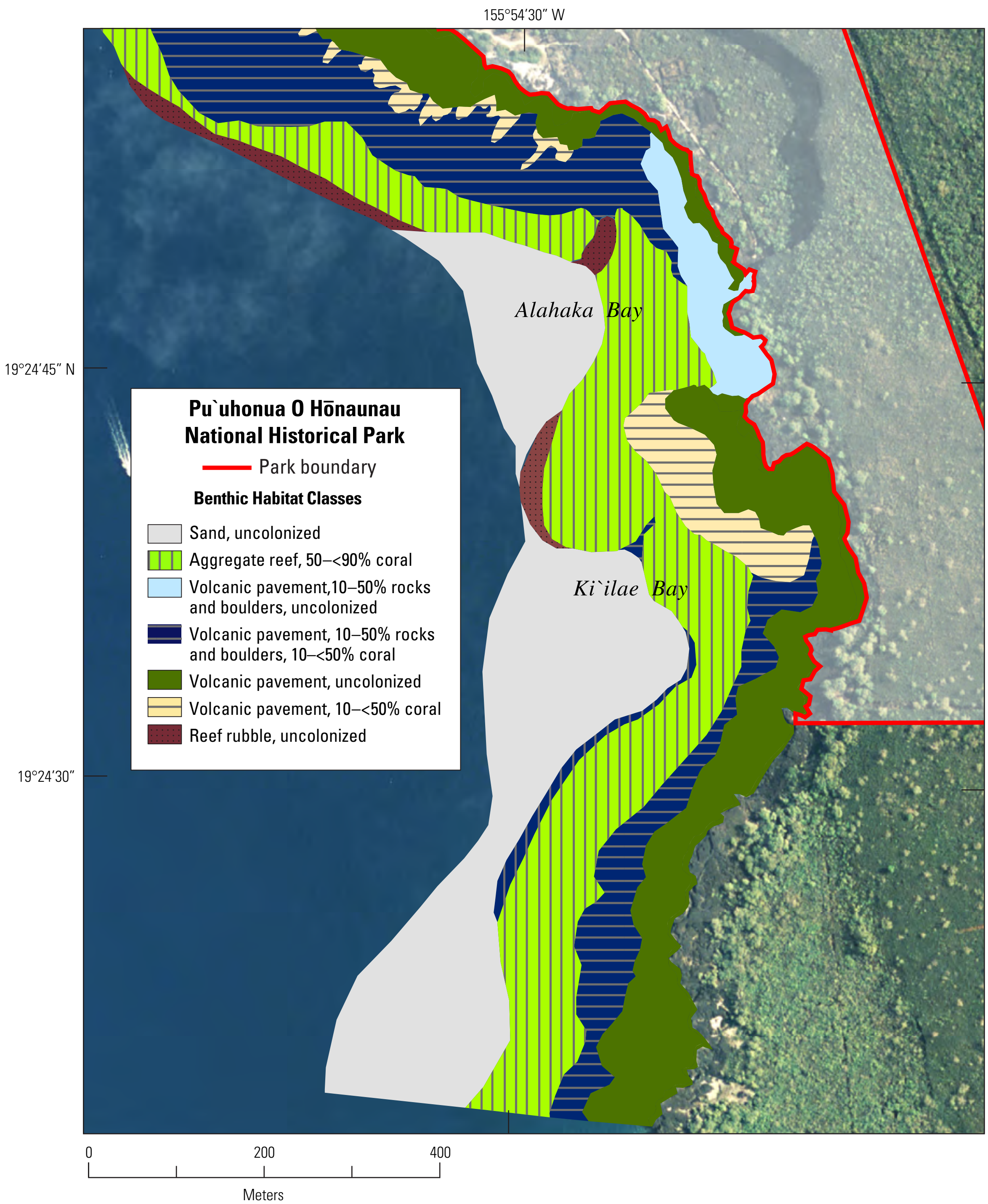

Figure 15. Aerial photomosaic of subarea 3 (Alahaka and Ki`ilae Bays), overlaid with benthic habitat classes. See text for discussion.

Summary

The three subareas in this mapping project, Hōnaunau Bay, Pu`uhonua Point, and Alahaka and Ki`ilae Bays, are distinctly different in their major benthic habitats. Wave energy appears to be a dominant control. Sheltered Hōnaunau Bay has a lush coral reef environment both in the shallows and at deeper depths; Pu`uhonua Point is a sparsely covered volcanic platform where coral growth is apparently limited by wave energy; Alahaka and Ki`ilae Bays have limited corals growing in patches on rocky pavement near the shoreline, but have an aggregate reef found between –12 and –30 m (–40 and –100 ft).

