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# Natural Resource Condition Assessment

## *Puʻukoholā Heiau National Historic Site*

Aerial view of the Puʻukoholā Heiau National Historic Site; Puʻukoholā Heiau and Mailekini Heiau are the large temple structures in the center; Kawaihae Harbor lands are in the foreground and Mauna Kea is in the distance.

NPS / A. JOHNSON

# Natural resource condition assessment: Puʻukoholā Heiau National Historic Site

Science Report NPS/SR—2024/177

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# Abstract

The report summarizes known natural resource conditions found in Puʻukoholā Heiau National Historic Site. Natural Resource Condition Assessments provide a snapshot-in-time evaluation of park resource conditions. Seven resource elements were evaluated in this assessment: air resources, night sky, watersheds, terrestrial vegetation, terrestrial fauna, brackish water resources, and marine resources with emphasis on four focal themes: native plant communities, marine fish, water quality and ecology of brackish water resources, and watershed integrity.

# Executive Summary

Natural Resource Condition Assessments (NRCAs) evaluate current conditions of natural resources and resource indicators in national park units (parks). NRCAs are meant to complement—not replace—traditional issue- and threat-based resource assessments. NRCAs employ a multi-disciplinary, hierarchical framework within which reference conditions for natural resource indicators are developed for comparison against current conditions. NRCAs do not establish management targets for study indicators and reference conditions are not necessarily target conditions, but rather provide a frame of reference upon which to assess change or trends in the condition of a resource where sufficient data is available. The goal of a NRCA is to deliver science-based information that will assist park managers in their efforts to describe and quantify a park's desired resource conditions and management targets and inform management practices related to natural resource stewardship. This NRCA is companion to and follows the previous Watershed Condition Assessment by Hoover and Gold (2006).

The resources and indicators emphasized in a given NRCA depend on the park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators, and availability of data and expertise to assess current conditions for a variety of potential study resources and indicators. Puʻukoholā Heiau National Historic Site (Puʻukoholā Heiau NHS) is a small park located in the South Kohala District of the Hawaiʻi Island. The park encompasses 34.8 ha (86 acres) within two parcels: a larger one, which includes Puʻukoholā Heiau, a national historic landmark at a large luakini (war temple) built by King Kamehameha I and Hale o Kapuni, a submerged temple within Pelekane Bay believed to be dedicated to the shark gods, and a smaller parcel protecting the Homestead site of John Young, English advisor to King Kamehameha I. The park is centered on a bluff overlooking Kawaihae Harbor and Pelekane Bay at the base of Kohala and Mauna Kea volcanoes. The climate is warm and dry, with mean high temperature of 28.5° C (83° F), a mean low temperature of 20.1° C (68° F), and an average of 22 cm (8.7 in) of rainfall per year. Two ephemeral streams enter the park from the east where they merge into Makeāhua Gulch. At the mouth of Makeāhua Gulch is a perennial body of water that is usually separated from Pelekane Bay by a sand bar, but which at times exhibits estuarine characteristics when the sand bar is breached.

Seven resource elements were evaluated in this assessment: air resources, night sky, watersheds, terrestrial vegetation, terrestrial fauna, brackish water resources, and marine resources with emphasis on four focal themes: native plant communities, marine fish, water quality and ecology of brackish water resources, and watershed integrity. Resource conditions were determined through reviewing existing literature, meta-analysis, and where appropriate, analysis of unpublished datasets. However, in several cases, data were unavailable or insufficient to either establish a quantitative reference condition or conduct a formal statistical comparison of the status of a resource to a quantitative reference condition. In those cases, data gaps are noted, and comparisons were made based on qualitative descriptions.

Overall, the natural resources at Puʻukoholā Heiau NHS are in poor condition. The state of the hydrologic processes, vegetation community, benthic invertebrates and near shore marine fish all

warrant significant concern. Levels of light pollution and water quality in the unnamed brackish waterbody and marine waters in Pelekane Bay warrant moderate concern. None of the natural resources evaluated in this assessment are in good condition.

The condition of natural resources within Puʻukoholā Heiau NHS reflects the landscape surrounding this small park. All lands immediately adjacent to Puʻukoholā Heiau NHS are zoned for urban development. Existing nearby urban development contributes significant light pollution to the park. Most of the lands inland from the park are zoned for agriculture, and the legacy of historic and ongoing grazing is a vegetative community dominated by fire-prone, nonnative grasses. Upstream damage to the riparian corridor of Makeāhua Gulch results in heavy sediment loads during storm events, which are deposited into Pelekane Bay. These sediments are frequently resuspended, leading to high turbidity in the estuarine water body within Puʻukoholā Heiau NHS and in the marine waters adjacent to the park.

The legacy of historic land use in the region is also reflected in the biotic communities observed within Puʻukoholā Heiau NHS. Nonnative plants dominate the park's vegetation, particularly buffelgrass and kiawe (mesquite), though outplantings of native and Polynesian introduced plants are leading to improved conditions of vegetation resources within small areas of the park. Nonnative terrestrial vertebrates are common within the park, including goats and mongooses. The bird community within the park is dominated by nonnative species, with few natives compared to bird surveys elsewhere on the West Hawaiʻi coast. There are few crustaceans or mollusks within the estuarine body compared to fishponds on the West Hawaiʻi coast. The marine waters adjacent to Puʻukoholā Heiau NHS have a lower abundance of corals, biomass and diversity of nearshore fish, and a higher abundance of macroalgae, crustose coralline algae and bare substrate than elsewhere along the West Hawaiʻi coast.

Terrestrial resources within Puʻukoholā Heiau NHS have been poorly quantified both within the park and in adjacent conservation areas. Comparisons to reference conditions were typically based on overall conditions of the West Hawaiʻi coast. Goat exclusion and mongoose trapping projects elsewhere on Hawaiʻi Island, including a landscape-level restoration project adjacent to the John Young homestead parcel, suggest that invasive species management techniques can be used to improve conditions within Puʻukoholā Heiau NHS. Improvements of natural resources at Puʻukoholā Heiau NHS and the adjacent waters of Pelekane Bay will require coordinated, community-based efforts both to reduce upstream erosion and to manage native species that typically have home ranges larger than the park or represent culturally important extractive resources (e.g., fish). A framework for establishing this kind of multi-stakeholder, community-based restoration and management can be found in the longstanding tie between Hawaiian culture and native species conservation efforts.

