

Prepared in cooperation with the National Park Service

Evaluation of Benthic Habitat Change within the National Historic Sites of Hawai‘i’s Kona Coast



Open-File Report 2026–1061

Cover: Tethered drop-camera system acquiring imagery of the coral reef in Kaloko-Honokōhau National Historic Park, Hawaii, during the April 2022 survey. Photograph courtesy of Joshua Logan, U.S. Geological Survey.

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By Meredith L. McPherson, Joshua B. Logan, Kristen A. Alkins, Sarah Groff, Gerald A. Hatcher, Ann E. Gibbs, Susan A. Cochran, and Curt D. Storlazzi

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
Area		
square kilometer (km ²)	247.1	acre
square kilometer (km ²)	0.3861	square mile (mi ²)

Datum

Vertical coordinate information is referenced to the local mean sea level (LMSL).

Horizontal coordinate information is referenced to the Pacific Plate realization of the North American Datum of 1983 (NAD83(PA11)).

Vertical positions used for depth are referenced to the Local Mean Sea Level (LMSL) tidal datum.

Abbreviations

CRAMP	Coral Reef Assessment and Monitoring Program (Hawai'i)
DEM	digital elevation model
GNSS	global navigation satellite system
GPS	global positioning system
I&M	inventory and monitoring
KAHO	Kaloko-Honokōhau National Historic Park
LED	light-emitting diode
lidar	light detection and radar
LMSL	local mean sea level
NCRMP	National Coral Reef Monitoring Program
NHP	national historic park
NHS	national historic site
NPS	National Park Service
PUHE	Pu'ukoholā Heiau National Historic Site
PUHO	Pu'uhonua o Hōnaunau National Historic Park
USGS	U.S. Geological Survey

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Executive Summary

Coral bleaching events have become increasingly common across the Hawaiian Archipelago since 1996 because of more frequent and intense marine heatwaves. The most significant bleaching event to date occurred from 2014 to 2015, which resulted in catastrophic state-wide coral loss. Bleaching events with less severe effects also occurred in 1996 and 2019. To understand the long-term effects of repeated bleaching events, along with other anthropogenic factors such as water quality, storms, sewage runoff, and coastal development, on coral reefs on the Kona Coast of the Island of Hawai‘i, the U.S. Geological Survey, in collaboration with the National Park Service, collected underwater imagery in the early 2000s (baseline survey) and again in 2022 (resurvey). These images were captured within and adjacent to the National Historic Parks (NHP) and National Historic Sites (NHS) of Kaloko-Honokōhau NHP (KAHO), Pu‘uhonua o Hōnaunau NHP (PUHO), and Pu‘ukohola Heiau NHS (PUHE). Imagery was classified for live coral cover and dominant type (four coral types, rubble, macroalgae, and two bottom substrate types). Change of percent live coral cover was determined for all sites. Change of coral and non-coral dominant types were calculated by aggregating classifications for each park into coral and non-coral. Net coral cover decreased between the baseline and resurvey period across all three parks, though PUHE exhibited the greatest loss of live coral cover. Across all three parks, the occurrence of lower coral cover classes (0–20 percent) increased and higher coral cover classes (greater than 50 percent) decreased. Furthermore, the total occurrence of non-coral dominant type classifications (rubble, macroalgae, sand, and volcanic pavement) increased by approximately 25 percent across all three parks, with PUHE experiencing a nearly 90-percent increase in the occurrence of non-coral types. There was little to no effect of water depth on change of live coral cover, indicating that marine heatwave driven bleaching events and additional anthropogenic influences affected the entire reef across all water depths from the lower fore reef to the reef flat.

Because coral loss was more severe at PUHE and PUHO than KAHO, creating a monitoring framework that utilizes periodic underwater camera surveys and fixed diver

transects by the National Park Service would contextualize the periodic spatial surveys to the fixed transects that have greater temporal resolution. Similarly, increased frequency of spatial surveys would allow for the National Park Service to continue monitoring changes to critical nearshore habitats and marine resources relevant to National Park jurisdiction.

Introduction

Large-scale changes are happening to coral reef ecosystems around the world. Bleaching events occur as a result of prolonged increases in sea surface temperature, more commonly known as marine heatwaves (Hughes and others, 2017; Lough and others, 2018). Coral reefs typically exist at their upper thermal limits making them vulnerable to pollution, overharvesting, and marine heatwaves (Donovan and others, 2021). As a result, the resistance to bleaching events and subsequent recovery of coral reefs is dependent on other local anthropogenic stressors such as poor water quality, more frequent storms, and coastal development (Donovan and others, 2021; Baum and others, 2023; Gove and others, 2023). Investigating changes to nearshore coral reef habitat is critical to understanding physical and biological processes that influence live coral patterns across space, time, and biological scales. This is especially relevant in the context of more frequent and intense marine heatwaves that will be highly influential in shaping these systems (Mellin and others, 2024).

Coral bleaching events have become increasingly common across the Hawaiian Islands since 1996 (Rodgers and others, 2015). The most significant bleaching event in 2015 (Eakin and others, 2019; Skirving and others, 2019) resulted in catastrophic coral loss state-wide. Bleaching events with less severe effects also occurred in 1998 and 2019 (McCarthy and others, 2024). These repeated events have led marine resource managers to want more information on benthic habitat status and resources.

The National Park Service (NPS) Pacific Island Inventory and Monitoring (I&M) network tracks coral trends at four parks in the Pacific Ocean on fixed diver transects, including at Kaloko-Honokōhau National Historic Park (KAHO) (NHP) on the Kona Coast, which is on the west coast of the Island of Hawai‘i. The U.S. Geological Survey (USGS) worked with

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the NPS in the early 2000s (Cochran and others, 2007a, 2007b; Gibbs and others, 2007) to collect geolocated seafloor imagery to map the seafloor geomorphology and benthic habitats within or adjacent to the national parks on the Kona Coast. The results of this work (Gibbs and others, 2007) provided NPS resource managers with the necessary information to establish permanent monitoring sites in KAHO in 2007, which have increased the understanding of the diversity and spatial patterns of marine benthic habitats in this region.

Several subtidal monitoring programs show that coral cover is in decline along the Kona Coast. I&M surveys at KAHO found a 77-percent loss in coral cover across the NHP during the 2014–15 bleaching event with little to no recovery of nearly all coral species (with the exception of *Porites compressa*) through 2019 (McCutcheon and McKenna, 2021). Although information regarding benthic habitat change and the consequences of bleaching events at Pu'ukoholā Heiau NHS (PUHE) and Pu'uhonua o Hōnaunau NHP (PUHO) is temporally and spatially limited, it is likely that the

other Kona Coast National Parks (PUHO and PUHE) were similarly acutely affected by the 2014–15 bleaching event. The National Coral Reef Monitoring Program (reports every 3 years from 2013 to present) reported similar declines in coral cover between 2013 and 2016 to the I&M findings for the entire Kona coastline (National Oceanic and Atmospheric Administration Pacific Islands Fisheries Science Center, 2018). Prior to the 2014–15 bleaching event, the Hawai'i Coral Reef Assessment and Monitoring Program (CRAMP; annual reports from between 1999 and 2012) reported significant declines in coral cover at PUHE for shallow and deep sites (Rodgers and others, 2015).

In 2022, the USGS returned to the Kona coastline with the primary objective to acquire and analyze new underwater imagery to quantify benthic habitat changes across nearly 20 years. In this report, we detail, with high spatial coverage, the changes in the distribution of live coral cover and dominant habitat type observed in 2022 relative to the early 2000s.

Study Sites

There are three National Parks situated along the Kona Coast (fig. 1, table 1), including the terrestrial and submerged lands of KAHO and the terrestrial lands of PUHO and PUHE. Zonation of corals along the Kona Coast is divided into four zones across a steep nearshore slope with incremental depth categories defining those zones: 1) boulder zone: 2.5–8 meters (m), 2) bench zone: 6–14 m, 3) slope zone: 14–30 m, and 4) rubble zone: 30–50 m (Dollar, 1975). Each zone is dominated by a particular species of coral and is in different phases of succession. The boulder zone has bottom cover consisting of basaltic boulders with *Pocillopora meandrina* dominating coral cover. The bench zone is characterized by sloping basalt with *Porites lobata* growing in lobed and encrusting colonies. The slope zone is covered by *Porites compressa*, a highly competitive coral species.

Figure 1. Index map of the Island of Hawai'i showing the location of the three National Parks along the Kona Coast. Shaded relief from U.S. Geological Survey digital data.

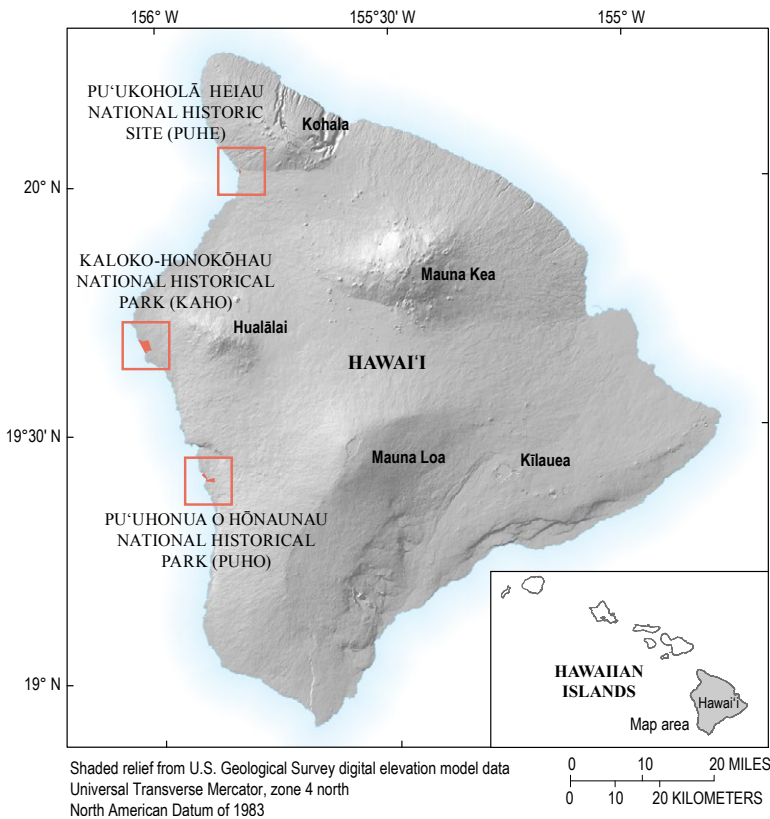


Table 1. Kona Coast attributes by park.

[Mean depth was determined from the depths of all image locations by park. °, degree; m, meter; PUHE, Pu'ukoholā Heiau National Historic Site; KAHO, Kaloko-Honokōhau National Historic Park; PUHO, Pu'uhonua o Hōnaunau National Historic Park]

Park	Mean park longitude (°)	Mean park latitude (°)	Number of sites	Mean site depth (m)	Standard depth (m)
PUHE	-155.8	20.0	29	11.0	5.9
KAHO	-156.0	19.7	79	14.2	5.6
PUHO	-155.9	19.4	24	15.1	4.8

Storm waves tend to be most destructive in this zone. Some specialized coral species grow on rubble fragments in the rubble zone, but the lack of solid substrate limit coral growth. This zonation pattern along the Kona Coast is inconsistent with more common coral zonation pattern where there is a reef flat, reef crest, and a forereef.

The Kona Coast is considered a low wave-energy coast but can experience wave events in four primary wave patterns including 1) North Pacific swell, 2) Northeast trade wind waves, 3) Kona storm waves, and 4) Southern swell (Gibbs and others, 2007). The primary wave energies that influence the Kona Coast are from the westerly North Pacific swell, Southern swell, and Kona storm waves. Kona storm waves are erratic and infrequent, and the largest waves are from the southwest in the wintertime. The Kona Coast is protected from the effects of the Northeast trade winds by its location on the west coast of the island. It is also partially protected by the other Hawaiian Islands from all but the most westerly of the North Pacific swell.

The Kona Coast has less vertical accretion of carbonate material and reef growth than the rest of the Hawaiian Islands, likely due to a combination of the geologically young age of the surface where corals grow, combined with episodic destruction of coral colonies by storms and transport of carbonate material downslope. Sediment delivery is low along the Kona Coast because of the relatively younger geologic age of the adjacent volcanoes, poor soil development, and low annual rainfall (Gibbs and others, 2007). However, land-sea effects exist on the Kona Coast. Reefs with increased herbivorous fish and fewer land-based influences experienced lower coral mortality and positive recovery after disturbances such as marine heatwaves (Gove and others, 2023).

Pu'ukoholā Heiau National Historic Site

The mapping efforts at PUHE focused on the benthic habitats of the waters offshore of PUHE (fig. 2) and excluded inside the Kawaihae Harbor. PUHE boundaries do not officially extend into the marine environment; however, effects downslope of any activity in PUHE are of concern to NPS management (personal communication). The area of Kawaihae Bay mapped by USGS extends from the north edge of Kawaihae Harbor approximately 3.5 kilometers south to the north edge of the Mauna Kea Golf Course and Beach Resort at Waikoloa, and from the shoreline to depths of approximately 40 m below local mean sea level (LMSL) where the fore reef drops off to the sandy shelf.

PUHE is located within the Kawaihae watershed, which contributes approximately 75 percent of the drainage in the northern portion of the study area. The Waikoloa and Waiulaula watersheds contribute approximately 25 percent of the drainage in the southern portion of the study area (Cochran and others, 2007b). Drainages from these watersheds are responsible for the increased input of sediment and urban runoff relative to other unpopulated areas of the island (Gove and others, 2023).

Kaloko-Honokōhau National Historic Park

The only park on the Kona Coast that includes submerged lands and marine resources within its official boundaries is KAHO (fig. 3). KAHO was established in 1978 and is 1,160 acres in size, including 596 acres of marine area. As of 2025, only a portion of the park has been acquired by the NPS, with the remaining acreage either held privately or by the State of Hawaii Department of Land and Natural Resources Division of Aquatic Resources. KAHO is bordered on the south by the Honokōhau small-boat harbor and on the north by residential homes, a resort, and a golf course.

Although the zonation and community structure transitions described above are evident in KAHO, the seafloor morphology in the park is more complex than along much of the Kona Coast. The mid shelf cliffs, the semi-protected environments provided by the pinnacles off Kaloko Fishpond, and the embayed coastline close to the harbor support

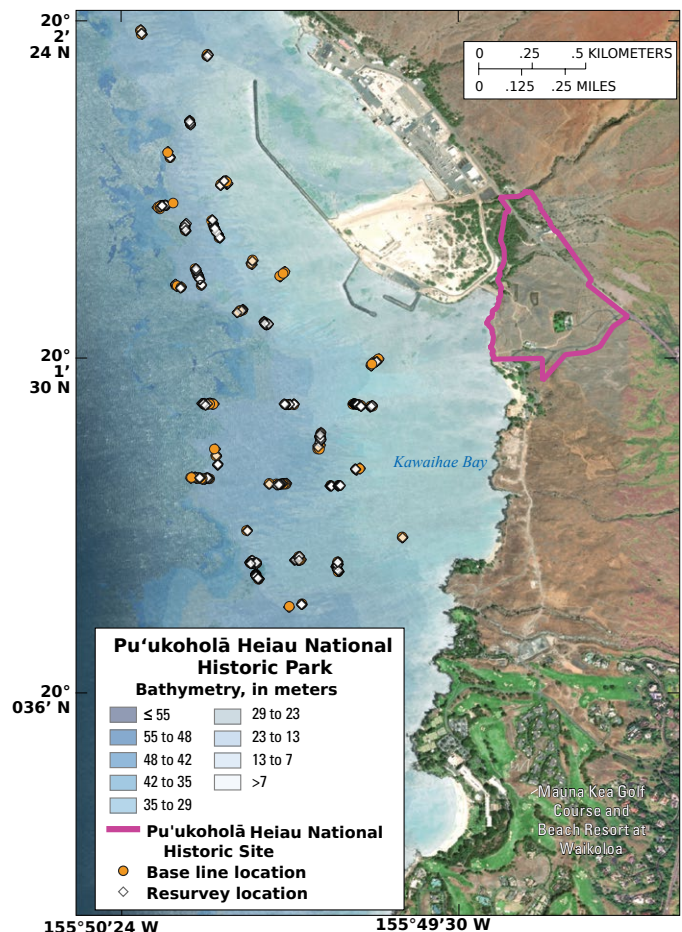


Figure 2. Satellite map overlaid with Office for Coastal Management [OCM] Partners (2022) light detection and ranging (lidar) derived depths (in meters) and locations of baseline and resurvey imagery within the Pu'ukoholā Heiau National Historic Site area. Base imagery from QGIS and its licensors.