Of the nearly 1 km^2 that was mapped for this portion of the project, 25 percent (221,083 m^2) was classified as volcanic pavement with 10–<50 percent scattered rocks and boulders covered with 10–<50 percent coral (fig. 16). Although Hōnaunau Bay itself boasts one of the lushest coral reef environments along the Kona coast, the high percentage of sparsely covered, rocky volcanic pavement shown here is due to the inclusion of the wave-swept platform of Pu`uhonua Point in the study area. The next predominant benthic habitats in the study area were uncolonized volcanic pavement (24 percent), and aggregate reef with 50–<90 percent coral (19 percent). The highly colonized aggregate reef is mostly found between –15 to –25 m (–50 to –82 ft) (fig. 17). Sparse coral cover is found throughout the study area, but is mainly focused between –5 m and –15 m (–16 and –25 ft). From the shoreline to –10 m (–33 ft) the uncolonized areas are bare volcanic pavement, whereas from –20 to –35 m (–66 to –115 ft) the uncolonized areas are sand.

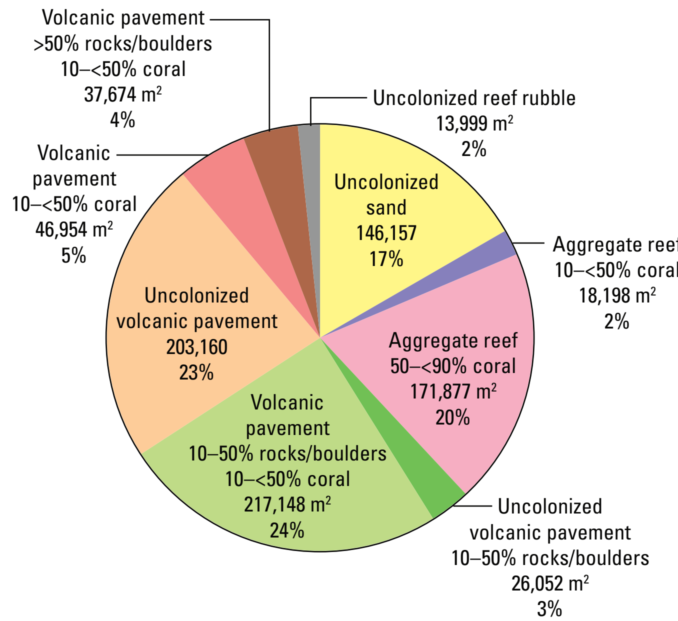

Figure 16. Pie chart showing the breakdown of benthic habitats of the PUHO study area. More than 0.2 km^2 (25 percent) of the study area was classified as volcanic pavement with 10–<50 percent scattered rocks and boulders covered with 10–<50 percent coral. The next predominant benthic habitats in the study area were uncolonized volcanic pavement (24 percent) and aggregate reef with 50–<90 percent coral (20 percent).

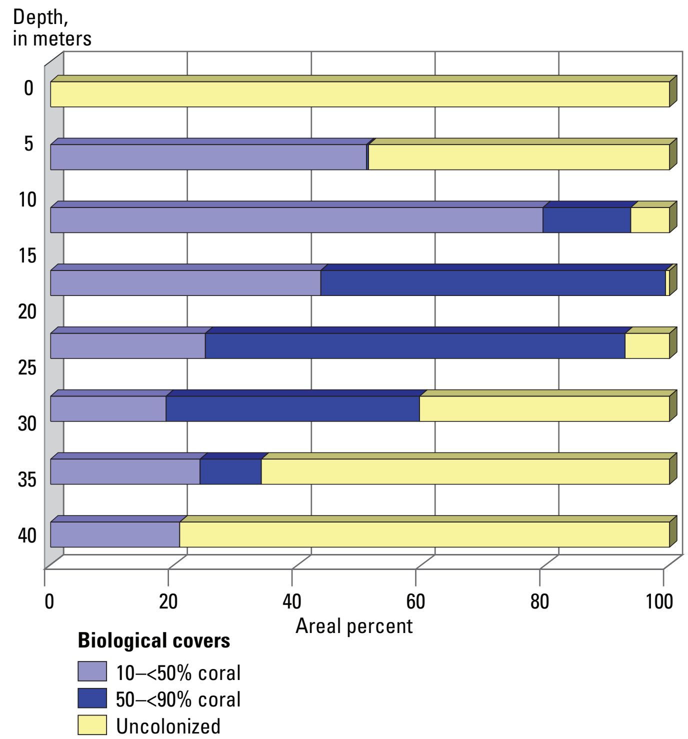

Figure 17. Graph showing major biological covers with depth at PUHO. Sparse coral cover is found throughout the study area, but is mainly focused between –5 m and –15 m.