# Acknowledgments

Many people beyond the listed authors and cited experts contributed to putting together this NRCA and deserve thanks. From the NPS, we thank Daniel Kawaiaea, Benjamin Saldua, Malia Hayes, Adam Johnson, and Sallie Beavers, who served as points of contact and provided invaluable sources of information and context. Also from the NPS, we thank Marsha Davis, Darcy Hu, Ryan Monello, Alison Ainsworth, Kelly Kozar, Sheila McKenna, and David Raikow for their thoughtful comments and contributions. We thank Cathy Schwemm for her guidance on a number of occasions throughout the process. The assessment also benefited from comments and suggestions provided by numerous outside reviewers. Funding was provided by the NPS and IWS.

# Acronyms and Abbreviations

| | |
|---|---|
| **ALR:** | All Sky Light Pollution Ratio |
| **amsl:** | above mean sea level |
| **B.P.:** | before present |
| **CBSFA:** | Community-Based Subsistence Fishing Areas |
| **CCA:** | crustose coralline algae |
| **cfu:** | colony-forming units |
| **CI:** | Confidence Interval |
| **COTS:** | Crown-of-Thorns seastar |
| **CRAMP:** | Coral Reef Assessment and Monitoring Program |
| **CRED:** | Coral Reef Ecosystem Division, NOAA Pacific Islands Fisheries Science Center |
| **CWA:** | Clean Water Act |
| **DAR:** | Division of Aquatic Resources (State of Hawaiʻi DLNR) |
| **DLNR:** | Department of Land and Natural Resources, State of Hawaiʻi |
| **FHUS:** | Fish Habitat Utilization Study |
| **FRA:** | Fish Replenishment Area |
| **FY:** | Fiscal Year |
| **GA:** | Growth Anomalies |
| **GIS:** | Geographic Information System |
| **GPS:** | Global Positioning System |
| **HAVO:** | Hawaiʻi Volcanoes National Park |
| **HDOH:** | Hawaiʻi Department of Health |
| **I&M:** | Inventory & Monitoring |
| **IRMA:** | Integrated Resource Management Applications portal |
| **IUCN:** | International Union for Conservation of Nature |
| **KAHO:** | Kaloko-Honokōhau National Historical Park |
| **KALA:** | Kalaupapa National Historical Park |
| **MHI:** | Main Hawaiian Islands |
| **MPA:** | Marine Protected Area |

**NHP:** National Historical Park

**NHS:** National Historic Site

**NOAA:** National Oceanic and Atmospheric Administration

**NP:** National Park

**NPS:** National Park Service

**NRCA:** Natural Resource Condition Assessment

**NTU:** Nephelometric Turbidity Units

**NWHI:** Northwest Hawaiian Islands

**PACN:** NPS Pacific Island Network, Inventory and Monitoring Program

**PUHE:** Puʻukoholā Heiau National Historic Site

**RATS:** Rapid Assessment Transects

**RAWS:** Remote Automatic Weather Station

**SE:** Standard Error

**TDN:** Total Dissolved Nitrogen

**TDP:** Total Dissolved Phosphorus

**TL:** Tissue Loss (diseases)

**TNC:** The Nature Conservancy

**TPERP:** Tidepool Protection, Education and Restoration Program

**TRE:** Porites trematodiasis

**UH:** University of Hawaiʻi

**VIP:** Volunteers-In-Parks program

**WHAP:** DAR West Hawaiʻi Aquarium Project

**WCHI:** West coast of Hawaiʻi Island

**WHRP:** West Hawaiʻi Recruitment Project

# Chapter 1. NRCA Background Information

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources and resource indicators in national park units, hereafter "parks." NRCAs also report on trends in resource condition (when possible), identify critical data gaps, and characterize a general level of confidence for study findings. The resources and indicators emphasized in a given project depend on the park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators, and availability of data and expertise to assess current conditions for a variety of potential study resources and indicators.

NRCAs strive to provide:

- Credible condition reporting for a subset of important park natural resources and indicators, and
- useful condition summaries by broader resource categories or topics, and by park areas.

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement—not replace—traditional issue- and threat-based resource assessments. As distinguishing characteristics, all NRCAs:

- Are multi-disciplinary in scope;[1]
- Employ hierarchical indicator frameworks;[2]
- Identify or develop reference conditions/values for comparison against current conditions;[3]
- Emphasize spatial evaluation of conditions and GIS (map) products;[4]
- Summarize key findings by park areas; and[5]

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[1] The breadth of natural resources and number/type of indicators evaluated will vary by park.

[2] Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures ⇨ conditions for indicators ⇨ condition summaries by broader topics and park areas.

[3] NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions. Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-up response (e.g., ecological thresholds or management "triggers").

[4] As possible and appropriate, NRCAs describe condition gradients or differences across a park for important natural resources and study indicators through a set of GIS coverages and map products.

[5] In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on an area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested.

- Follow national NRCA guidelines and standards for study design and reporting products.

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs.

Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

The credibility of NRCA results is derived from the data, methods, and reference values used in the project work, which are designed to be appropriate for the stated purpose of the project, as well as adequately documented. For each study indicator for which current condition or trend is reported, we will identify critical data gaps and describe the level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject-matter experts at critical points during the project timeline is also important. These staff will be asked to assist with the selection of study indicators; recommend data sets, methods, and reference conditions and values; and help provide a multi-disciplinary review of draft study findings and products.

NRCAs can yield new insights about current park resource conditions, but, in many cases, their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers science-based information that is both credible and has practical uses for a variety of park decision making, planning, and partnership activities.

Important NRCA success factors:

- Obtaining good input from park staff and other NPS subject-matter experts at critical points in the project timeline,
- using study frameworks that accommodate meaningful condition reporting at multiple levels (measures → indicators → broader resource topics and park areas), and
- building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings.

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What an NRCA can do is deliver science-based information that will assist park managers in their ongoing, long-term efforts to describe and quantify a park's desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource planning[6] and help parks to report on government accountability measures.[7] In addition, although in-depth analysis of the effects of climate change on park natural resources is outside the scope of NRCAs, the condition analyses and data sets developed for NRCAs will be useful for park-level climate-change studies and planning efforts.

NRCAs also provide a useful complement to rigorous NPS science support programs, such as the NPS Natural Resources Inventory & Monitoring (I&M) Program.[8] For example, NRCAs can provide current condition estimates and help establish reference conditions, or baseline values, for some of a park's vital signs monitoring indicators. They can also draw upon non-NPS data to help evaluate current conditions for those same vital signs. In some cases, I&M data sets are incorporated into NRCA analyses and reporting products.