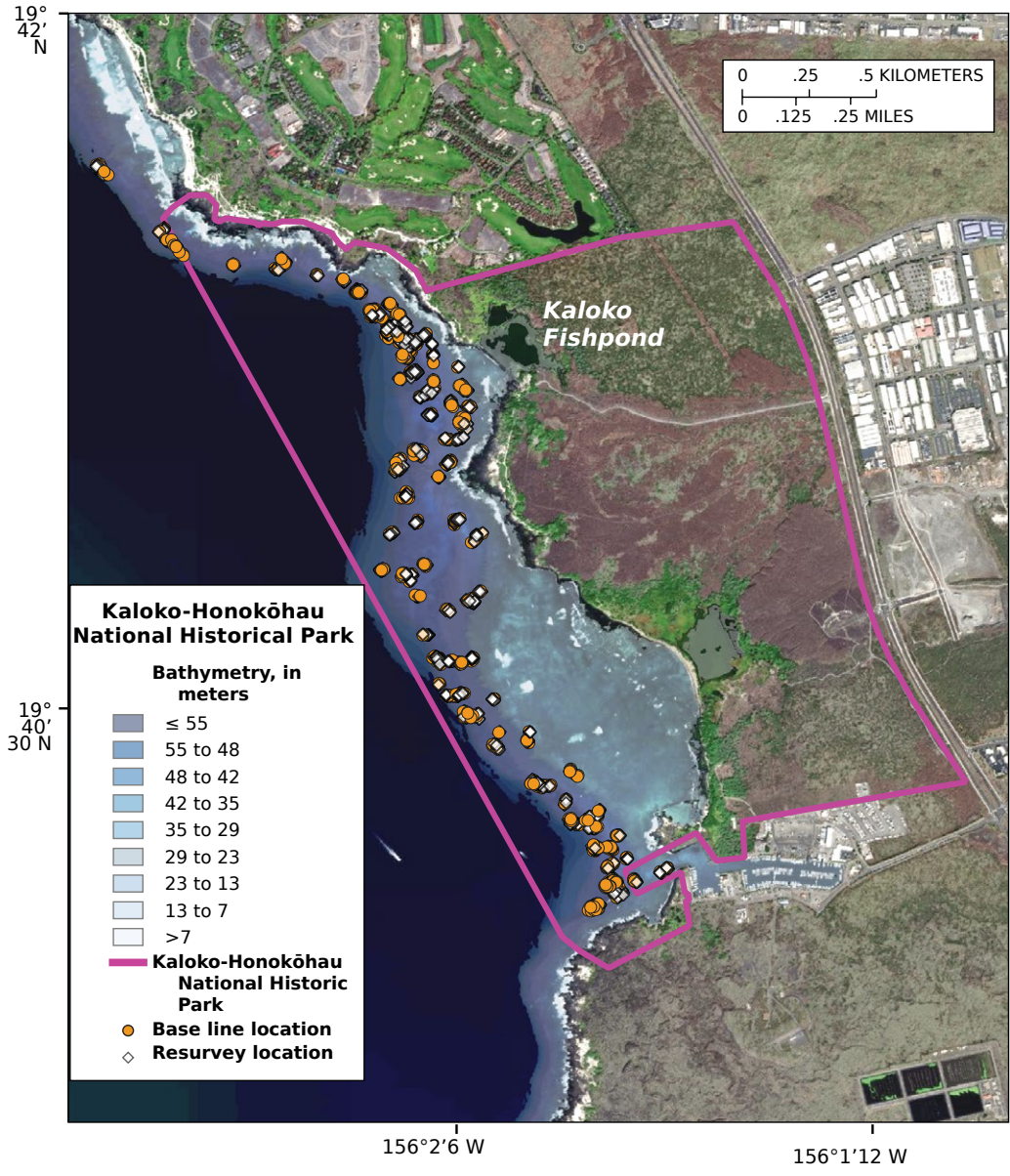


Figure 3. Satellite map overlaid with Office for Coastal Management [OCM] Partners (2022) light detection and ranging (lidar) derived depths (in meters) and locations of baseline and resurvey imagery within the Kaloko-Honokōhau National Historic Park area. Base imagery from QGIS and its licensors.

localized coral ecosystems that are unique to KAHO. The highest coral covers are generally off the harbor mouth and Kaloko Fishpond (Gibbs and others, 2007).

Pu'uhonua o Hōnaunau National Historic Park

The area mapped for PUHO extends from Mīana Point around Pu'uhonua Point to Ki'ilae Bay and past the southern park boundary (fig. 4). PUHO park boundaries do not officially extend into the marine environment; however, effects downslope of any activity in PUHO are of concern to management (personal communication). PUHO lies within the nearly 850-square-kilometer Ki'ilae watershed, which begins at the crest of Mauna Loa (Cochran and others, 2007a). 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.

PUHO experiences the lowest land-based effects of all three of the parks (Gove and others, 2023), though groundwater flow may be of concern (Cochran and others, 2007a).

Methods

Reef Surveys

The Kona Coast baseline and resurvey mapping efforts were conducted from the Research Vessel Alyce C, a 32-foot vessel operated by Captain Joe Reich of Moloka'i, Hawaii.

Baseline Imagery Collection

Baseline underwater imagery for this study were acquired during three field activities conducted by the USGS in 2003 and 2004 (activity IDs A-803-HW, A-204-HW, and

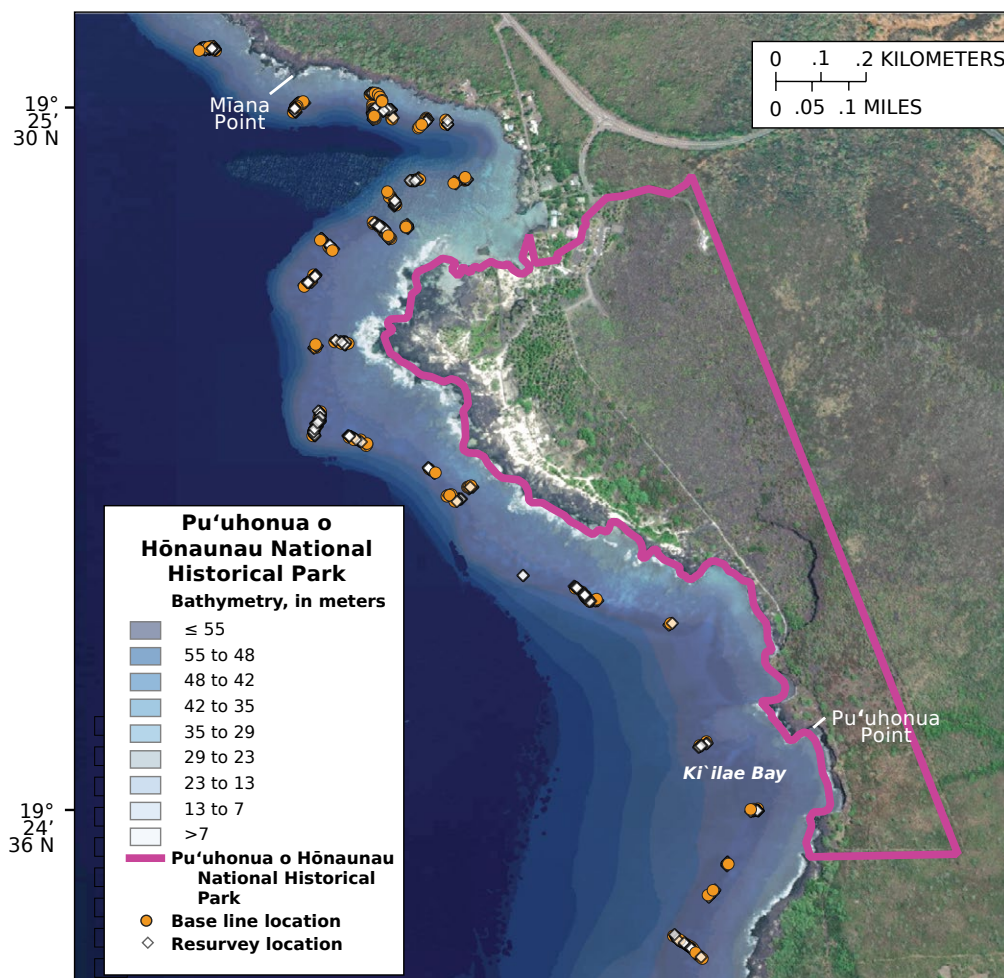


Figure 4. Satellite map overlaid with light detection and ranging (lidar) derived depths (in meters) and locations of baseline and resurvey imagery within the Pu'uuhonua o Hōnaunau National Historical Park area. Base imagery from QGIS and its licensors.

A-604-HW), as part of a benthic habitat mapping project done in collaboration with NPS (Cochran and others, 2007a, 2007b; Gibbs and others, 2007).

Georeferenced underwater video was collected along single pass transects distributed throughout the offshore portions of each of the three Kona Coast parks using an underwater standard definition (640 by 480 resolution) video camera illuminated with a light-emitting diode ring designed by SeaViewer Underwater Video Systems. The camera was mounted on a small aluminum hand-deployed frame with a rear-mounted plastic fin. Time, date, location, and ship speed were overlaid on the video using the Sea-Trak global positioning system (GPS) method developed by SeaViewer Cameras, Incorporated. Geographic positioning was obtained using a wide area augmentation system (WAAS) enabled Garmin GPS76 receiver. The stated horizontal accuracy of the Garmin GSP76 is less than 3 m when receiving WAAS corrections.

Video imagery was acquired either by towing the camera along transects while underway (towed video) or by lowering the camera near the seafloor at a given location while drifting

slowly (drop camera). Still images were acquired from the videos by sampling one frame every 10 seconds using an automated routine in the Media Mapper software package. The software recorded the GPS coordinates for the resulting images in the image Exif headers. The resulting set of georeferenced images was used for the baseline classifications. The original image set contains 10,229 640- by 480-pixel resolution images of the seafloor from varying heights above the seafloor and from various orientations ranging from oblique to downward looking driven by currents and drag on the camera while the boat was underway.

Positional accuracy and uncertainty varied for baseline imagery collection depending on the method used. The uncertainty of towed video was tens of meters, especially in deeper water where the angle of the cable to the camera was greater than in shallow water. Drop camera imagery had estimated uncertainties of around 5 m from the position of the GPS antenna. The final dataset used for this study was predominantly composed of imagery obtained from towed video (1,512 images from towed video, 112 images from drop camera imagery).

Resurvey Imagery Collection

Resurvey underwater imagery was acquired during a single field activity conducted by the USGS in 2022 (USGS activity ID 2022-615-FA) to investigate changes to the nearshore benthic habitat relative to baseline surveys conducted in 2003 and 2004. A total of 146 sites were resurveyed across all three parks. Sites for resurvey were selected based on where coral cover was observed in the baseline surveys. Imagery was acquired at each site while drifting by lowering the camera to 1 to 2 m above the seafloor at each site. The length of the site transects were similar in length to the baseline survey transect lengths because the goal was to “resurvey” the baseline sites.

The underwater image collection system was comprised of three major components. First, a pole-mounted, downward facing digital camera clamped to the side of the surface vessel which extended approximately 1 m below and above the water surface. A global navigation satellite system (GNSS) antenna was fixed at the top of the pole above the downward facing camera and remained approximately 1 m above the water surface to provide accurate image capture locations. Second, a tethered drop-camera system was lowered below the vessel and held roughly 1–3 m above the seabed (fig. 5). Third, a data acquisition and control system was located in the weather protected space of the surface vessel and operated in real-time to maintain image quality by adjusting camera collection rate, exposure, and gain settings of both cameras. The data acquisition system provided real-time position information via a local area network to a separate laptop located on the flying bridge to assist with navigation in the context of the previous survey and planned resurvey locations.

The surface camera was a 12.3-megapixel machine vision camera with a global shutter and a 2.8-centimeter (cm) sensor. The camera was made by Teledyne FLIR (model #BFS-PGE-122S6C-C). The lens used was a manual focus computer (model #V12280MPY) 12-millimeter (mm) focal length, which is approximately equivalent to a 30-mm focal length full frame (35-mm) camera lens. The lens was fixed at f-stop 5.6. The purpose of the surface camera was to collect larger area imagery coincident with the drop camera to facilitate estimating the extent of and continuity of features imaged at close range with the drop camera. The surface camera was designed with a slightly longer focal length lens and higher pixel count than the drop camera so the ground sample distance (amount of seabed imaged per pixel) would be more closely comparable to the drop camera.

The drop camera was a 5.0 MP machine vision camera with a global shutter and a 1.7-cm sensor. The camera was made by Teledyne FLIR (model #BFS-PGE-50S5C-C). The lens used was a manual focus Fujinon (model #HF6XA-5M) 6-mm focal length, which is approximately equivalent to a 23-mm focal length full frame (35-mm) camera lens. The lens was fixed at f-stop 5.6. The drop camera package was tethered to the surface with a sea-cable that provided unlimited power and enabled real-time camera control and image data transfer. In addition to the camera, the subsurface package included dual Ikelite DS160 light-emitting diode strobes modified to accept external power and were included to improve color rendering and image exposure with the limited natural light available at depth. A Tritech PA500 precision altimeter was mounted on the drop camera to measure and display the height above the seafloor to assist with our attempt to maintain a relatively consistent height above the reef.

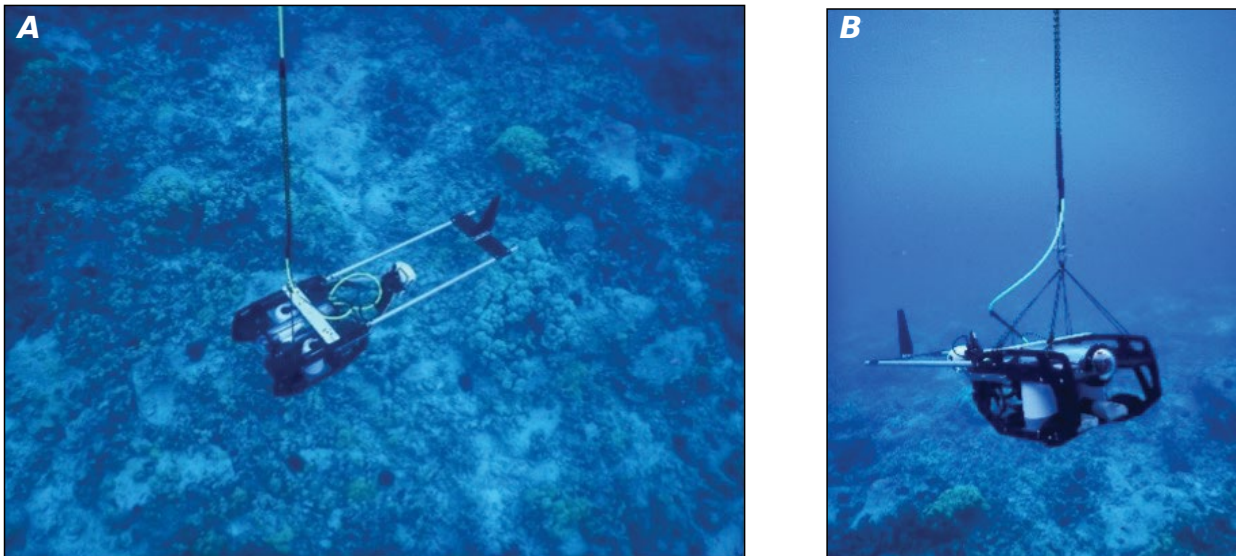


Figure 5. U.S. Geological Survey photographs of the tethered drop-camera system. *A*, Camera system lowered below the vessel. *B*, Camera system held roughly 1–3 meters above the seabed.

The drop- and surface-camera housings were designed with identical 50-mm diameter dome windows made from 5-mm-thick optical quality BK7 glass. In both cases, the cameras were rigidly mounted longitudinally in alignment with the long axis of the housings and adjusted fore and aft so that the entrance pupil of the lens aligned with the dome window radius of curvature. This provided the maximum depth of focus and minimized distortion away from image center.

The surface acquisition system included a Trimble R7 GNSS, an electronics interface box that provided power and network communication to the drop camera, a hand reel which incorporated a slip ring for the drop camera tether, and a computer system on which two instances of custom acquisition software were run concurrently to control and acquire images from the two cameras and record the associated GNSS position and precise Coordinated Universal Time (UTC) time at the instant of image capture from either system. Image acquisition frequency was typically set on both cameras to record at a rate of one image every 2 seconds.