Accuracy of Maps

An accuracy assessment was performed for the major biological covers (table 5). A total of 241 randomly selected points for all three National Parks (PUHO, KAHO, and PUHE) were checked in the field. The overall accuracy of 91.29 percent (with a 95-percent confidence interval of ± 1.1) indicates which points on the map were classified correctly according to the field check. Producer's accuracy is an indication of how well we correctly identified pixels for each different class (*for example*, coral = 96.39 percent, uncolonized = 75.00 percent). User's accuracy is the probability that, for a classified pixel on the map, the map user will actually find that class in the field (*for example*, coral = 94.67 percent, octocoral = 60.00 percent). A tau coefficient of 0.9005 was calculated as described by Ma and Redmond (1995), and indicates that 90.05 percent more points were classified correctly than would be expected by chance alone.

After accuracy assessment calculations were performed, any misinterpreted polygons identified on the Kona coast reef maps were corrected using the field check data, thus increasing the overall accuracy of the final maps to greater than 91.29 percent.

Table 5. Matrix showing accuracy assessment for the major biological cover classes.

		Found to be in field							Total	User's Accuracy
		Coral	Coralline Algae	Macro-algae	Turf Algae	Octocoral	Emergent Vegetation	Uncolonized		
As mapped	Coral	160							169	94.67%
	Coralline Algae	0	15	0	0	0	0	1	16	93.75%
	Macroalgae	0	0	0	0	0	0	3	3	0.00%
	Turf Algae	0	0	0	0	0	0	0	0	
	Octocoral	0	0	1	0	3	0	1	5	60.00%
	Emergent Vegetation	0	0	0	0	0	0	0	0	
	Uncolonized	6	0	0	0	0	0	42	48	87.50%
Total		166	16	1	0	4	0	54		
Producer's Accuracy		96.39%	93.75%	0.00%		75.00%		77.78%	241	
										Diagonal Sum = 220
										Overall Accuracy = 91.29%

Resource concerns

No submerged archeological features are known to exist offshore of Pu`uhonua O Hōnaunau National Historical Park, nor did we find evidence of any during our video transects. The main concern for park management should be ground-water flow to the nearshore environment. Although sedimentation from the uplands does not appear to be a problem at this time, other particles and nutrients may affect the health of the ecosystem. Any future projects should take into account the effects to the ground-water system and plan accordingly.

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The authors wish to thank Pat Chavez and his group from the USGS in Flagstaff for coordinating our acquisition of the SHOALS bathymetric data. Ku`ulei Rodgers and colleagues from the University of Hawai`i Coral Reef Assessment and Monitoring Program (CRAMP) team collected the rapid assessment data referred to in this document. Will Smith and other CRAMP team members performed the third-party field-check observations and provided the accuracy assessment calculations. Melia Laber of the National Park Service provided the aerial photography in digital format. Sallie Beavers from Kaloko-Honokōhau NHP assisted with logistics while we were on island. This manuscript benefited from reviews by Mike Field and Guy Cochrane. A special mahalo goes to Captain Joe Reich, owner of the *Alyce C* on Moloka`i, whose exceptional navigation and local expertise was critical to the success of this project.

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Appendix
Detailed Classification Scheme

The following describes the classification scheme used by the U.S. Geological Survey for benthic habitat mapping of National Parks on the Kona Coast of Hawai`i. Each of the habitats and zones is described in detail with some example photos. Many of the descriptions are from NOAA's 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, fishponds).