NRCA Reporting Products provide a credible, snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:

- Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations (near-term operational planning and management),
- Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values (longer-term strategic planning)
- Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public ("resource condition status" reporting).

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[6] An NRCA can be useful during the development of a park's Resource Stewardship Strategy (RSS) and can also be tailored to act as a post-RSS project. An NRCA can be useful during the development of a park's Resource Stewardship Strategy (RSS) and can also be tailored to act as a post-RSS project.

[7] While accountability reporting measures are subject to change, the spatial and reference-based condition data provided by NRCAs will be useful for most forms of "resource condition status" reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget.

[8] The I&M program consists of 32 networks nationwide that are implementing "vital signs" monitoring in order to assess the condition of park ecosystems and develop a stronger scientific basis for stewardship and management of natural resources across the National Park System. "Vital signs" are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values.

Over the next several years, the NPS plans to fund an NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information visit the NRCA Program website.

# Chapter 2. Introduction and Resource Setting

Environment at Puʻukoholā Heiau National Historic Site. (IWS Photo, B. Hudgens).

## 2.1 Introduction

Puʻukoholā Heiau National Historic Site is a small park located in the South Kohala District of Hawaiʻi Island. It is bounded by Kawaihae Harbor on the north and Spencer Beach County Park on the south. The park comprises two parcels, a larger one on the coastal side of State Highway 270 and a smaller parcel containing the John Young Homestead on the upslope/eastern side of the highway. The National Historic Site (NHS) was established in 1972 to protect Puʻukoholā Heiau, a national historic landmark comprised of a large luakini (war temple) built by King Kamehameha I in the late 1790s, and to preserve the Homestead site of John Young, English advisor to King Kamehameha I.

### *2.1.1 Enabling Legislation*

Formation of Puʻukoholā Heiau National Historic Site was established with the passing of Public Law (PL) 92–388, in 1972, by the 92nd Congress of the United States of America. The park was created to "*restore and preserve in public ownership the historically significant temple associated with Kamehameha the Great, who founded the historic Kingdom of Hawaiʻi, and the property of John Young who fought for Kamehameha the Great during the period of his ascendancy to power.*" Originally, the site was designated as Puukohola Heiau National Historic Site, however, the "Hawaiian National Park Language Correction Act of 2000" (106 S. 939) to "*correct spelling errors in the statutory designations of Hawaiian National Parks*" added Hawaiian diacriticals to the

National Historic Site name. The enabling legislation also restricted the maximum size of the park to 100 acres (40.5 ha); it currently encompasses 87.0 acres (35.2 ha).

Though relatively small in area, Puʻukoholā Heiau NHS contains resources of natural and cultural significance including:

- Puʻukoholā Heiau
- Historic properties of John Young
- Mailekini Heiau
- Numerous traditional and historic archaeological sites
- Numerous WWII archaeological features
- Ecologically and culturally significant blacktip reef and other shark populations
- Brackish water pool at end of Makeāhua Stream, and associated flora and fauna
- Sections of the Ala Kahakai National Historic Trail

In addition, the Hale o Kapuni Heiau is submerged in Pelekane Bay just off the park's shoreline, though its exact location is unknown—it may be covered by sediment.

### *2.1.2 Geographic Setting*

Puʻukoholā Heiau National Historic Site is situated in the Kohala region on the west coast of Hawaiʻi Island (Figure 1).[9] The park sits on the lower flanks of Kohala and Mauna Kea volcanoes and is centered on a bluff overlooking Kawaihae Harbor and Pelekane Bay. The bluff rises approximately 38 meters (120 feet) above sea level and is the highest point in the park. Puʻukoholā Heiau NHS is bordered by the Pacific Ocean to the west, Samuel M. Spencer Beach Park (Hawaiʻi County) on the south, and Kawaihae Commercial and Small Boat Harbors to the northwest. The park's inland boundary on the east-northeast follows and crosses Kawaihae Road (State HWY 270). At present, the lands surrounding Puʻukoholā Heiau NHS are undeveloped except for the commercial harbor and Spencer Beach Park.

Hoover and Gold (2006) characterize the climate at Puʻukoholā Heiau NHS as "*...warm, dry, and windy.*" Because Puʻukoholā Heiau NHS is in the rain shadows of Mauna Kea and Kohala, which block many of the tradewind-driven showers, its climate is considerably drier than the eastern side of the island (Hoover and Gold 2006). Hoover and Gold (2006) report an annual average temperature of 25° C (77° F), with limited daily or seasonal variation. The mean high and low temperatures in the park averaged 28.5° C (83.3° F) and 20.1° C (68.2° F), respectively, over the past 35 years (Figure 2). Temperatures are typically highest during July–October and lowest during January–March (Figure 3). Rainfall averaged 22 cm per year from 1980–2015 (Figure 2). Monthly precipitation is typically greater during November–February than during April–October (Figure 3).