The GNSS data for the imagery were post-processed using nearby GNSS base stations from the National Park Service real-time GNSS network. The North American Datum of 1983 (NAD83) ellipsoid heights for the GNSS positions were transformed to orthometric heights referenced to LMSL using the National Geodetic Survey GEOID12B. Precise positions were derived for each image using the GNSS-synchronized image acquisition times and were written into the image Exif headers. Orthometric heights for the imagery from the boat-mounted camera were calculated using the 2.005-m fixed vertical offset between the GNSS antenna and the camera lens. Vertical positions were not recorded for the towed camera imagery; instead, the vertical measurements to the seabed from the camera-mounted altimeter were recorded in the image Exif tags.

Image Analysis

Sub-Selection of Underwater Imagery for Classification

Images from the baseline and resurvey datasets were subsampled to facilitate comparable classification of the images. For the baseline data, still frames from the underwater video were created by sampling one frame every 10 seconds using an automated routine in the Media Mapper software package. These baseline images were further subsampled by targeting selected sites where coral cover was previously observed (n=1,621; Cochran and others, 2007a, 2007b; Gibbs and others, 2007) but does not fully exclude other predominant benthic habitat types such as sand and volcanic pavement. For the resurvey data, to ensure a more consistent comparison with the baseline imagery, images from the surface camera were excluded from classifications and only the images from

the resurvey drop camera system were used. The images were subsampled to select one image every 10 seconds as an initial step to reduce the large number of images from the same location. The resurvey images were further sub-sampled by only keeping images with GPS positions within a 5-m radius of a baseline image location. Finally, if multiple resurvey images fell within a 2-m grid space, only a single image was kept for classification (n=3,332).

Image Classification Platform

Percent live coral cover (referred to hence forth as “coral cover”) and dominant bottom type classifications of selected baseline and resurvey imagery were performed manually by a single specialist with a background in ecological studies. The open-source software, Label Studio version 1.4 (Tkachenko and others, 2020), was used to enable efficient classification of the baseline and resurvey images using a custom, two-variable classification scheme for live coral cover and dominant bottom type (described in more detail in the “Image Classification of Live Coral Cover” section). The software provided the functionality to sequentially display each image to the specialist and allowed for the use of keyboard hot keys to rapidly assign classification labels to each image. At the end of each classification session, a tabulated comma delimited text file was generated containing the image filenames, geographic coordinates, and classification labels, which were then imported to Python for data analysis.

Image Classification of Live Coral Cover

Coral cover is a commonly measured attribute of coral community composition and was the primary metric used to assess change in coral abundance at the Kona Coast parks. Coral cover was determined visually by assessing the live coral cover as a fraction of total coral (live and dead) cover in each image relative to reference diagrams of percent cover after Terry and Chilingar (1955). Cover estimates were made in multiples of 10 from 0 to 100 percent. A total of 4,282 baseline and resurvey images were visually classified for percent cover. A total of 783, 2,798, and 701 images were classified for PUHE, KAHO, and PUHO, respectively. The classified baseline and resurvey images and associated classifications are available in a USGS data repository (Logan and others, 2025).

The baseline and resurvey imagery differed in resolution, field of view, and camera orientations at each site. This unavoidably resulted in differing image footprints and scales between the surveys, meaning we were unable to ensure the same amount of reef area was covered and analyzed between sampling periods. To mitigate this, we averaged the coral cover by site before determining change in coral cover. We also relied on park-wide density distributions of coral to assess larger scale change.

Image Classification of Dominant Bottom Type

A total of eight coral and non-coral categories were used to classify the dominant bottom type of the imagery. Each image was only assigned one dominant bottom type class (fig. 6). Coral dominant bottom type categories were selected based on the most common coral species occurring along the Kona Coast and included *Montipora capitata*, *Pocillopora meandrina*, *Porites compressa*, and *Porites lobata*. We distinctly classified *P. compressa* (finger coral) and *P. lobata* (lobe coral), but because of morphological genus it is possible that corals classified as either may have similarities across the different *Porites* species.

The non-coral dominant bottom type categories were macroalgae, coral rubble, sand, and volcanic pavement. The non-coral categories were selected based on 1) what common benthic habitat classes were previously classified at the three parks (for instance, sand and volcanic pavement; Cochran and others, 2007a, 2007b; Gibbs and others, 2007), and 2) the hypothesis that reef composition shifts from coral to non-coral cover after coral bleaching events. We hypothesized that macroalgae occurrence would increase between the two survey periods due to a coral-macroalgal phase shift that often occurs following bleaching events (Fukunaga and others,

2022). Furthermore, we hypothesized that coral rubble would increase in occurrence as bleaching events produce dead and bleached coral that can then break down and produce rubble.

A total of 2,047 images were assigned one of the 8 above dominant bottom type classifications and 2,235 images were assigned an “Unknown” dominant type classification (table 2).

Quantifying Change

Percent Live Coral Cover

Change in live coral cover for each park and site was determined by:

$$\Delta_C = \frac{\bar{C}_R - \bar{C}_B}{\bar{C}_B} \times 100 \quad (1)$$

where

Δ_C is the percent change of live coral cover,

\bar{C}_R is the mean resurvey coral cover, and

\bar{C}_B is the mean baseline coral cover.

Sites that did not have at least two images classified for the baseline and resurvey were excluded from the coral change analysis (PUHE: 2 sites; KAHO: 6 sites; PUHO: 4 sites).

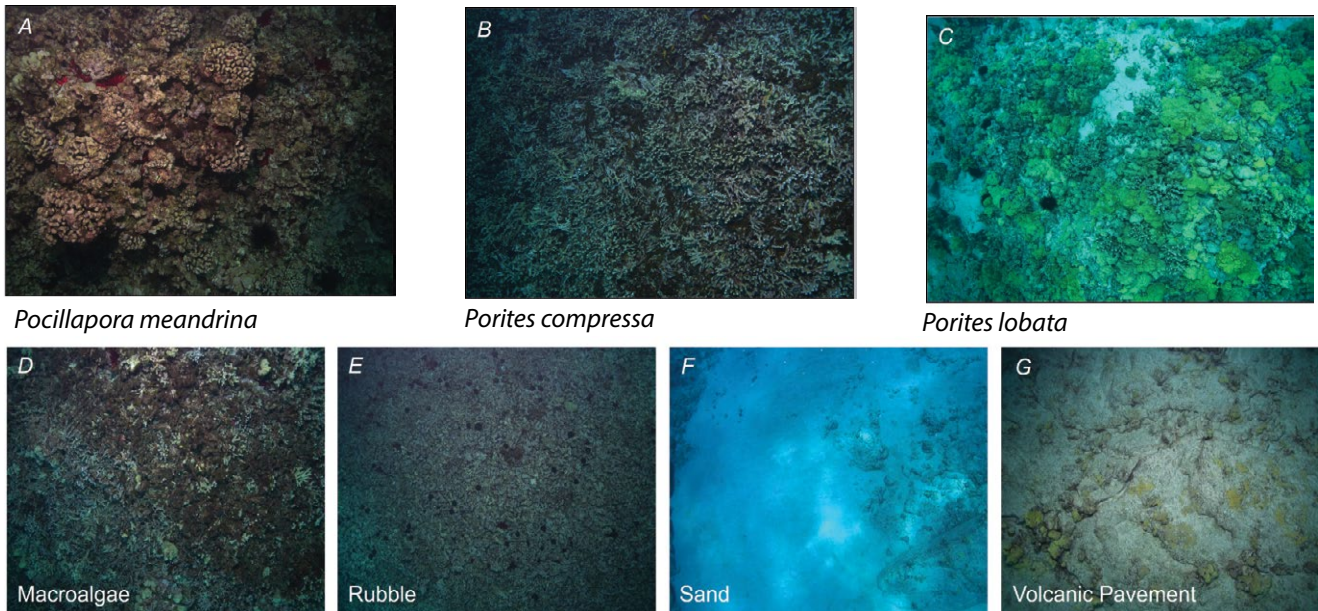


Figure 6. Images of classified coral and non-coral dominant bottom types from resurvey imagery. A, *Pocillopora meandrina*. B, *Porites compressa*. C, *Porites lobata*. D, Macroalgae. E, Rubble. F, Sand. G, Volcanic pavement.

Dominant Bottom Type

Because of the uneven distribution of the number of images within each dominant bottom type category (table 2), all eight dominant types were aggregated by park into either coral or non-coral prior to calculating percent change of these two groups by:

$$\Delta_{PC} = \frac{PC_R - PC_B}{PC_B} \times 100 \quad (2)$$

$$\Delta_{PN} = \frac{PN_R - PN_B}{PN_B} \times 100 \quad (3)$$

$$PC = \frac{\sum Co}{\sum Co + \sum NC} \quad (4)$$

$$PN = \frac{\sum NC}{\sum Co + \sum NC} \quad (5)$$

where

Δ_{PC} is the percent change of aggregated coral,

Δ_{PN} is the percent change of non-coral dominant types,

PC is the proportions of coral (Co) classifications to the total classifications calculated for both the baseline (PC_B and PN_B) and resurvey (PC_R and PN_R), and

PN are the proportions of non-coral (NC) classifications to the total classifications calculated for both the baseline (PC_B and PN_B) and resurvey (PC_R and PN_R).

Unknown classifications were not included in the total number of classifications.

Percent change of individual dominant bottom types was also calculated, but *M. capitata*, macroalgae and volcanic pavement were excluded from the results because of low sample size (less than $n=5$) in either one or both survey periods (table 2).

Elevation Data

Elevation data were extracted for each baseline and resurvey image location from the U.S. Army Corp of Engineers National Coastal Mapping Program topobathy light detection and radar (lidar) data collected in 2013 for the Island of Hawai'i (Office for Coastal Management [OCM] Partners, 2022). The digital elevation model (DEM) data were derived from lidar data that were adjusted to LMSL with a spatial resolution of 1 m. Elevation data are relative to LMSL, and negative elevations were converted to positive depth values to examine patterns of coral cover and live coral cover change.

Water depth has been determined to be an important driver of recovery and predictor of ecosystem trajectory (Graham and others, 2015). To understand if baseline and resurvey coral cover differed in their water depth dependent patterns, we compared 10-m binned water depth density distributions of coral between the two survey (early 2000s baseline survey and 2022 resurvey) periods. We also evaluated the influence of water depth as a driver of coral change by applying least squares regression analysis to water depth and live coral cover change at each park.

Table 2. A summary of the number of assigned classifications for each dominant bottom type category, unknown category, and the total number of known classifications for each survey type at each of the three Kona Coast parks.

[PC, proportion of all aggregated coral types; PN, proportion of non-coral types; PUHE, Pu'ukoholā Heiau National Historic Site; BL, baseline; RS, resurvey; KAHO, Kaloko-Honokōhau National Historic Park; PUHO, Pu'uhonua o Hōnaunau National Historic Park]

Park	Survey	<i>Montipora capitata</i>	<i>Pocillopora meandrina</i>	<i>Porites compressa</i>	<i>Porites lobata</i>	Macroalgae	Rubble	Sand	Volcanic pavement	Unknown	Total known	PC ¹ (percent)	PN ¹ (percent)
PUHE	BL	0	0	64	40	0	0	11	0	17	115	90.4	9.5
PUHE	RS	0	5	344	167	2	45	79	0	9	642	80.4	19.6
KAHO	BL	1	12	2	43	1	25	50	1	777	135	43.0	57.0
KAHO	RS	0	0	42	227	0	110	111	22	1,354	511	52.5	47.4
PUHO	BL	0	15	63	103	3	2	11	0	16	197	91.2	8.1
PUHO	RS	0	4	207	169	0	37	9	0	62	426	89.2	10.8

¹Proportion of all aggregated coral types (PC) and non-coral (PN) types relative to the total known samples assigned a dominant bottom type.

Results

General Patterns of Coral Cover and Other Dominant Types

A decrease in coral cover was observed across all three Kona Coast parks. PUHE experienced the greatest decrease of 61.6 percent, followed by PUHO with a decrease of 52.2 percent, and KAHO with a decrease of 11.7 percent (fig. 7A; table 3). Site variability of coral cover was high in the baseline and resurvey (figs. 7B, 7C; appendix 1;

figs. 1.1, 1.2, 1.3; tables 1.1, 1.2, 1.3), indicating high spatial variability of coral cover. Despite this high spatial variability, distinct patterns of coral cover loss were evident, especially at PUHE and PUHO.

Pu'ukoholā Heiau National Historic Site

The mean coral cover of PUHE was 60.4 plus or minus (±) 25.2 percent and 23.2±24.5 percent in the baseline and resurvey periods, respectively (table 4; fig. 7). There were no obvious spatial patterns of live coral cover or coral

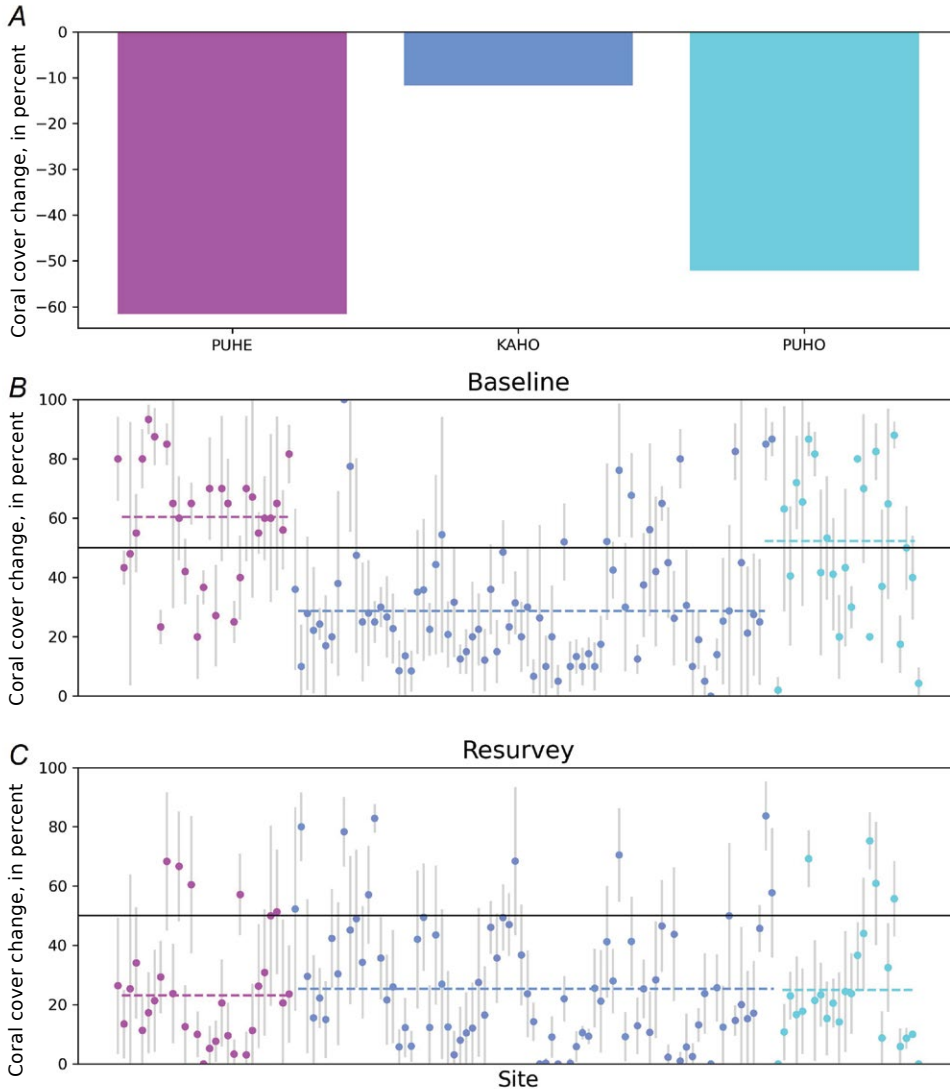


Figure 7. Graphs depicting coral cover depending on the park. A, Bar plot of mean coral cover change for each Kona Coast park (Pu'ukoholā Heiau National Historic Site [PUHE], Kaloko-Honokōhau National Historic Park [KAHO], and Pu'uhonua o Hōnaunau National Historic Park [PUHO]). B, Mean baseline coral cover, colored by park. C, Mean resurvey coral cover, colored by park. Vertical gray lines represent the standard deviation of the coral cover for each site. Colored horizontal dashed lines represent the mean baseline and resurvey coral cover, separated by park. Solid black horizontal line indicates 50 percent coral cover (B and C).

Table 3. Percent change of live coral cover, percent change of coral dominant types, percent change of non-coral dominant types, and percent change of dominant bottom types with greater than five samples by park.