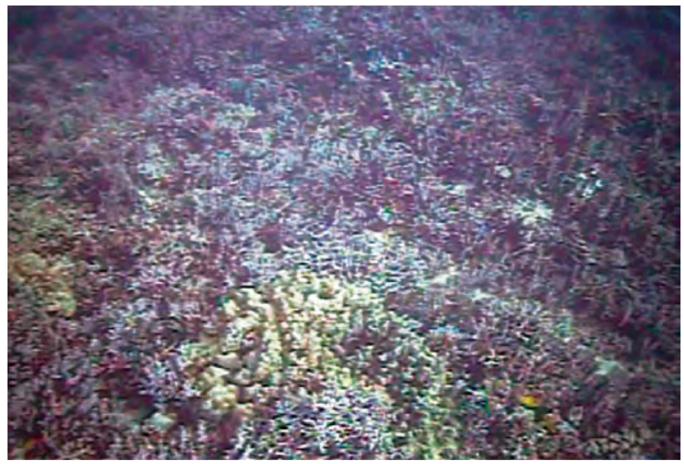
Example of muddy shallow area exposed at low tide. (Kawela, Moloka`i)

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

Example of uncolonized sand. (Kaloko-Honōkohau, Hawai`i)

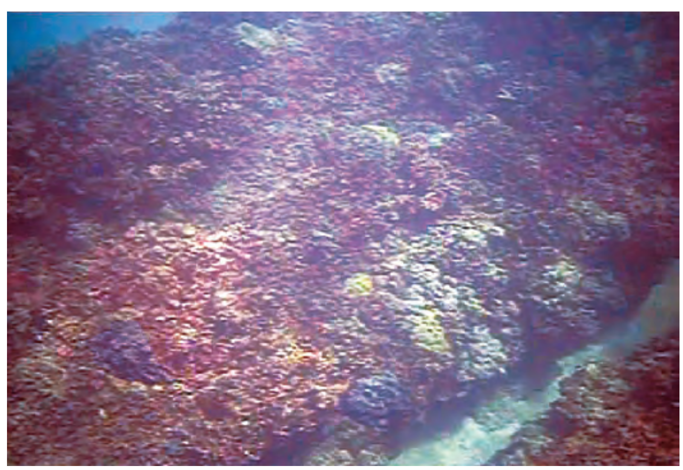
Major Structure—Reef and Hardbottom

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.



Example of aggregate reef with 90–100 percent coral. (Kawaihae Bay, Hawai`i)

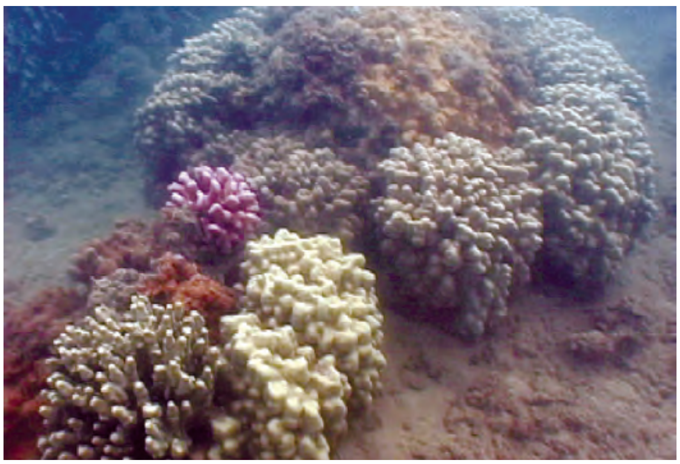
Spur-and-groove Elongate, alternating sand and coral formations that are oriented perpendicular to the shore or bank/shelf escarpment. The coral formations (spurs) of this feature typically have a high vertical relief relative to the pavement with the channels, and are separated from each other by 1–5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



Example of spur-and-groove reef system with 90–100 percent coral cover on the spurs. (Kawaihae Bay, Hawai`i)

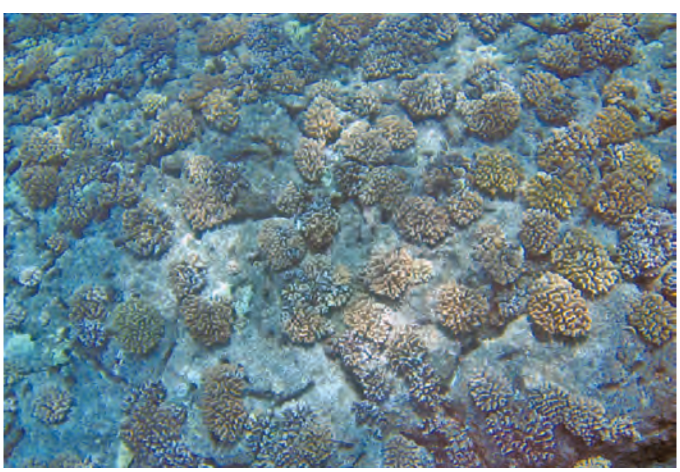
Individual patch reef Coral formations, larger than or equal to the MMU (100 m^2 in this study), that are isolated from other coral reef formations by sand, seagrass, or other habitats and that have no organized structural axis relative to the contours of the shore or shelf edge.