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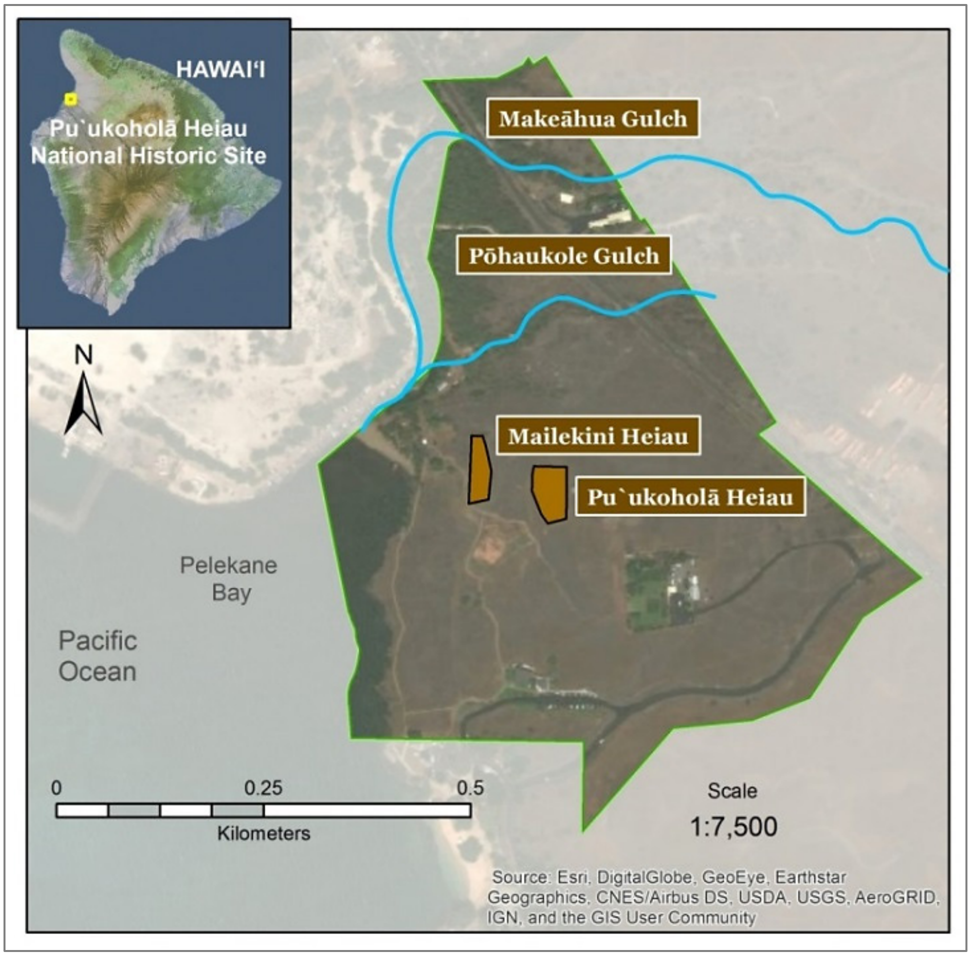
[9] For park brochure map designed for general reference, see: Collection Item (nps.gov)



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

**Figure 1.** Location and main features of Puʻukoholā Heiau National Historic Site.

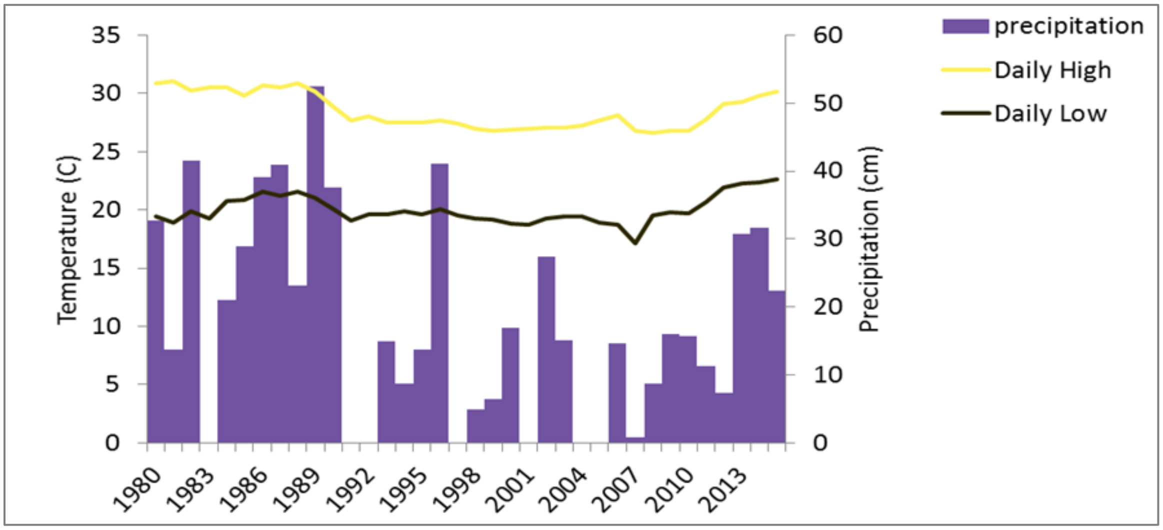


**Figure 2.** Annual mean daily high and low temperatures and total precipitation for Puʻukoholā Heiau 1980–2015. Data from National Weather Service station GHCND:USC00518422. Data at this station begin in 1977 and are available from NOAA's National Center for Environmental Information data portal (https://www.ncdc.noaa.gov/). Years with no bar indicate missing data.

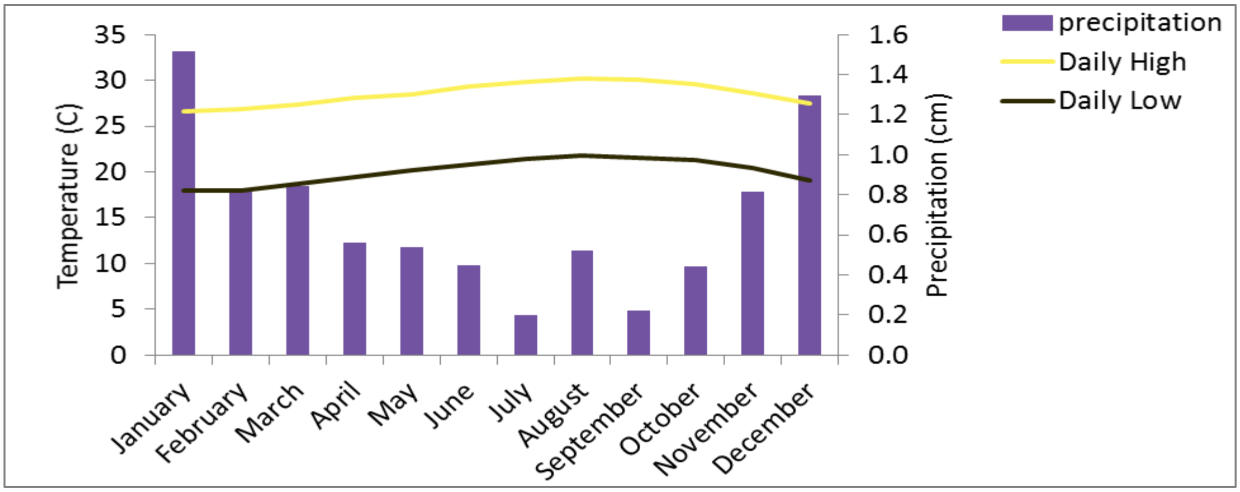


**Figure 3.** Monthly means for daily high and low temperatures and total precipitation for Puʻukoholā Heiau from 1980–2015. Data for National Weather Service station GHCND:USC00518422 were obtained from NOAA's National Center for Environmental Information data portal (https://www.ncdc.noaa.gov/).