[%, percent; Δ, change in; PUHE, Pu'ukoholā Heiau National Historic Site; —, no data; KAHO, Kaloko-Honokōhau National Historic Park; PUHO, Pu'uhonua o Hōnaunau National Historic Park]

Park	Change of live coral cover (%)	Change of coral dominant types (%)	Change of non-coral dominant types (%)	Δ <i>Pocillopora meandrina</i>	Δ <i>Porites compressa</i>	Δ <i>Porites lobata</i>	Δ Rubble	Δ Sand
PUHE	-61.6	-11.1	105.2	—	-3.7	-25.2	7.0	28.6
KAHO	-11.7	22.3	-16.8	-100.0	453.7	39.2	16.0	-41.5
PUHO	-52.2	-2.9	32.9	-87.7	51.9	-24.1	755.5	-62.2

Table 4. Baseline (BL) and resurvey (RS) percent live coral cover statistics including mean and standard deviation of percent live coral cover, and median of percent live coral cover.

[%, percent; PUHE, Pu'ukoholā Heiau National Historic Site; KAHO, Kaloko-Honokōhau National Historic Park; PUHO, Pu'uhonua o Hōnaunau National Historic Park]

Park	Survey	Mean (%)	Standard deviation (%)	Median (%)
PUHE	BL	60.4	25.2	60
PUHE	RS	23.2	24.5	10
KAHO	BL	28.7	24.9	20
KAHO	RS	25.3	24.7	20
PUHO	BL	52.3	31.5	60
PUHO	RS	25.0	23.0	20

cover change between the baseline and resurvey (fig. 8). There was widespread decrease in live coral cover (park mean = -61.6 percent; table 3; figs. 7, 8), although there were three sites where positive changes in live coral cover were observed (fig. 8C).

The occurrence of coral cover between 0 and 40 percent increased, whereas the occurrence of coral cover greater than 40 percent decreased at PUHE between the baseline and resurvey periods (figs. 9A, 9B). Most of the site-specific coral cover change was negative, with a strong bias towards 100-percent loss in the distribution curve of percent change (fig. 9C).

Coral types were classified as the dominant type in 90.4 percent of the baseline imagery (table 2; fig. 9). *P. compressa* was the most common coral type, comprising 55.7 percent of the known dominant type classifications. *P. lobata* was also relatively common, making up 34.8-percent

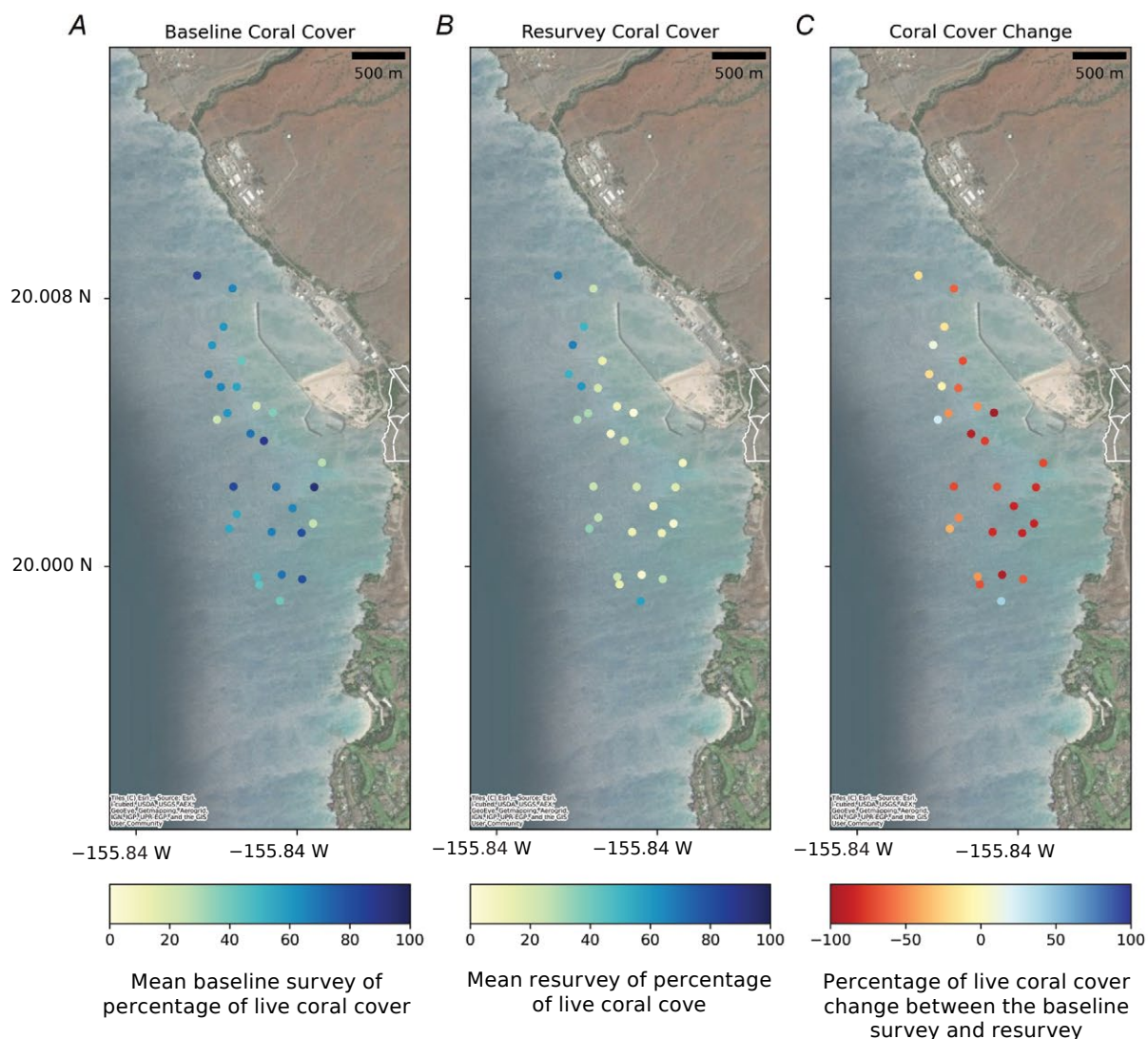


Figure 8. Maps of spatial patterns of live coral cover and change by site at Pu'ukoholā Heiau National Historic Site. A, Mean baseline survey of percentage of live coral cover (\bar{C}_B). B, Mean resurvey of percentage of live coral cover (\bar{C}_R). C, Percent change of live coral cover (Δ_C) between the baseline and resurvey. Park boundaries are represented in white. Base imagery from Esri and its licensors.

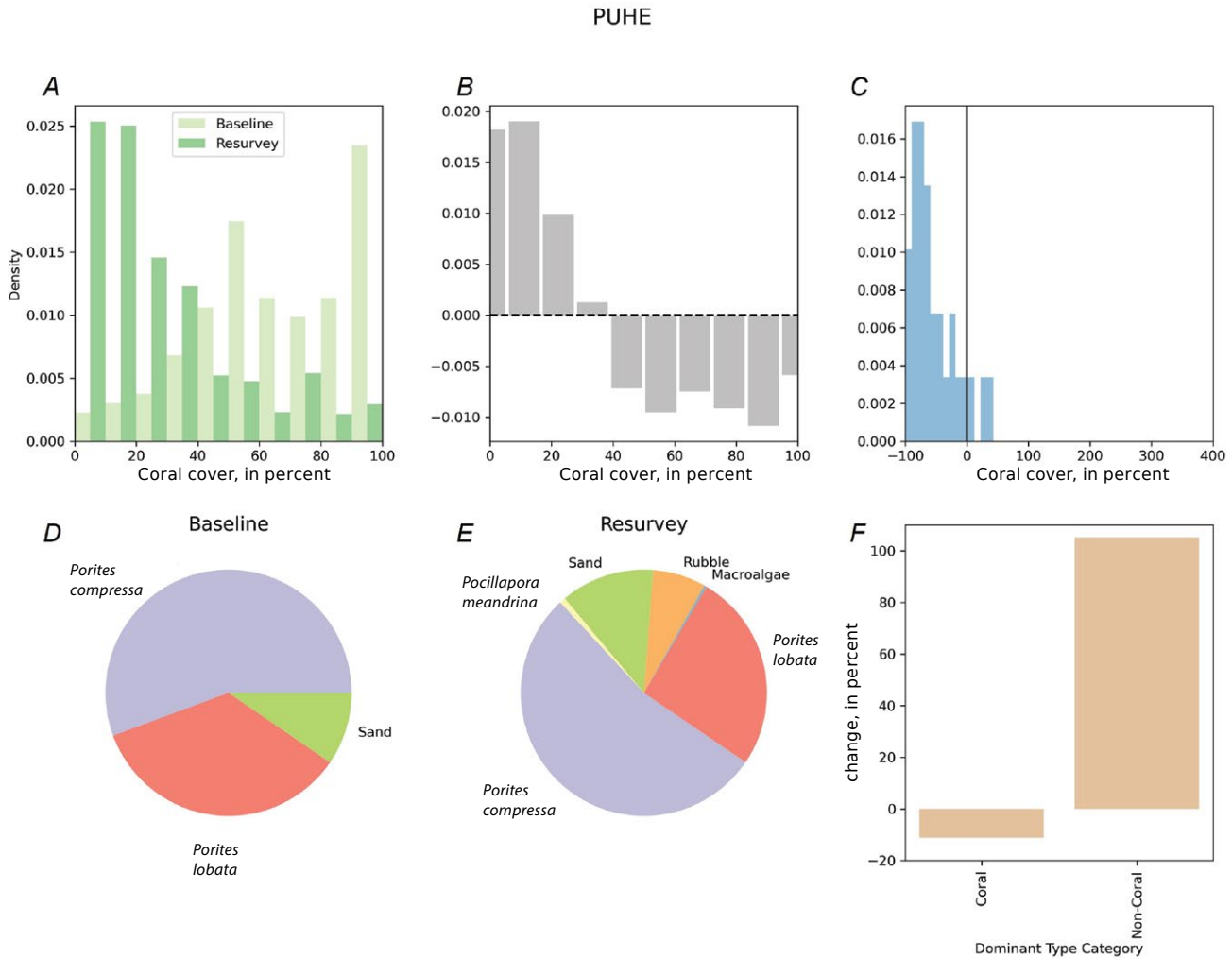


Figure 9. Graphs showing park trends of percent baseline, resurvey, and change of live coral cover and dominant types for Pu'ukoholā Heiau National Historic Site. *A*, Density distribution of percentage of baseline and resurvey coral cover. *B*, Bar graph showing the difference in baseline and resurvey density distributions (resurvey minus baseline). *C*, Density distribution of live coral cover (Δ_c). *D*, Pie chart of the eight dominant bottom types in the baseline imagery (n equals 115). *E*, Pie chart of the eight dominant bottom types in the resurvey imagery (n equals 642). *F*, Bar graph showing the change of coral (Δ_{pC}) and non-coral (Δ_{pN}) dominant types.

of the known baseline classifications. The most common non-coral type was sand. In the resurvey, coral types were classified as the dominant type in 80.4 percent and non-coral types were classified in 19.6 percent of the images. Again, *P. compressa* and *P. lobata* were the most common coral types in the resurvey at 53.6 percent and 26.0 percent, respectively. Sand continued to be the most common non-coral type, whereas rubble increased between the baseline (0 percent) and resurvey (7.0 percent).

PUHE experienced the greatest increase in non-coral of the three parks (105.2 percent; table 3; fig. 9*F*), and the greatest decrease of coral (-1.1 percent). This pattern was driven by an increase in the proportion of sand and rubble classification and a decrease in the proportion of *P. lobata*.

Kaloko-Honokōhau National Historic Park

The mean percent live coral cover at KAHO was 28.7 ± 24.9 percent and 25.3 ± 24.7 percent for the baseline and resurvey periods, respectively (table 4; figs. 7, 10*A*, 10*B*). The variability of coral cover was higher at KAHO than PUHE and PUHO. In both the baseline and resurvey, the highest percent coral cover was found adjacent to Kaloko Fishpond and near the northern end of the park (fig. 10).

Live coral cover in KAHO decreased by 11.7 percent between the baseline and resurvey (table 3). Despite this loss, there were sites where an increase in coral cover was observed (fig. 10*C*), including many of the sites adjacent to Kaloko Fishpond and around the harbor. This positive change in coral

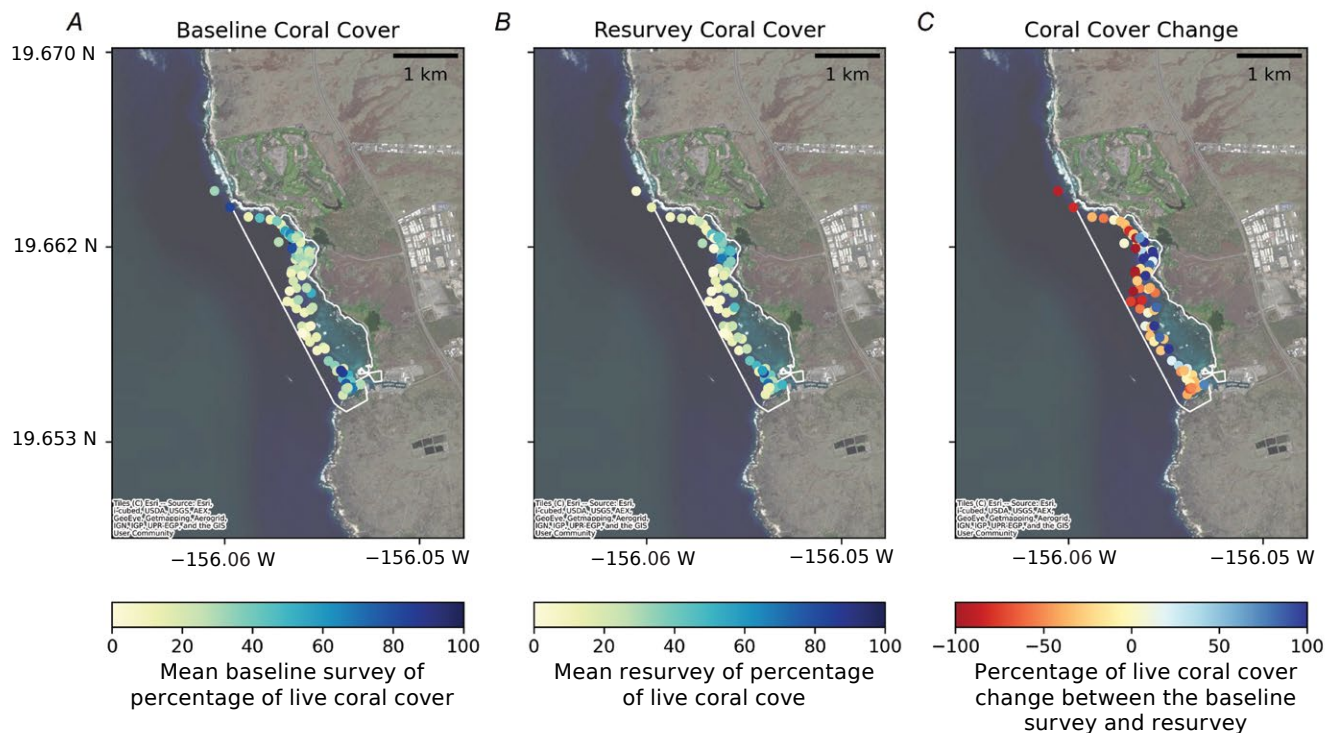


Figure 10. Three maps of spatial patterns of live coral cover and change by site at Kaloko-Honokōhau National Historic Park. A, Mean baseline survey of percentage of live coral cover (\bar{C}_B). B, Mean resurvey of percentage of live coral cover (\bar{C}_R). C, Percentage of live coral cover change (Δ_C) between the baseline and resurvey. Park boundaries are represented in white. Base imagery from Esri and its licensors.

cover was also reflected in the change of coral and non-coral types, where non-coral types decreased by 16.8 percent and coral types increased 22.3 percent (table 3).

Though there were similar distributions of coral cover between the baseline and resurvey periods at KAHO (fig. 11A), the lowest coral cover bin (0 to 10 percent) showed the greatest increase in occurrences, whereas coral cover bins with percentages greater than 10 percent varied in gains or losses (fig. 11B). Most of the site-specific coral cover change was negative, with a strong bias towards 100-percent loss in the distribution curve of percent change (fig. 11C). The distribution of coral change at KAHO was more weighted towards positive change than PUHE and PUHO with the tail of the distribution extending to gains of 400-percent (fig. 11C). These large gains in cover were relatively rare ($n=2$) and may be driven by high uncertainties in the locational data of the baseline imagery or the heterogeneity of coral cover of a particular site.