Aggregated patch reefs 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.



Example of aggregated patch reefs covered with 50–<90 percent coral. These patch reefs are smaller than the minimum mapping unit and so could not be called individual patch reefs. They would be digitized together, along with the others shown in the background, as aggregated patch reefs. (Moloka`i)

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



Example of volcanic pavement with 50–<90 percent coral cover. (Hōnaunau Bay)

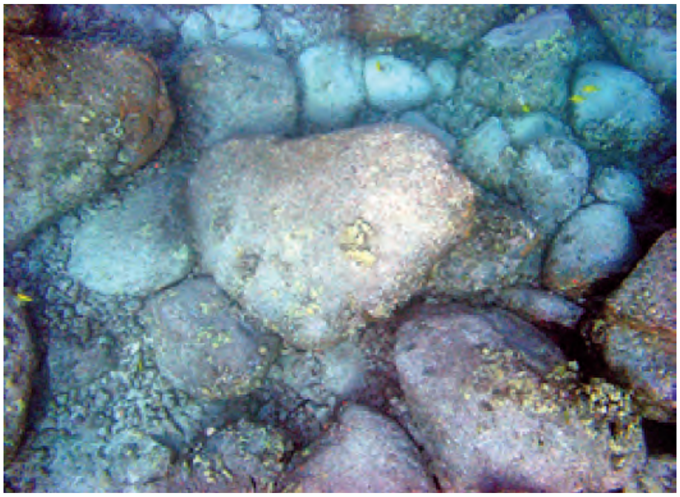
Volcanic pavement with sand channels Having volcanic substrate alternating with sand channels that are oriented perpendicular to the shore or bank/shelf escarpment. The sand channels have low vertical relief relative to spur-and-groove formations.

Example of volcanic pavement with sand channels, with 90–100 percent coral cover. (Kaloko-Honokōhau, Hawai`i)

Volcanic pavement with 10–50 percent rocks/boulders Volcanic substrate with 10–50 percent 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.

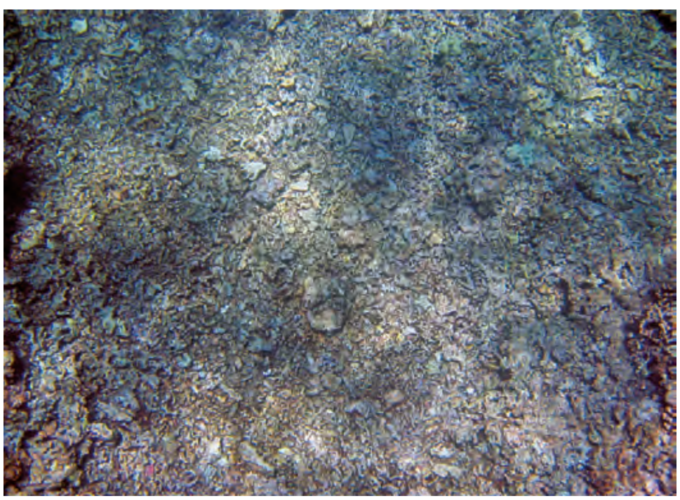
Example of volcanic pavement with 10–50 percent rocks/boulders, with 10–50 percent coral cover. (Hōnaunau Bay, Hawai`i)

Volcanic pavement with >50 percent rocks/boulders Volcanic substrate with >50 percent 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.



Example of volcanic pavement with >50 percent rocks/boulders with <10 percent cover, therefore 90–100 percent uncolonized. (Kaloko-Honokōhau, Hawai`i)

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



Example of reef rubble with <10 percent cover, therefore 90–100 percent 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 is typically 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 The 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. (Not typically used for the Kona Coast.)

Back reef (with lagoon) Area between the seaward edge of a lagoon floor and the landward edge of a reef crest. This zone is only present when a reef crest and lagoon exist. Typical habitats include sand, coral rubble, seagrass, algae, and patch reefs. (Not typically used for the Kona Coast.)

Reef flat (without lagoon) Shallow, semiexposed 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, rubble, pavement, algae, mud, and patch reefs.

Reef crest The flattened, emergent (especially during low tides) or nearly emergent segment of a reef, usually where the waves break. This zone lies 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. Also defined as fore reef are 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 at approximately 20 to 30 meters depth, 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 rubble, sand, and mud.

Unknown Zone uninterpretable because of turbidity, cloud cover, water depth, or other interference.