Mean daily high temperatures generally cooled from the late 1980s through 1999, and then fluctuated from 2000 through 2015 (Figure 2). Mean daily low temperatures remained relatively stable throughout the 35-year data set, although there is an upward trend from 2007 through 2015 (Figure 2). The data set from within Puʻukoholā Heiau NHS is too short to differentiate between a long-term trend and long-period cycles. Climate patterns may be tied to oceanographic cycles, such as the Pacific Decadal Oscillation (Mantua and Hare 2002), which was in a relatively warm phase during the 1980s and fluctuated generally in cooler phases during the first two decades of the 21st century. There was no evidence of a long-term trend in precipitation at Puʻukoholā Heiau NHS in the 35 years of climate data available from the park.

Monahan and Fisichelli (2014) report a regional warming and drying trend for Hawaiian parks when comparing the last 10–30 years against a 1901–1912 baseline. The warming trend appears to be largely due to a sharp increase in temperatures between the 1950s and 1970s, with temperatures remaining relatively stable from the 1980s through 2012, the period used for this report. Monahan and Fisichelli's analysis was conducted at a resolution of 0.5 degrees latitude/longitude (~3000 $km^2$ [~1200 $mi^2$]) and the climate stations for the grid containing Puʻukoholā Heiau NHS did not include any that were located along the arid eastern coastline. It is therefore unknown if long-term trends at Puʻukoholā Heiau NHS follow the regional trend.

### Geologic Setting

Puʻukoholā Heiau NHS straddles the boundary of two coalescing volcanoes: the extinct Kohala volcano and the dormant Mauna Kea volcano. As with the rest of the Island of Hawaiʻi, this site has been dominated by two processes: volcanic deposition and island subsidence. Volcanic activity at Puʻukoholā Heiau NHS ceased at least 65,000 years ago (Richmond et al. 2008); thus, the risk to Puʻukoholā Heiau NHS from active volcanic flows is extremely low (Mullineaux et al. 1987, Richmond et al. 2008). Kohala Volcano, which underlies the park, has subsided nearly 1.2 km (0.7 mi) over the past 450,000 years at a rate of 2.6 mm (0.1 in) per year (Zhong and Watts 2002).

The most prominent sedimentary feature on the coastline is Pelekane Beach, which is comprised of stream sediment derived from weathered volcanic material and carbonate sediment of marine origin. Other coastal features include a rocky shoreline with gently sloping lava flows and scattered basalt boulders.

### Landscape Processes

Because of its small size, the natural and cultural resources within Puʻukoholā Heiau NHS are heavily influenced by landscape processes outside of the park. The lands immediately adjacent to Puʻukoholā Heiau NHS on all sides, and coastal properties extending at least four km on either side of the park, are all zoned for urban development (Figure 4), with the Kawaihae Harbor being the most prominent land use (the newer small boat marina, south basin, is not shown on the map). Existing development and associated roads have the potential to shed chemical, light, and noise pollution into the park. Properties inland from the park are predominantly zoned for agriculture (Figure 4). The South Kohala Community Development Plan calls for lands immediately south of Puʻukoholā Heiau NHS to be preserved as conservation lands, but for a greater extent of urban development east of the park than the current zoning implies (South Kohala Community 2008). The legacy of historic grazing in the region is abundant, fire-prone, nonnative grasses, which on undeveloped lands are still maintained by grazing livestock and feral goats (Figure 5). Abundant buffelgrass (*Pennisetum ciliare*) increases the risk and potential severity of fire in the park (Hauser 2008, NPS 2006). Increased fire frequency creates a positive feedback mechanism that leads to increased abundance of invasive grasses, and further increased fire in the area (Dʻ Antonio and Vitousek 1992).

Natural and cultural resources within Puʻukoholā Heiau NHS are also potentially influenced by extreme natural disturbances, such as earthquakes, tsunamis, and sea level rise. Low lying coastal areas are subject to flooding from seasonal high waves, storm-driven overwash, and stream flooding caused by heavy rainstorms (Fletcher et al. 2002, Vitousek et al. 2009).

The geography of Pelekane Bay demonstrates the interaction between anthropogenic and natural landscape processes. Prior to the construction of the Kawaihae Harbor in the late 1950s, there was an open shoreline in the area that is now a protected bay. Construction of the harbor's breakwater blocked wave action and created today's calm water conditions (Storlazzi et al. 2013). During harbor construction, the mouth of Makeāhua Gulch was moved from its original position (further to the north) to its present position inside the park. Floods carry large amounts of sediment down Makeāhua Gulch and into Pelekane Bay, gradually changing the bathymetry of the bay (Storlazzi et al. 2013), smothering benthic ecosystems (Stender et al. 2014), leading to beach accretion (Vitousek et al. 2009), and increasing turbidity in Pelekane Bay. Fine sediment eroded by wind and deposited into Pelekane Bay also contributes to the sediment load.