KAHO was more characteristic of lower coral cover in the baseline and resurvey periods as evidenced by a higher proportion of non-coral type classifications (table 2; figs. 11D–F). The most common dominant bottom type in the baseline survey was sand (37 percent), but rubble was significantly more common at KAHO than the other two parks across both surveys. In the resurvey, the occurrence of coral and non-coral types was nearly equal with corals comprising 52.5 percent and non-coral types comprising 47.4 percent

of the images. *P. lobata* was the most common coral type in both survey periods. KAHO was the only site where positive change of coral types and negative change of non-coral types was observed (table 3; fig. 11F).

Pu‘uhonua o Hōnaunau National Historic Park

The mean percent live coral cover at PUHO was 52.3 ± 31.5 percent and 25.0 ± 23.0 percent in the baseline and resurvey periods, respectively (table 4; figs. 7, 12). Live coral cover decreased by 52.2 percent between the baseline and resurvey (table 3; figs. 7, 12). Generally, live coral cover decreased across the entire park (fig. 12C).

Like PUHE, the occurrence of coral cover between 0 and 40 percent increased, whereas the occurrence of coral cover more than 50 percent decreased at PUHO (figs. 13A, 13B). Most of the site-specific coral cover change was negative, with a strong bias towards 100 percent loss in the distribution curve of percent change (fig. 13C). Despite overwhelming negative coral change across the park, there were some sites that experienced positive change in live coral cover.

Coral types were classified as the dominant type in 91.2 percent of the baseline images at PUHO (table 2; fig. 13). For the baseline survey, *P. lobata* was the most common bottom type (52.3 percent), followed by *P. compressa* (32.0 percent). Non-coral types were classified

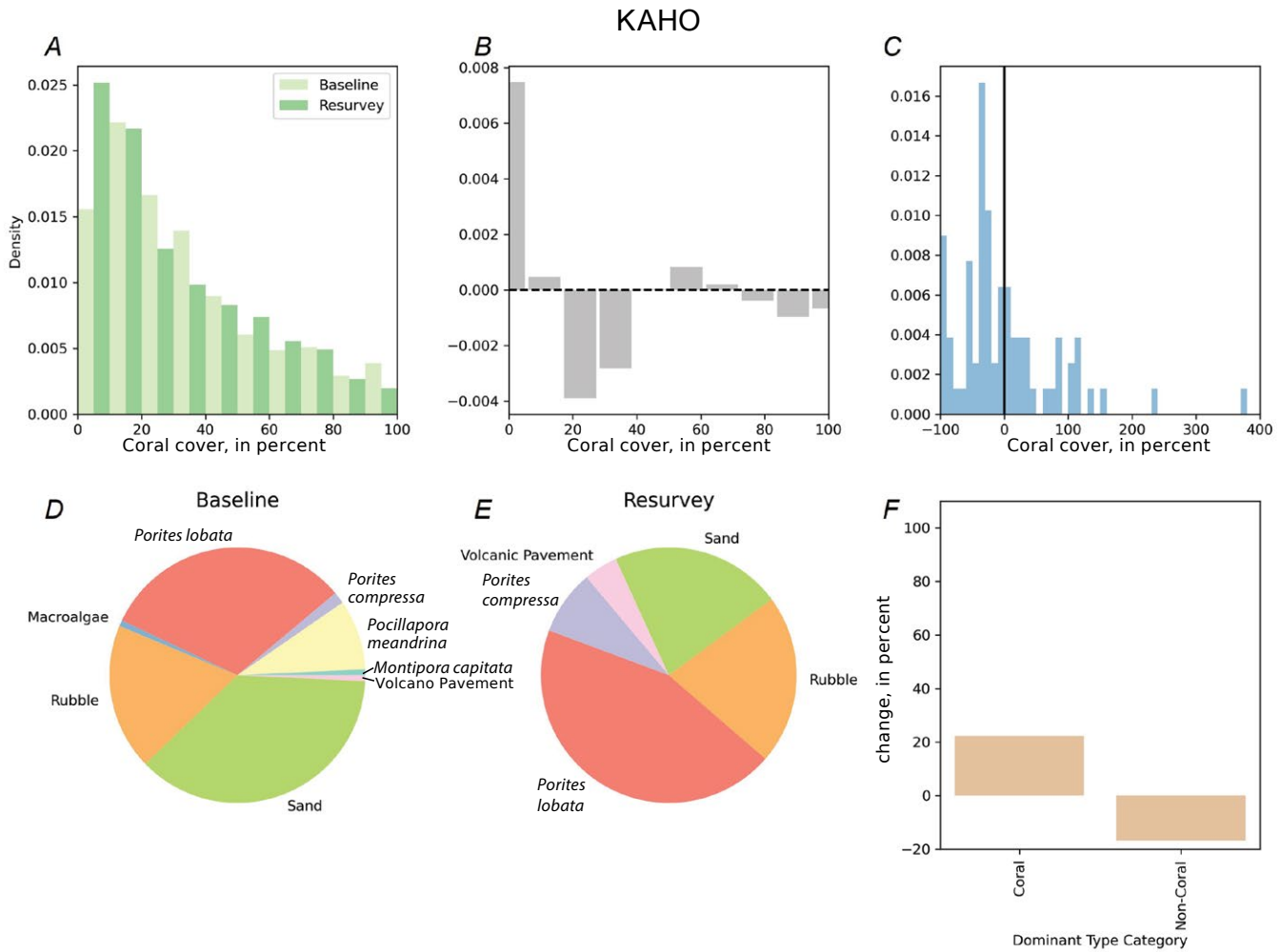


Figure 11. Graphs showing park trends of percent baseline, resurvey, and change of live coral cover and dominant types for Kaloko-Honokōhau National Historic Park. A, Density distribution of percentage of baseline and resurvey coral cover. B, Difference in baseline and resurvey density distributions (resurvey minus baseline). C, Density distribution of live coral cover (Δ_c). D, Pie chart of the eight dominant bottom types in the baseline imagery (n equals 135). E, Pie chart of the eight dominant bottom types in the resurvey imagery (n equals 512). F, Change of coral (Δ_{pc}) and non-coral (Δ_{pn}) dominant types.

as the dominant type in 6.6 percent of the baseline images. In the resurvey, coral types were classified in 89.2 percent of the images and non-coral in 10.8 percent. *P. compressa* was the most common dominant bottom type in the resurvey (47.9 percent); however, *P. lobata* was still relatively common (40.7 percent). Rubble increased from 1.0 percent of all classified dominant bottom types to 8.7 percent (a nearly 800- percent change) between the baseline and resurvey.

Depth Associated Patterns of Coral

Overall, the patterns of coral cover, live coral change, and dominant type were not found to be strongly associated with depth. PUHE sites were the shallowest site on average (mean depth=11±5.9 m), followed by KAHO (mean=14.2±5.6 m) and then PUHO (mean=15.1±4.8 m).

Depth Distributions of Live Coral Cover

The depth distribution of coral cover bins demonstrated high variability between the baseline and resurvey periods across all three parks (fig. 14). However, high percent cover bins became more concentrated at mid-depths (20 to 15 m) in the resurvey, especially at PUHE and PUHO.

Depth Related Associations of Live Coral Cover Change

Water depth had moderate or little influence on changes in live coral cover across all three parks (fig. 14). The relation between live coral cover change and water depth was significant at all three parks (probability value less than 0.005), but the relations were corroborated by low correlation

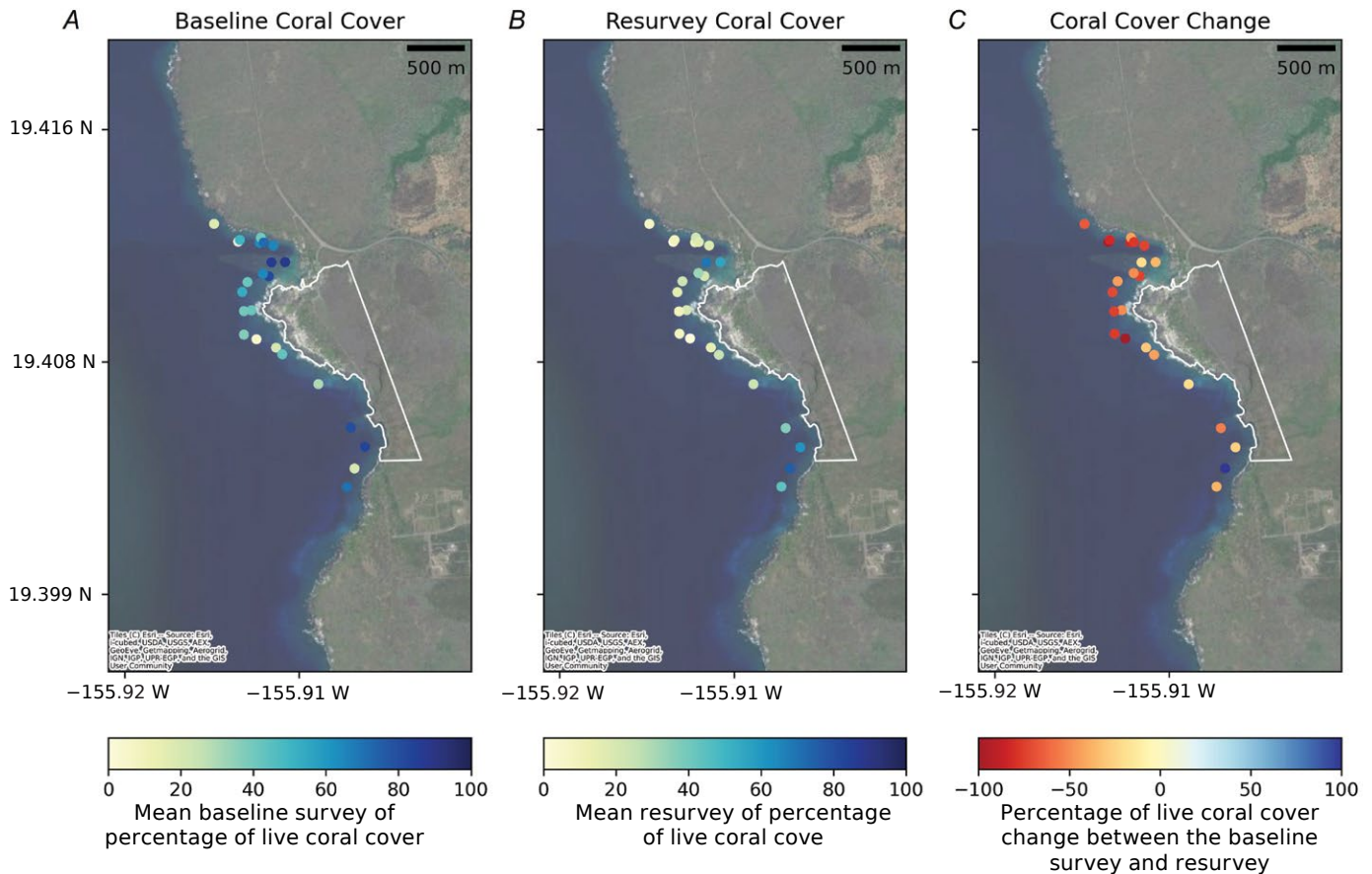


Figure 12. Three maps of spatial patterns of live coral cover and change by site at Pu'uhonua o Hōnaunau National Historic Park. A, Mean baseline survey of percentage of live coral cover (\bar{C}_B). B, Mean resurvey of percentage of live coral cover (\bar{C}_R). C, Percentage of live coral cover change (Δ_C) between baseline and resurvey. Park boundaries are represented in white. Base imagery from Esri and its licensors.

values ($R^2 < 0.2$), especially at KAHO and PUHO. At KAHO, increases in coral cover up to 400 percent were observed at certain sites. PUHE exhibited the strongest relation between coral change and depth (correlation value=0.48), where live coral cover loss was pronounced at shallower depths. However, the opposite was observed at KAHO, where coral loss was pronounced at deeper depths and large gains occurred at shallow depths.

Summary and Conclusions

This study aimed to investigate changes in live coral cover and bottom composition across three national parks on the Kona Coast through a comprehensive analysis of underwater imagery in the early 2000s and again in 2022. Our results indicate there was reduction of live coral cover across all three parks and increases in non-coral dominant bottom types at Pu'ukoholā Heiau National Historic Site (PUHE)

and Pu'uhonua o Hōnaunau National Historic Park (PUHO). PUHE experienced the greatest decrease of live coral cover, whereas Kaloko-Honokōhau National Historic Park (KAHO) experienced the smallest decrease in live coral cover.

Despite most of the sites in all three parks showing declines in live coral cover, there were sites where positive change in coral was observed. In KAHO, these sites were predominantly adjacent to Kaloko Fishpond and the southern half of the park. The protected nature of the pinnacles off Kaloko Fishpond and the embayment around the harbor may provide reprieve from storm damage and wave energy allowing coral to recover in these areas of KAHO. Furthermore, the highest historical coral cover measured was at these locations and indicates more recovery was possible than at other exposed sites in the KAHO study area. This explanation also supports the negative relation between depth and coral cover change at KAHO (fig. 15) where the shelf begins to transition into a steep shelf break at 12- to 20-m

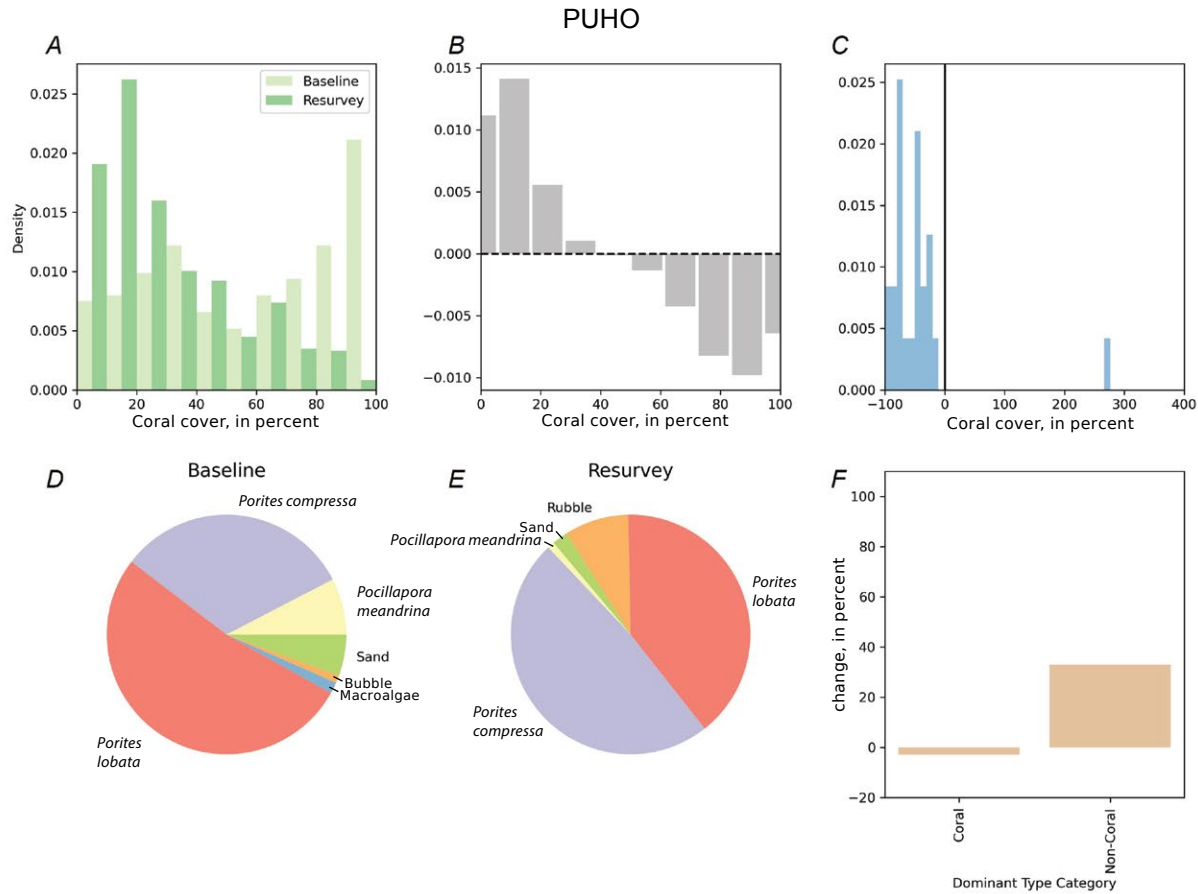


Figure 13. Graphs showing park trends of percent baseline, resurvey, and change of live coral cover and dominant types for Pu'uuhonua o Hōnaunau National Historic Park. A, Density distribution of percentage of baseline and resurvey coral cover. B, Difference in baseline and resurvey density distributions (resurvey minus baseline). C, Density distribution of live coral cover change (Δ_c). D, Pie chart of the eight dominant bottom types in the baseline imagery (n equals 197). E, Pie chart of the eight dominant bottom types in the resurvey imagery (n equals 426). F, Change of coral (Δ_{PC}) and non-coral (Δ_{PN}) dominant types.

depths. At these depths, coral cover naturally declines and uncolonized substrate increases, indicating that wave stress and damage might be driving coral cover and coral change. Unlike KAHO, there was a positive relation between depth and coral cover change at PUHE (fig. 15). This trend may be driven by patterns in depth distribution of aggregate reef, where the proportion of dominant substrate structure composed of aggregate reef peaks at 25 m, indicating deeper environments are more favorable for coral colonization at PUHE. Positive coral change was only observed at one site in PUHO and there was no significant relation between depth and coral cover change (fig. 15). This positive coral change may be due to locational errors between the baseline and resurvey periods.

Declines in coral cover have been observed in subtidal surveys across the Kona Coast by National Park Service Inventory and Monitoring (NPS I&M), National Coral Reef

Monitoring Program, and Coral Reef Assessment and Monitoring, though none are across the same period as the results presented from this study. Records of declining coral cover from multiple organizations, sampling strategies, and periods in this region demonstrate that continued and consistent monitoring across all three parks could be used to inform future decision making and policy development.

Because KAHO is currently the only park to have a fixed, long-term marine monitoring program, expanding the current KAHO I&M surveys to include permanent subtidal monitoring sites at PUHO and PUHE could provide relevant information on coral change for all three parks on the Kona Coast. Despite park boundaries not officially extending into the marine environment, these important ecosystems occur downslope of the parks and are of concern to NPS management. Additionally, validating survey results by crossing future periodic boat-based drop-camera surveys with

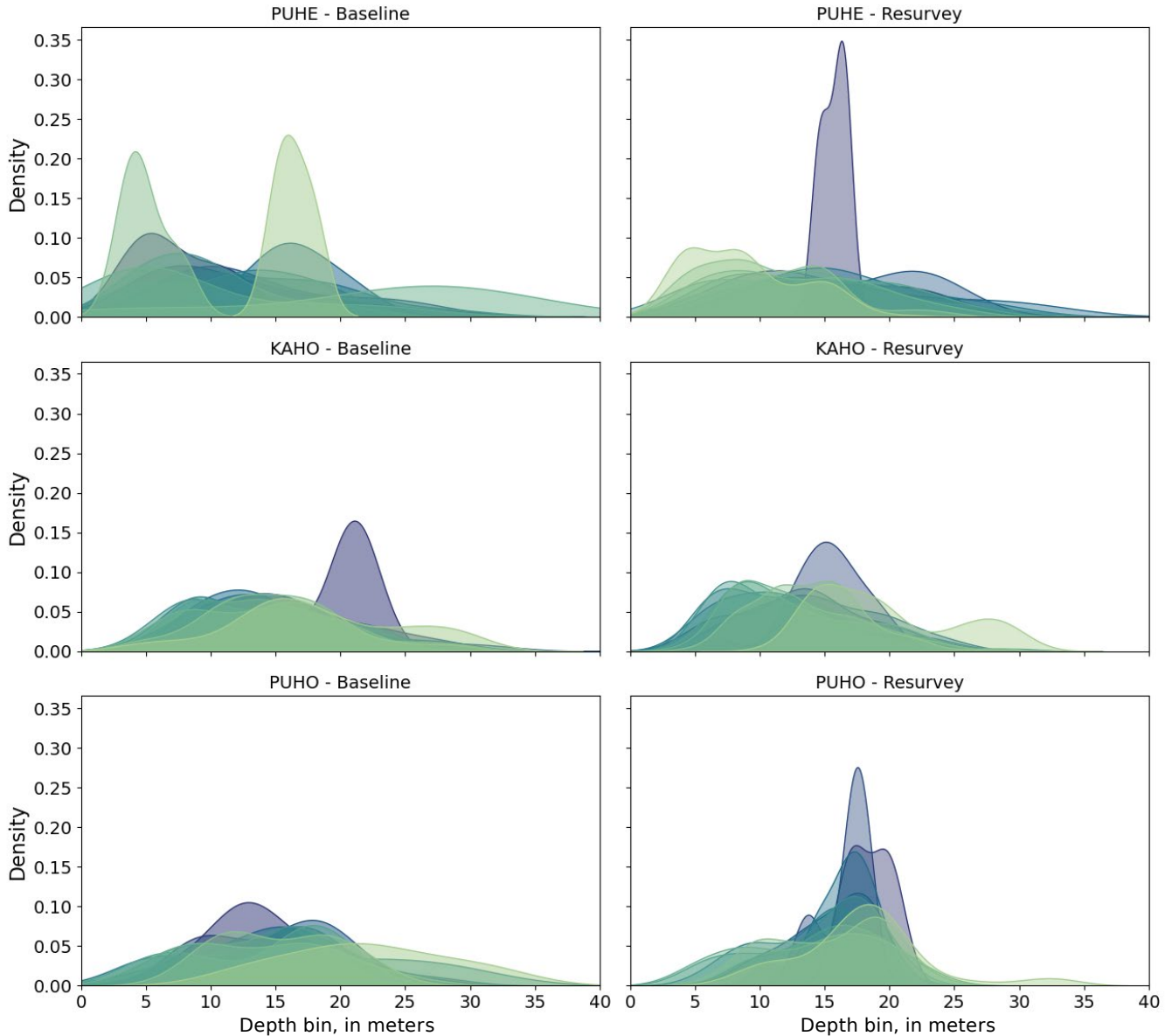


Figure 14. Plot of density distribution of 10 percent coral cover classes at depth bins at Pu'ukoholā Heiau National Historic Site (PUHE), Kaloko-Honokōhau National Historic Park (KAHO), and Pu'uuhonua o Hōnaunau National Historic Park (PUHO) from baseline (A, C, E) and resurvey (B, D, F) imagery classifications. Histograms do not have a common normalization.

I&M fixed diver transects across all three park regions would allow the managers to have a more robust understanding of coral cover and change. Continuing U.S. Geological Survey camera surveys in the future would provide consistency in imagery acquisition methodology by utilizing the approach taken in the resurvey period moving forward. Compared to the baseline surveys, the drifted survey approach in the resurvey provides higher-resolution imagery and increased positional control. Combining the drifted survey approach with precise GNSS global positioning system data would likely reduce uncertainty in the locational data across years.

Because of the collective multi-agency approach to management in this region, expanding survey efforts (such as systematic larger area camera system surveys, in conjunction with diver surveys concentrated on smaller sites of particular interest) could benefit multiple state and local agencies. Furthermore, ongoing and expanded surveys could help inform potential future protections of marine systems within NPS boundaries. These continued assessment surveys would enable the NPS to continue monitoring changes to critical nearshore habitats and marine resources under and adjacent to National Park jurisdiction.

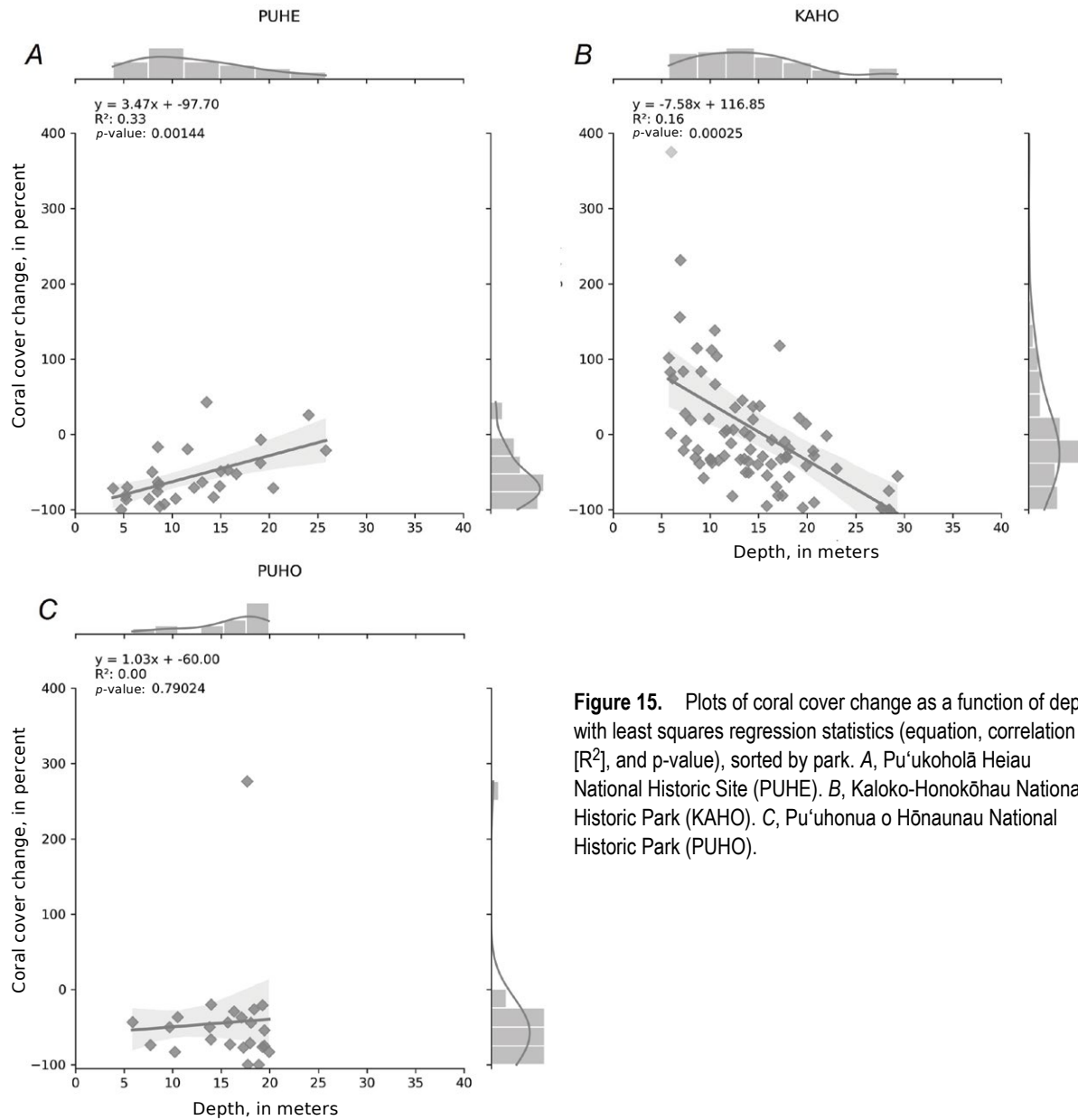


Figure 15. Plots of coral cover change as a function of depth with least squares regression statistics (equation, correlation [R^2], and p-value), sorted by park. A, Pu'ukoholā Heiau National Historic Site (PUHE). B, Kaloko-Honokōhau National Historic Park (KAHO). C, Pu'uhonua o Hōnaunau National Historic Park (PUHO).

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Appendix 1.

Appendix 1 provides the site-specific means, standard deviations, and distributions of baseline and resurvey percent live coral cover for Pu'ukoholā Heiau National Historic Site (PUHE), Kaloko-Honokōhau National Historic Park (KAHO), and Pu'uhonua o Hōnaunau National Historic Park (PUHO).

Live Coral Cover Distributions by Site

Table 1.1. Baseline (BL) and resurvey (RS) mean longitude, mean latitude, mean percent live coral cover (\bar{C}), standard deviation of percent live coral cover (σ_c), and the number of images classified by site at PUHE (Pu'ukoholā Heiau National Historic Site).

[°, degree; %, percent]

Site	Survey type	Mean site longitude (°)	Mean site latitude (°)	\bar{C} (%)	σ_c (%)	Number of classified images	Site	Survey type	Mean site longitude (°)	Mean site latitude (°)	\bar{C} (%)	σ_c (%)	Number of classified images
PUHE01	BL	-155.830	20.016	80	14.1	4	PUHE16	RS	-155.833	20.029	0	0	17
PUHE01	RS	-155.830	20.016	26.4	23.1	25	PUHE17	BL	-155.835	20.027	70	17.3	3
PUHE02	BL	-155.834	20.015	43.3	5.8	3	PUHE17	RS	-155.835	20.027	5.2	7.5	21
PUHE02	RS	-155.834	20.015	13.5	11.5	23	PUHE19	BL	-155.829	20.025	27.1	17	7
PUHE03	BL	-155.834	20.016	48	44.4	5	PUHE19	RS	-155.829	20.025	7.6	7	34
PUHE03	RS	-155.834	20.016	25.4	38.5	28	PUHE20	BL	-155.833	20.023	70	24.5	4
PUHE05	BL	-155.836	20.020	55	13.2	16	PUHE20	RS	-155.833	20.023	20.6	14.7	18
PUHE05	RS	-155.837	20.020	34.1	18.7	39	PUHE21	BL	-155.831	20.021	65	15.1	8
PUHE06	BL	-155.830	20.019	80	10	3	PUHE21	RS	-155.831	20.021	9.6	11.1	23
PUHE06	RS	-155.830	20.019	11.3	11.3	15	PUHE22	BL	-155.829	20.020	25	7.1	2
PUHE07	BL	-155.829	20.023	93.3	5	9	PUHE22	RS	-155.829	20.020	3.3	4.9	15
PUHE07	RS	-155.829	20.023	17.3	13.7	37	PUHE24	BL	-155.832	20.014	40	14.1	2
PUHE08	BL	-155.834	20.027	87.5	9.6	4	PUHE24	RS	-155.832	20.014	57.1	13.8	7
PUHE08	RS	-155.834	20.027	21.4	17.3	22	PUHE25	BL	-155.832	20.016	70	24.5	4
PUHE09	BL	-155.837	20.028	23.3	5.8	3	PUHE25	RS	-155.832	20.016	3.1	7.9	26
PUHE09	RS	-155.837	20.028	29.3	12.2	15	PUHE26	BL	-155.833	20.019	67.1	34	7
PUHE10	BL	-155.839	20.040	85	7.1	2	PUHE26	RS	-155.833	20.019	11.3	15.7	31
PUHE10	RS	-155.839	20.040	68.3	23.3	12	PUHE27	BL	-155.836	20.021	55	7.1	2
PUHE11	BL	-155.836	20.039	65	35.4	2	PUHE27	RS	-155.836	20.020	26.3	20.9	16
PUHE11	RS	-155.836	20.039	23.8	16.9	8	PUHE29	BL	-155.837	20.029	60	14.1	5
PUHE12	BL	-155.838	20.034	60	14.1	2	PUHE29	RS	-155.837	20.029	30.9	21.3	35
PUHE12	RS	-155.838	20.034	66.7	18.6	6	PUHE30	BL	-155.837	20.036	60	28.3	2
PUHE13	BL	-155.835	20.033	42	11	5	PUHE30	RS	-155.837	20.036	50	30.4	14
PUHE13	RS	-155.835	20.033	12.6	14	27	PUHE31	BL	-155.838	20.032	65	29.3	8
PUHE14	BL	-155.837	20.031	65	7.1	2	PUHE31	RS	-155.838	20.032	51.3	21	23
PUHE14	RS	-155.837	20.031	60.5	23.1	21	PUHE32	BL	-155.836	20.031	56	13.4	5
PUHE15	BL	-155.834	20.029	20	14.1	2	PUHE32	RS	-155.836	20.031	20.6	28.1	35
PUHE15	RS	-155.834	20.029	10	7.7	11	PUHE36	BL	-155.836	20.023	81.7	9.8	6
PUHE16	BL	-155.833	20.029	36.7	5.8	3	PUHE36	RS	-155.836	20.023	23.6	16.5	39