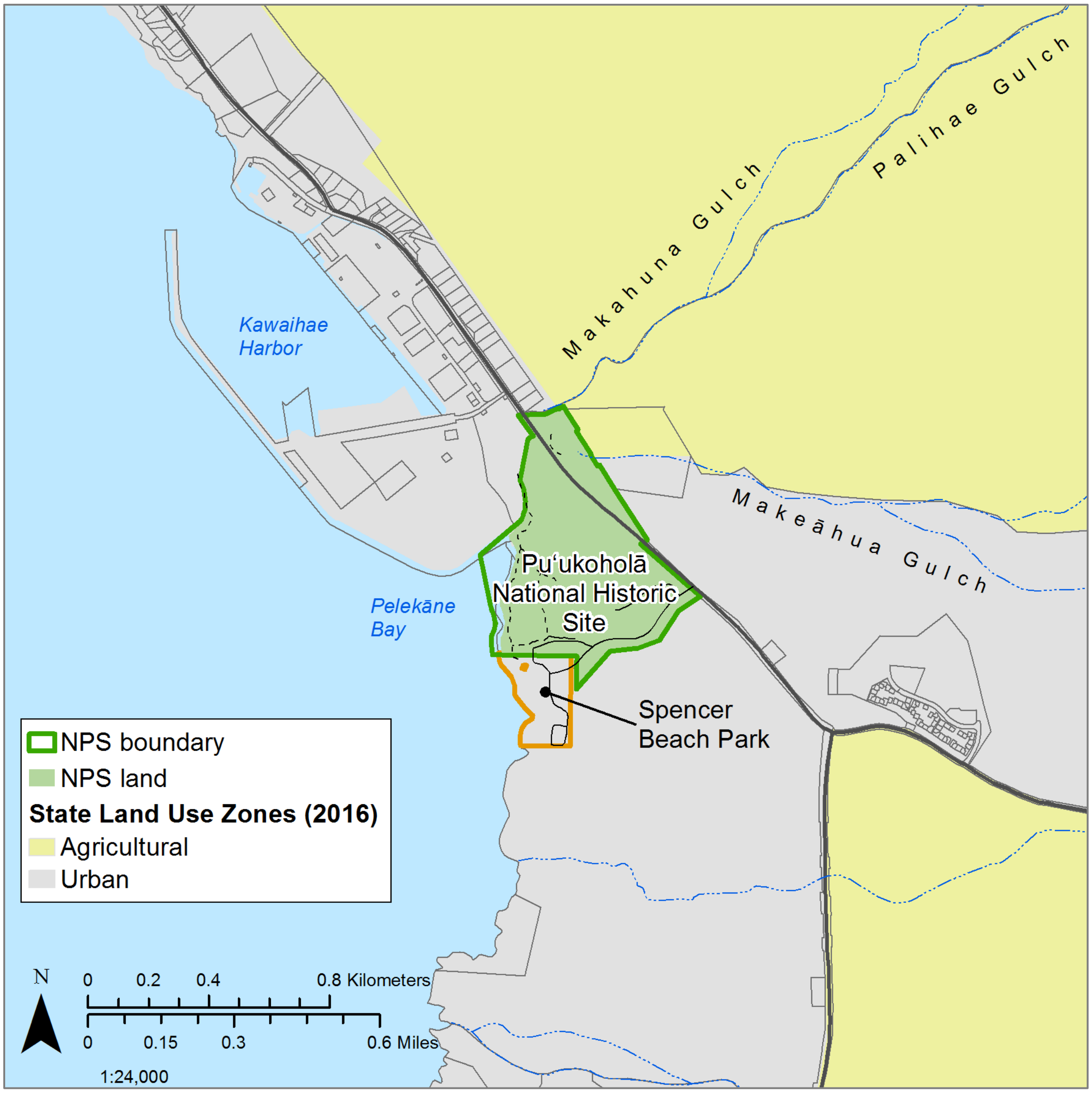


**Figure 4.** State land-use zones surrounding Puʻukoholā Heiau NHS. Data source: https://histategis.maps.arcgis.com/home/item.html?id=7b6e118ffe5d4370923dde14ed1ea6e3

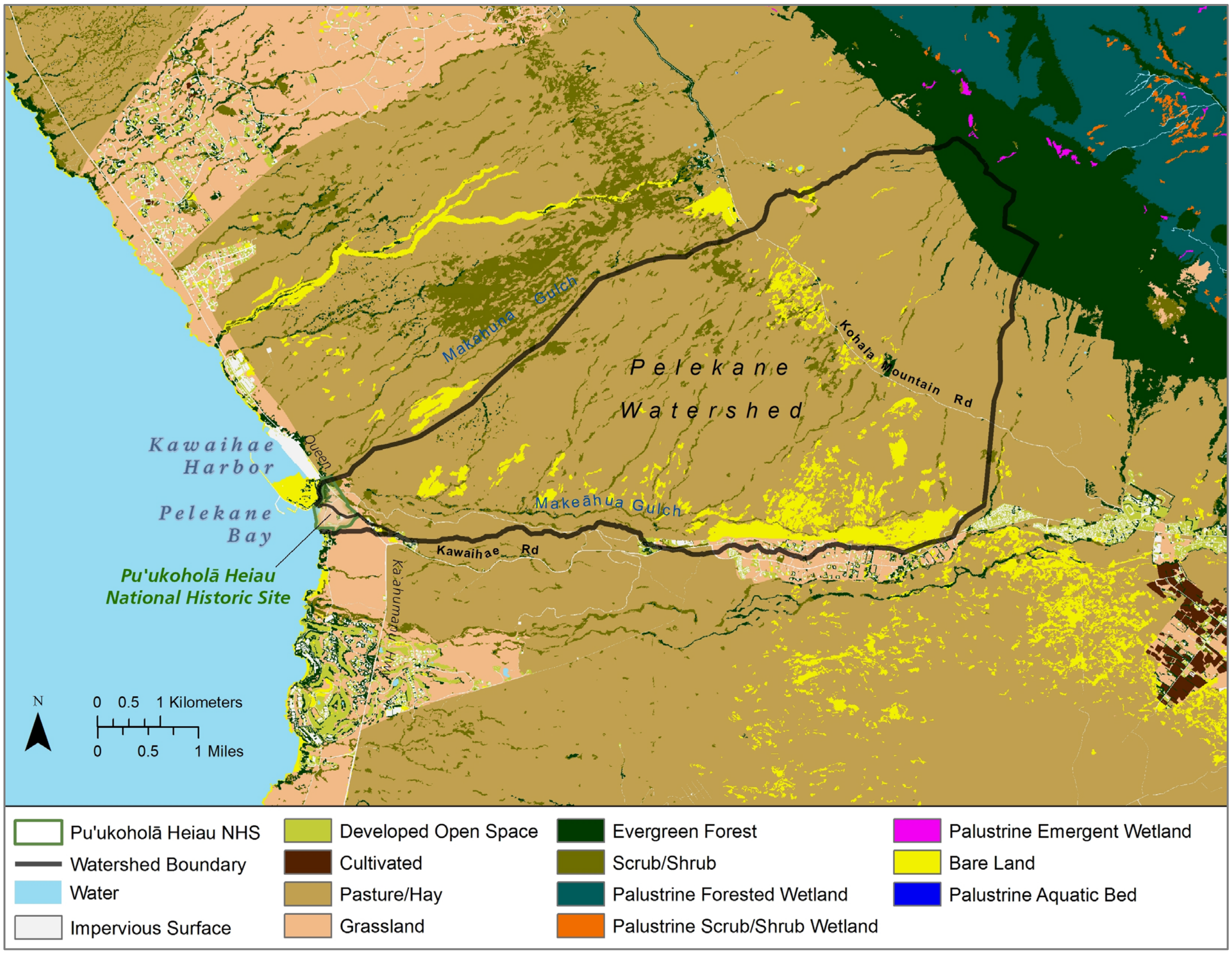


**Figure 5.** Land cover in the Pelekane watershed (Data from NOAA 2010/2015, map prepared by S. Margriter, NPS).

### *2.1.3 Visitation Statistics*

Visitation to Pu‘ukoholā Heiau NHS has shown a general increasing trend since the park’s establishment in 1974 (Figure 6). From 2010 through 2015, the number of recreational visitors to the park has averaged more than 130,000 annually (NPS 2016a). Since 2004, there have been five reported closures of the park and park facilities that may have influenced annual visitation rates. These closures were a result of construction activities in April 2005, brush fires in October 2007 and August 2015, federal government shutdown in October 2013, and Hurricane Flossie in July 2013.

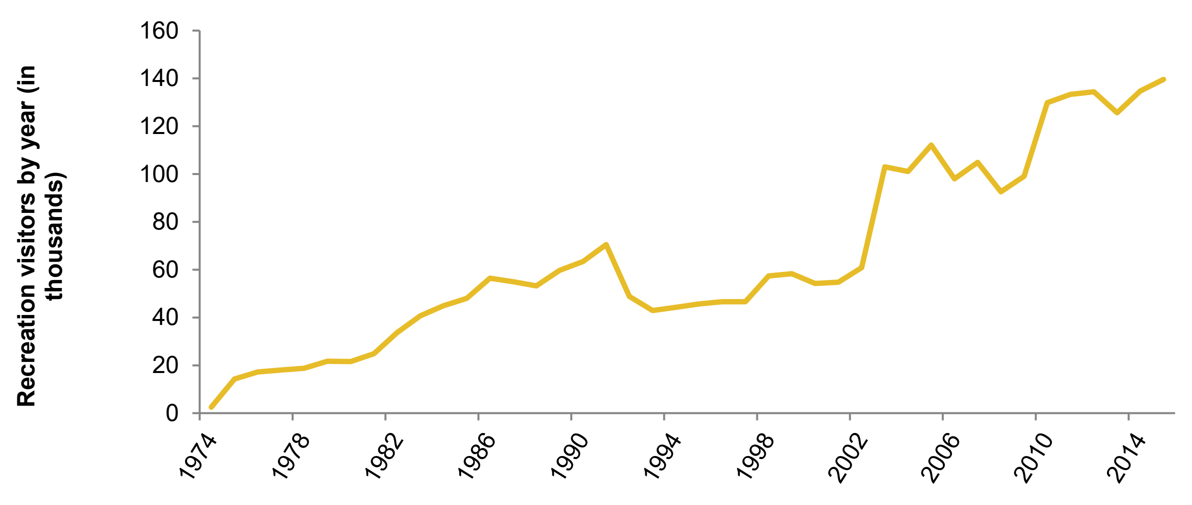


**Figure 6.** Recreational visitors to Puʻukoholā Heiau since 1974. Data from https://irma.nps.gov/Stats/Reports/Park/PUHE

## 2.2 Natural Resources and Cultural Resources

Blacktip reef shark (*Carcharhinus melanopterus*; NPS photo).

### *2.2.1 Ecological Setting and Watersheds*

Regionally, the vegetation in western Kohala is arid grassland with few trees or large woody brush. Pratt (1998) reviewed the literature of historical accounts by early European visitors, who described the area as “treeless and barren.” These lands were dominated by indigenous grass species, including pili (*Heteropogon contortus*), likely contributing to the reference of the area as “pili” lands. Though accounts of European visitors suggest an irreverent view of the region, grasses were an important resource for Polynesians, who utilized them for thatching materials and maintained productivity of the lands through fire (Kirch 1982, Pratt 1998). Puʻukoholā Heiau NHS contains two ephemeral stream channels: the larger Makeāhua Gulch and the smaller Pōhaukole Gulch, which joins Makeāhua Gulch about 160 m (175 yd) inland from the shoreline. The 4,000 ha (10,000 ac) watershed of Makeāhua stream extends upslope to an elevation of 1,600 m (4,900 ft). Frequently, the mouth of the channel is blocked by a sand berm, creating a brackish pond (referred to generally and within this document as the “unnamed brackish water body”) that occupies the lower reaches of Makeāhua and Pōhaukole Gulches. Occasionally, marine life is able to enter the brackish water body. There are marine habitats within the boundaries of Puʻukoholā Heiau NHS, and marine resources were important to the ancient Hawaiians for subsistence, culture, and survival (Malo 1951, Kahāʻulelio 2006, Friedlander et al. 2013).

### *2.2.2 Cultural Resource Descriptions*

The most prominent and interpreted cultural resources in the park include the temple sites of Puʻukoholā Heiau and Mailekini Heiau (Figure 7), and the John Young Homestead. These sites are all important for their roles in the early historic period in Hawaiʻi. Although likely the oldest temple site in the park, little is known about the function or construction date of Mailekini Heiau before it was repurposed into a fortification in the early nineteenth century by John Young.

**Figure 7.** Puʻukoholā and Mailekini Heiau temples (NPS photo).

The most promient feature in the park, Puʻukoholā Heiau, was reportedly built within a year’s time, between 1790–1791. This site is intrinsically linked to the founding of the Hawaiian Kingdom in 1810. Both temple sites hold value to contemporary Native Hawaiians and cultural practitioners and are actively used on an annual basis by park partners.

The John Young Homestead was the Kawaihae residence of John Young, one of the western advisors to Kamehameha I. The site contains a mixture of traditonal and western style structures and is the oldest European residence in the islands. The location of this homestead remains important because it stood testiment to many events in the history of Hawaiʻi. The John Young Homestead is the most intensively studied site in the park. It has undergone scholarly excavations in the 1970s and 1990s, and has received much preservation stabilization treatment to retain what remains of the site.

In addition to the archaeological investigation and stabilization and preservation of the John Young Homestead, the park has conducted stabilization of both Mailekini and Puʻukoholā Heiau. In the mid to latter 1970s, NPS Pacific Area Archaeologist, Edmund Ladd, directed the stabilization of earthquake damage to both temple sites.

From 2007–2011 an interdisciplinary group of park staff and park partners worked together to repair earthquake damage caused to the sites by seismic events in October 2006 (Figure 8). The park is also engaged in the stabilization and maintenance of various walls and sites located in highly visited areas of the park.

**Figure 8.** Earthquake repairs on north wall of Puʻukoholā Heiau with NPS staff and park partners (NPS photo, VIP Dave Boyle).