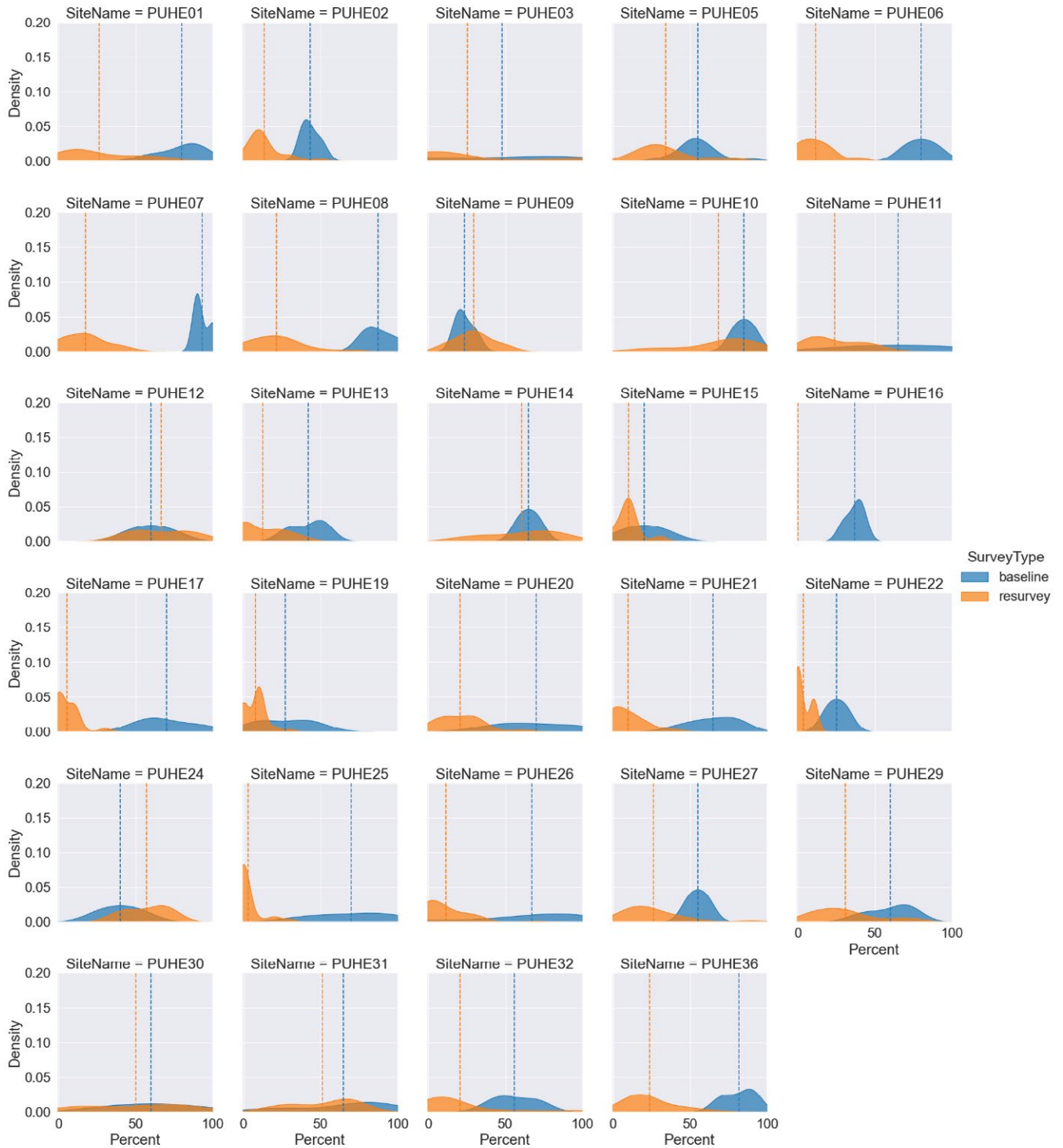


Figure 1.1. Graphs showing density distribution curves for percent live coral cover for baseline and resurvey sites at Pu'ukoholā Heiau National Historic Site (PUHE). Dashed vertical lines indicate the mean percent live coral cover for each survey period.

Table 1.2. Baseline (BL) and resurvey (RS) mean longitude, mean latitude, mean percent live coral cover (\bar{C}), standard deviation of percent live coral cover (σ_c), and the number of images classified by site at Kaloko-Honokōhau National Historic Park (KAHO).

[°, degree; %, percent]

Site	Survey type	Mean site longitude (°)	Mean site latitude (°)	\bar{C} (%)	σ_c (%)	Number of classified images	Site	Survey type	Mean site longitude (°)	Mean site latitude (°)	\bar{C} (%)	σ_c (%)	Number of classified images
HN05	BL	-156.030	19.670	36	27.2	10	KAHO21	BL	-156.032	19.672	35.1	20.8	45
HN05	RS	-156.030	19.670	52.3	34.4	22	KAHO21	RS	-156.032	19.672	42.1	23.3	39
HN07	BL	-156.029	19.669	10	14.1	2	KAHO22	BL	-156.031	19.672	35.8	23.9	12
HN07	RS	-156.029	19.669	80	11.5	7	KAHO22	RS	-156.031	19.672	49.5	18.1	19
KAHO01	BL	-156.039	19.688	27.9	25.9	70	KAHO23	BL	-156.031	19.671	22.5	8.9	8
KAHO01	RS	-156.039	19.688	29.6	26	91	KAHO23	RS	-156.031	19.671	12.3	14.2	13
KAHO02	BL	-156.033	19.674	22.2	21.3	73	KAHO24	BL	-156.030	19.670	44.3	30.3	23
KAHO02	RS	-156.033	19.675	15.6	21.1	135	KAHO24	RS	-156.030	19.670	43.5	23.4	17
KAHO04	BL	-156.036	19.685	24.3	5.3	7	KAHO25	BL	-156.029	19.669	54.4	39.7	9
KAHO04	RS	-156.036	19.686	22.2	10.1	27	KAHO25	RS	-156.029	19.668	26.9	25.3	26
KAHO05	BL	-156.037	19.686	17	17	10	KAHO26	BL	-156.030	19.668	20.8	11.2	13
KAHO05	RS	-156.035	19.677	15	13	22	KAHO26	RS	-156.030	19.668	12.5	18.9	4
KAHO06	BL	-156.037	19.689	20	8.9	6	KAHO27	BL	-156.048	19.694	31.7	18.5	12
KAHO06	RS	-156.037	19.688	42.4	16.7	38	KAHO27	RS	-156.048	19.694	3.1	8.1	29
KAHO07	BL	-156.037	19.686	38	31.1	5	KAHO28	BL	-156.043	19.691	12.5	5	4
KAHO07	RS	-156.035	19.682	30.4	24.1	26	KAHO28	RS	-156.043	19.691	8	11.4	10
KAHO08	BL	-156.037	19.688	100	0	3	KAHO29	BL	-156.039	19.690	15	7.6	8
KAHO08	RS	-156.037	19.688	78.3	11.7	6	KAHO29	RS	-156.039	19.690	10.5	13.6	21
KAHO09	BL	-156.037	19.687	77.5	22.2	4	KAHO30	BL	-156.038	19.689	20	18.5	8
KAHO09	RS	-156.037	19.687	45.2	25	31	KAHO30	RS	-156.038	19.689	12.1	15.3	24
KAHO10	BL	-156.036	19.687	47.5	32.8	8	KAHO31	BL	-156.038	19.689	22.5	12.2	12
KAHO10	RS	-156.036	19.687	49	23.3	10	KAHO31	RS	-156.037	19.689	27.5	25.1	20
KAHO11	BL	-156.036	19.686	25	20	8	KAHO33	BL	-156.037	19.688	12.1	10.5	14
KAHO11	RS	-156.036	19.686	34.3	18.9	28	KAHO33	RS	-156.037	19.688	16.5	16.4	40
KAHO12	BL	-156.035	19.686	28	17.8	15	KAHO34	BL	-156.036	19.689	36	15.2	5
KAHO12	RS	-156.035	19.686	57.1	16.5	24	KAHO34	RS	-156.036	19.688	46.1	8.9	23
KAHO13	BL	-156.035	19.686	25	7.1	2	KAHO35	BL	-156.036	19.688	15	10.7	8
KAHO13	RS	-156.035	19.686	82.9	4.9	7	KAHO35	RS	-156.036	19.688	35.7	15.1	7
KAHO15	BL	-156.035	19.685	30	6.7	10	KAHO36	BL	-156.035	19.687	48.6	10.7	7
KAHO15	RS	-156.035	19.685	35.7	14	7	KAHO36	RS	-156.035	19.687	49.4	11.2	16
KAHO16	BL	-156.036	19.684	26.7	13.7	12	KAHO37	BL	-156.035	19.687	23.3	5.8	3
KAHO16	RS	-156.036	19.684	21.6	15.2	25	KAHO37	RS	-156.035	19.687	47	10.6	10
KAHO17	BL	-156.036	19.677	22.8	11.8	18	KAHO38	BL	-156.036	19.686	31.4	10.7	7
KAHO17	RS	-156.036	19.677	26	19.1	40	KAHO38	RS	-156.036	19.686	68.4	25	19
KAHO18	BL	-156.035	19.676	8.5	10.3	27	KAHO39	BL	-156.035	19.685	20	11.8	11
KAHO18	RS	-156.035	19.676	5.8	5.9	40	KAHO39	RS	-156.035	19.685	36.8	17	40
KAHO19	BL	-156.035	19.675	13.6	16.2	28	KAHO40	BL	-156.035	19.684	30	20	3
KAHO19	RS	-156.035	19.675	12.3	10	40	KAHO40	RS	-156.035	19.684	23.7	14.6	19
KAHO20	BL	-156.034	19.674	8.5	6.9	13	KAHO41	BL	-156.036	19.683	6.7	5.8	3
KAHO20	RS	-156.034	19.674	6	5.2	10	KAHO41	RS	-156.036	19.683	14.3	6.5	14

Table 1.2. Baseline (BL) and resurvey (RS) mean longitude, mean latitude, mean percent live coral cover (\bar{C}), standard deviation of percent live coral cover (σ_c), and the number of images classified by site at Kaloko-Honokōhau National Historic Park (KAHO).—Continued

[°, degree; %, percent]

Site	Survey type	Mean site longitude (°)	Mean site latitude (°)	\bar{C} (%)	σ_c (%)	Number of classified images	Site	Survey type	Mean site longitude (°)	Mean site latitude (°)	\bar{C} (%)	σ_c (%)	Number of classified images
KAHO42	BL	-156.037	19.684	26.4	31.4	11	KAHO64	RS	-156.037	19.689	28.4	19.7	31
KAHO42	RS	-156.037	19.684	0	0	17	KAHO65	BL	-156.037	19.689	65	5.8	4
KAHO43	BL	-156.037	19.684	10	10.4	12	KAHO65	RS	-156.037	19.689	46.5	15.5	26
KAHO43	RS	-156.037	19.684	0.3	1.7	35	KAHO66	BL	-156.037	19.688	45	18.7	6
KAHO44	BL	-156.036	19.682	20	17.3	3	KAHO66	RS	-156.037	19.688	2.3	4.3	22
KAHO44	RS	-156.037	19.682	9.1	7	11	KAHO67	BL	-156.037	19.688	26.3	16	8
KAHO45	BL	-156.037	19.681	5	5.5	6	KAHO67	RS	-156.037	19.688	43.8	22.6	8
KAHO45	RS	-156.037	19.681	0	0	12	KAHO68	BL	-156.037	19.687	80	10	3
KAHO46	BL	-156.034	19.681	52	13	5	KAHO68	RS	-156.037	19.687	1	3.2	10
KAHO46	RS	-156.034	19.681	22	7.7	20	KAHO71	BL	-156.036	19.680	30.6	18.9	17
KAHO47	BL	-156.037	19.680	10	8.5	15	KAHO71	RS	-156.036	19.680	5.7	11.2	21
KAHO47	RS	-156.037	19.680	0.3	1.6	39	KAHO72	BL	-156.038	19.680	10	19.1	7
KAHO48	BL	-156.036	19.679	13.3	5.8	3	KAHO72	RS	-156.038	19.680	2.5	4.5	16
KAHO48	RS	-156.036	19.679	5.8	5.1	12	KAHO73	BL	-156.035	19.679	19	9.9	10
KAHO49	BL	-156.035	19.679	10	6.3	11	KAHO73	RS	-156.034	19.679	13.2	5.7	22
KAHO49	RS	-156.035	19.679	10.5	2.3	19	KAHO74	BL	-156.034	19.677	5	5.3	10
KAHO51	BL	-156.035	19.677	14.3	5.3	7	KAHO74	RS	-156.034	19.677	23.8	13.6	16
KAHO51	RS	-156.035	19.677	9.3	2.6	15	KAHO75	BL	-156.036	19.676	0	0	3
KAHO53	BL	-156.033	19.674	10	8.2	4	KAHO75	RS	-156.036	19.676	0	0	4
KAHO53	RS	-156.032	19.674	25.6	13.3	9	KAHO76	BL	-156.034	19.675	14	5.5	5
KAHO55	BL	-156.030	19.671	17.5	9.6	4	KAHO76	RS	-156.034	19.675	25.7	11.3	7
KAHO55	RS	-156.030	19.671	21.2	17.3	17	KAHO79	BL	-156.029	19.669	25.3	21.2	17
KAHO56	BL	-156.029	19.670	52.1	26.4	14	KAHO79	RS	-156.029	19.669	12.4	13.9	33
KAHO56	RS	-156.029	19.670	41.3	18.9	8	KAHO80	BL	-156.028	19.669	28.8	29	8
KAHO57	BL	-156.029	19.670	42.5	9.6	4	KAHO80	RS	-156.028	19.669	50	24.5	13
KAHO57	RS	-156.029	19.670	28	11	5	KAHO81	BL	-156.046	19.692	82.5	9.6	4
KAHO58	BL	-156.030	19.669	76.2	22.6	13	KAHO81	RS	-156.046	19.692	14.7	5.2	15
KAHO58	RS	-156.030	19.669	70.5	15.7	20	KAHO82	BL	-156.042	19.691	45	63.6	2
KAHO59	BL	-156.030	19.669	30	21.7	18	KAHO82	RS	-156.042	19.691	20	26.2	10
KAHO59	RS	-156.030	19.669	9.2	8.3	37	KAHO83	BL	-156.037	19.683	21.3	22.3	8
KAHO60	BL	-156.029	19.669	67.7	14.2	13	KAHO83	RS	-156.037	19.683	15.3	16.1	19
KAHO60	RS	-156.029	19.669	41.3	15.1	15	KAHO84	BL	-156.035	19.682	27.5	20.5	8
KAHO61	BL	-156.040	19.691	12.5	5	4	KAHO84	RS	-156.035	19.682	17.1	17.6	21
KAHO61	RS	-156.040	19.691	12.9	9.5	7	KAHO85	BL	-156.034	19.679	25	21.2	2
KAHO62	BL	-156.039	19.691	37.5	17.5	8	KAHO85	RS	-156.034	19.679	45.7	7.9	7
KAHO62	RS	-156.039	19.690	25.3	9.9	15	KAHO87	BL	-156.030	19.671	85	12.2	6
KAHO63	BL	-156.038	19.689	56.1	29.1	18	KAHO87	RS	-156.030	19.671	83.7	11.6	19
KAHO63	RS	-156.038	19.689	10.6	13.9	31	WHAP11	BL	-156.030	19.671	86.7	5.8	3
KAHO64	BL	-156.038	19.689	42	25.3	10	WHAP11	RS	-156.030	19.671	57.8	21.8	18

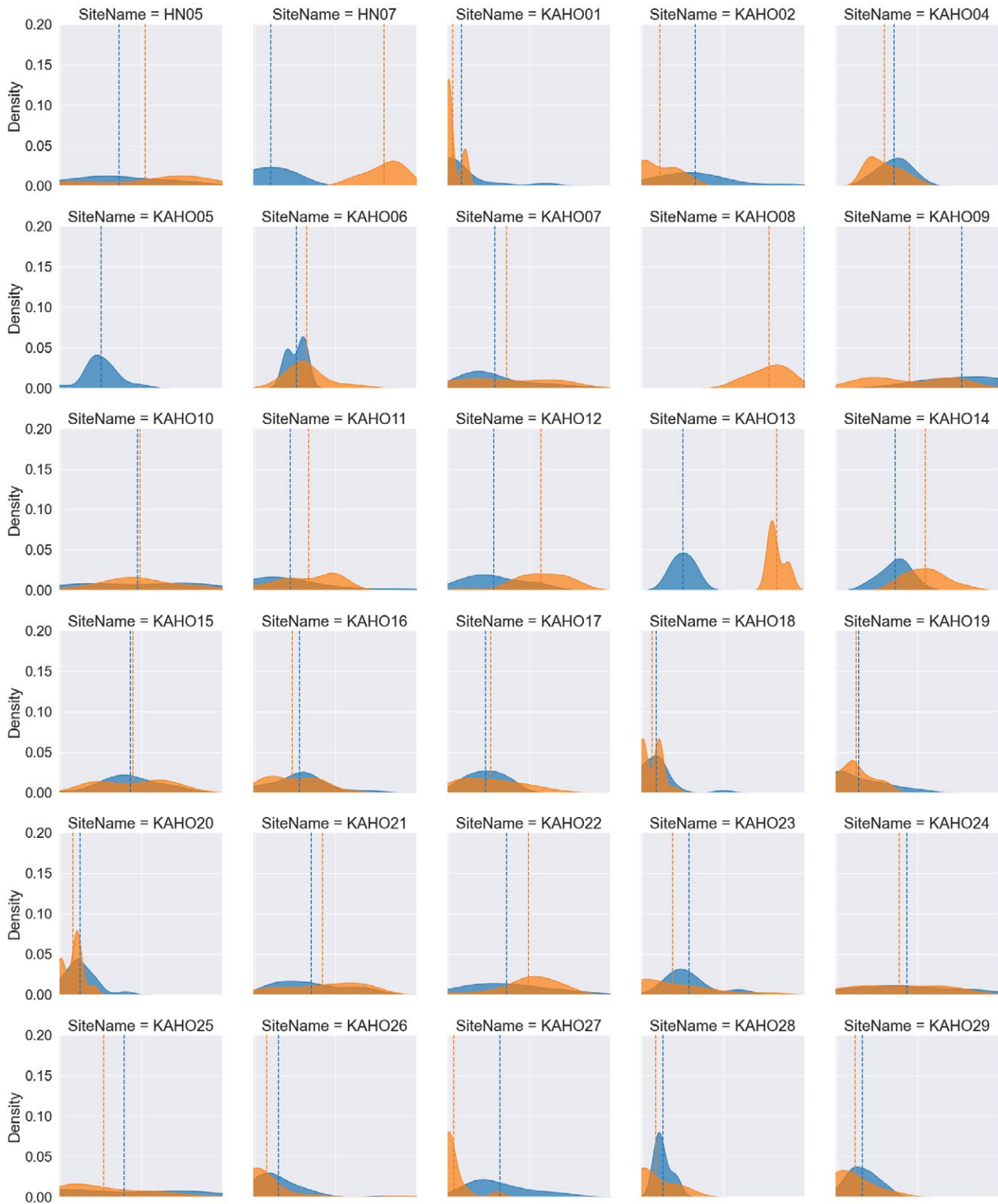


Figure 1.2. Density distribution curves for percent live coral cover for baseline and resurvey sites at Kaloko-Honokōhau National Historic Park (KAHO). Dashed vertical lines indicate the mean percent live coral cover for each survey period.

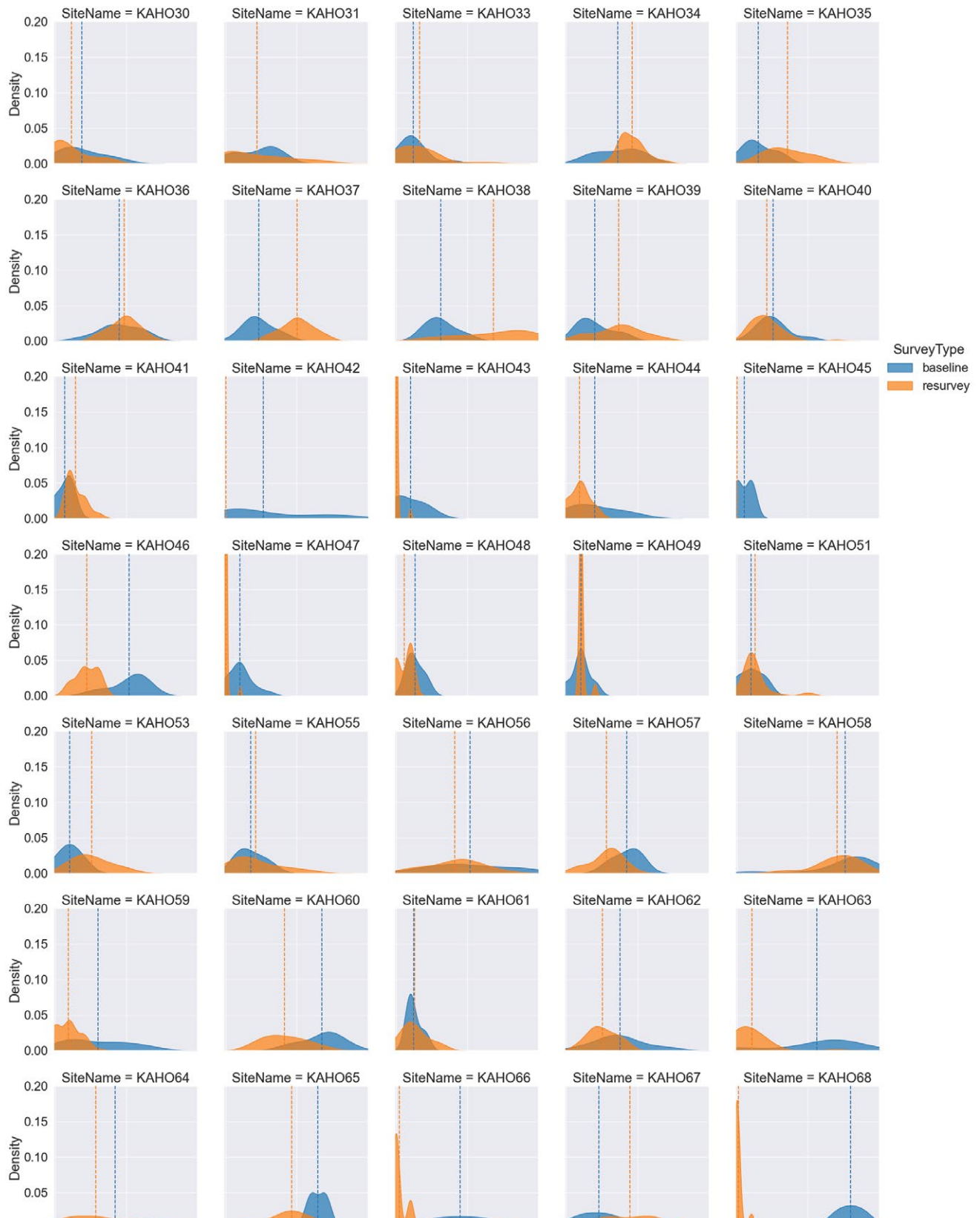


Figure 1.2. —Continued.

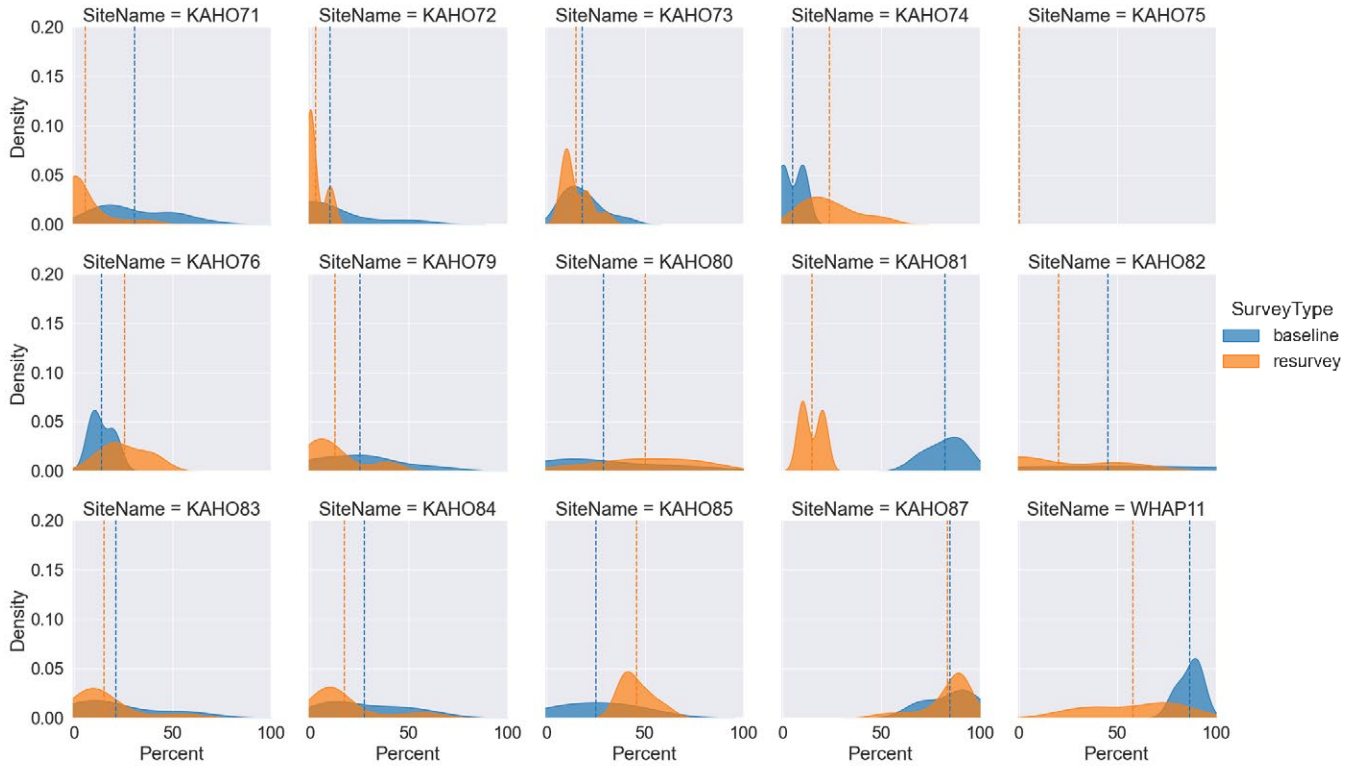


Figure 1.2. —Continued.

Table 1.3. Baseline (BL) and resurvey (RS) mean longitude, mean latitude, mean percent live coral cover (\bar{C}), standard deviation of percent live coral cover (σ_c), and the number of images classified by site at Pu'uhonua o Hōnaunau National Historic Park (PUHO).

[°, degree; %, percent]

Site	Survey type	Mean site longitude (°)	Mean site latitude (°)	\bar{C} (%)	σ_c (%)	Number of classified images	Site	Survey type	Mean site longitude (°)	Mean site latitude (°)	\bar{C} (%)	σ_c (%)	Number of classified images
PUHO01	BL	-155.916	19.425	2	4.5	5	PUHO17	BL	-155.910	19.415	30	7.1	5
PUHO01	RS	-155.916	19.425	0	0	10	PUHO17	RS	-155.910	19.415	23.8	13.6	32
PUHO02	BL	-155.915	19.425	63.1	34.6	16	PUHO19	BL	-155.908	19.411	80	0	2
PUHO02	RS	-155.915	19.425	10.8	9.5	25	PUHO19	RS	-155.908	19.411	36.7	11.2	9
PUHO03	BL	-155.915	19.425	40.5	23.4	19	PUHO20	BL	-155.908	19.407	70	25.1	14
PUHO03	RS	-155.915	19.425	23	8	20	PUHO20	RS	-155.908	19.407	44	18.8	40
PUHO04	BL	-155.914	19.425	72	15.7	15	PUHO21	BL	-155.907	19.408	20	0	3
PUHO04	RS	-155.914	19.425	16.7	19.5	15	PUHO21	RS	-155.907	19.408	75.3	9.6	19
PUHO05	BL	-155.914	19.425	65.5	35	11	PUHO22	BL	-155.907	19.410	82.5	9.6	4
PUHO05	RS	-155.914	19.425	17.8	14.4	18	PUHO22	RS	-155.907	19.410	60.9	20.7	11
PUHO10	BL	-155.914	19.424	86.7	5.8	3	PUHO24	BL	-155.916	19.418	37	25.8	10
PUHO10	RS	-155.914	19.424	69.2	9.5	13	PUHO24	RS	-155.916	19.418	8.8	9.1	40
PUHO11	BL	-155.914	19.423	81.7	7.5	6	PUHO25	BL	-155.914	19.423	64.8	32.1	31
PUHO11	RS	-155.914	19.423	21.4	20.4	7	PUHO25	RS	-155.914	19.423	32.5	15	40
PUHO12	BL	-155.916	19.422	41.7	27.9	6	PUHO27	BL	-155.913	19.424	88	4.5	5
PUHO12	RS	-155.916	19.422	23.3	10.7	12	PUHO27	RS	-155.913	19.424	55.7	12.7	7
PUHO13	BL	-155.916	19.421	53.3	20.8	3	PUHO28	BL	-155.918	19.426	17.5	9.7	12
PUHO13	RS	-155.916	19.421	15.3	12.5	15	PUHO28	RS	-155.918	19.426	5.9	6.1	34
PUHO14	BL	-155.915	19.420	41.1	19	9	PUHO29	BL	-155.916	19.425	50	14.1	4
PUHO14	RS	-155.915	19.420	20.5	8.3	20	PUHO29	RS	-155.916	19.425	8.7	3.5	15
PUHO15	BL	-155.913	19.417	20	14.1	2	PUHO30	BL	-155.916	19.420	40	14.1	2
PUHO15	RS	-155.913	19.417	14.2	16.8	12	PUHO30	RS	-155.916	19.420	10	0	7
PUHO16	BL	-155.913	19.417	43.3	26.6	15	PUHO31	BL	-155.915	19.418	4.3	5.3	7
PUHO16	RS	-155.913	19.417	24.4	20.4	27	PUHO31	RS	-155.915	19.418	0	0	21

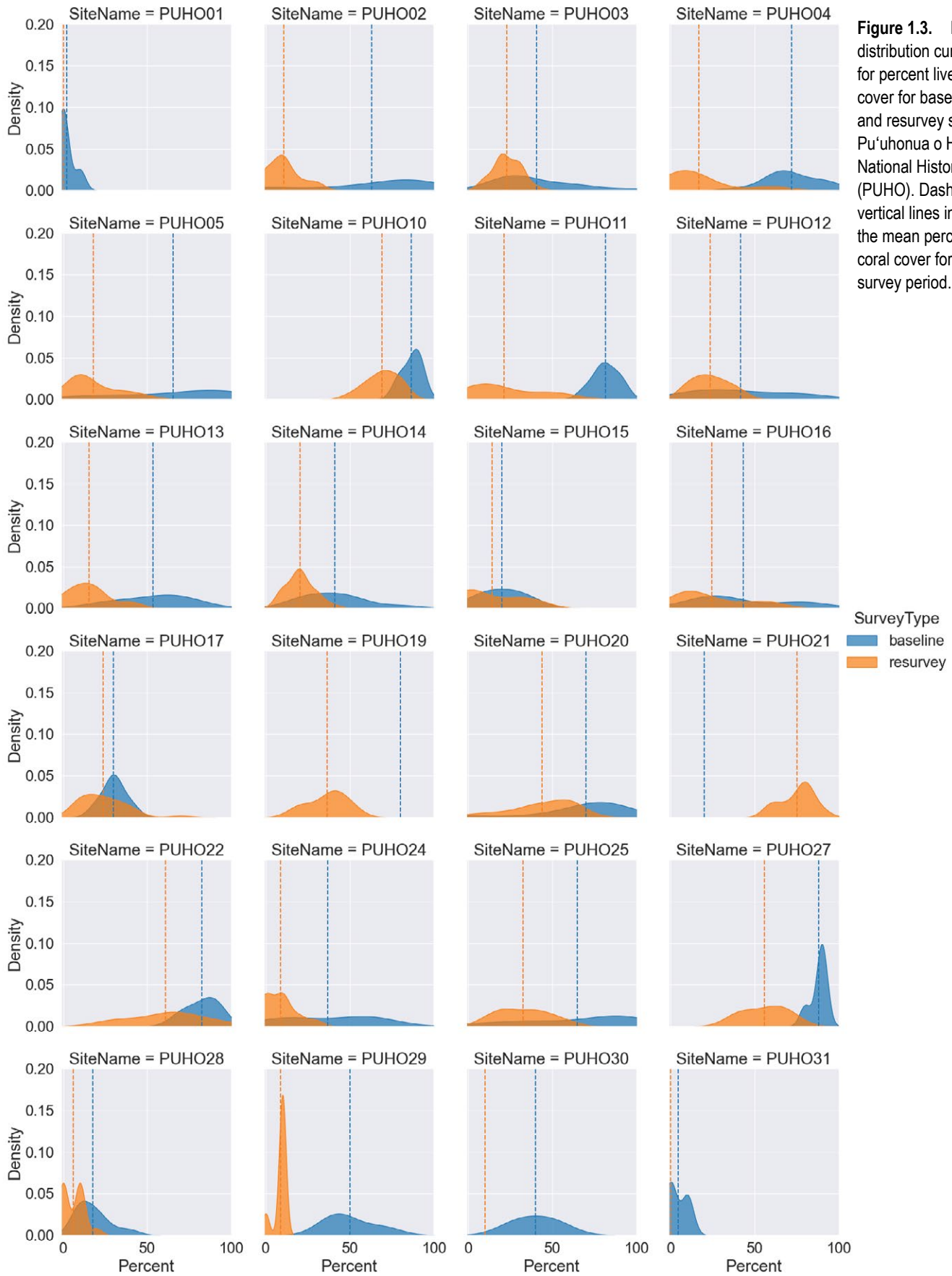


Figure 1.3. Density distribution curves for percent live coral cover for baseline and resurvey sites at Pu'uhonua o Hōnaunau National Historic Park (PUHO). Dashed vertical lines indicate the mean percent live coral cover for each survey period.

SurveyType
■ baseline
■ resurvey