### *2.2.3 Natural Resource Descriptions*

<u>Air Quality</u>
Visitor enjoyment, the health of park ecosystems, and the integrity of cultural resources depend upon clean air. A major purpose of the Clean Air Act is “[T]o preserve, protect, and enhance the air quality in national parks, national wilderness areas, national monuments, national seashores and other areas of special national or regional natural, recreational, scenic, or historic value” (42 U.S.C. §7470(2)).

The 1977 Clean Air Act amendments designated 48 national parks as Class I areas, affording them special air quality protection. All other NPS areas, including Puʻukoholā Heiau NHS, are Class II air quality areas. In addition to the Clean Air Act, the NPS Organic Act, the Wilderness Act, and NPS 2006 Management Policies provide the basis for protection of air quality and air quality-related values in areas managed by the NPS. Air quality-related values are resources sensitive to air quality, including visibility, lakes, streams, vegetation, soils, and wildlife.

Air quality at Puʻukoholā Heiau NHS is affected periodically by fugitive dust from agriculture, by smoke from wildfire and ignited fires, and vog during periods of volcanic activity. Air pollution from the nearby commercial port, automobile exhaust from traffic along the two highways bordering the park, and container ship exhaust are also of concern.

The State of Hawaiʻi Department of Health Clean Air Branch collects ambient air quality data at several locations throughout the state. Although periodic haze affects visibility, the closest air quality monitoring stations are currently in Kona and in Hilo. Neither of these stations adequately represent air quality in the park due to distance and topography. Given the lack of data, it is not possible to determine air pollution concentrations or resource effects at Puʻukoholā Heiau NHS. Therefore, there will not be any further discussion of air quality in this NRCA. If opportunities arise in the future, it would be valuable to collect air quality data in the park to determine current pollutant concentrations and better clarify the threat to park resources from air pollution. In the meantime, the NPS should encourage minimizing human-caused pollution near Puʻukoholā Heiau NHS.

### Night Sky

The night sky is one of the most valued resources in a park. Natural cycles of light and dark also play a role in vital ecological processes such as predator/prey relationships, reproduction, navigation and migration. Impacts on the night sky can originate from light sources within the park, such as lighted parking lots or buildings, and adjacent development. Since there is little development within Puʻukoholā Heiau NHS— only two buildings have outside lights at night— the largest light sources impacting the night sky may be expected to originate from development adjacent to the park.

### Soundscape

Sound also plays a critical role in the visitor experience, and in wildlife communication, courtship and mating, predation and predator avoidance, and effective use of habitat. Most of the time, the acoustic environment at Puʻukoholā Heiau NHS includes human-made sounds associated with the highway adjacent to the park, and visitors to both the park and nearby Spencer Beach; a completely natural soundscape is experienced only about 15% of the time (Lee et al. 2016). Air traffic is relatively rare over the park, with airplane noise heard around 15% of the time (Lee et al. 2016).

### Geology and Soils

There are four types of geologic materials in Puʻukoholā Heiau NHS: the Hāwi Volcanic series, the Pololū Volcanic series, the Hāmākua Volcanic series, and young unconsolidated sediment. The Hāmākua Volcanic series covers approximately 85% of the park and is comprised of basaltic ʻaʻā and pāhohoe lava flows from Mauna Kea Volcano that are between 65,000 and 250,000 years old (Wolfe and Morris 1996, Richmond et al. 2008). The Hāwi Volcanic series (basalt lava flows that are 120,000–230,000 years old) and the Pololū Volcanic series (70,000–250,000 years old) were erupted from Kohala Volcano. The Hāwi Volcanic series is basaltic whereas the Pololū flows are largely benmoreite, a rock that is similar to basalt but more silica-rich. Benmoreite erupted late in the life-cycle of Hawaiian volcanoes. Minor amounts of volcanic ash have likely been deposited by wind in topographic depressions.

On Hawaiʻi Island, the degree of soil development depends primarily on the age of lava flows and amount of rainfall. The lava flows in Puʻukoholā Heiau NHS are considerably older than lava flows found in the other west Hawaiʻi National Parks and thus exhibit a greater degree of weathering and disintegration, resulting in more developed soils. Arid conditions at Puʻukoholā Heiau NHS, however, mean that its soils are less developed than those on the eastern side of Hawaiʻi Island. Most of the soils in the park are classified as a very cobbly medial silt loam with a very cobbly surface layer (Soil Survey Staff 2020). Near Makeāhua Gulch, soils are classified as a medial very fine sandy loam. All of these soils are well-drained.

### Water Resources

Fresh water resources are limited in Puʻukoholā Heiau NHS. Near-surface groundwater is brackish. Although there are no perennial streams, there are two ephemeral streams that occasionally flood, sending large quantities of water and suspended sediments to the ocean (Hoover and Gold 2006). The streambeds are above the water table, so streamflow occurs only for a brief time after intense or prolonged rainfall.

The smaller Pōhaukole Gulch joins Makeāhua Gulch a short distance from the shoreline. With a drainage area of approximately 4,000 ha (10,000 ac), Makeāhua Stream (occupying Makeāhua Gulch) is the main source of floods.

Much of the time a sand berm blocks the mouth of Makeāhua Gulch, impounding a brackish pool that is fed by brackish groundwater. Currently, this is the only perennial water body in the park (Raikow and Farahi 2013). Previous reports, however, have described this area as containing several anchialine pools (Hoover and Gold 2006 and Cheney et al. 1977).

Early accounts describe a managed fishpond at the mouth of Makeāhua Gulch and a valuable brackish spring (Greene 1993). These were apparently destroyed during the construction of Kawaihae harbor in the late 1950s. During construction the outlet reach of Makeāhua Gulch was moved from its original position further to the north to its present position within the park (MKSWCD 2005).

### Vegetation

Nonnative grasses and kiawe (mesquite, *Prosopis pallida*) trees had overgrown Puʻukoholā Heiau NHS by the 1920s (National Park Service 2003). Cattle and other livestock grazing likely had the greatest influence on the structure and composition of the extant plant community, which is dominated by exotic species introduced since 1830 (Cogan et al. 2011, Cuddihy and Stone 1990). Of particular concern are fountain grass (*Cenchrus setaceus*, formerly *Pennisetum setaceum*) and buffelgrass (*Cenchrus ciliaris*). Both of these invasives are competitively dominant species that rapidly re-establish post-burn. Open-space areas in Puʻukoholā Heiau NHS are generally dominated by buffelgrass. Moving from open grasslands to areas of higher moisture such as drainages and stream banks, introduced kiawe trees and shrubs become more prevalent. Efforts to re-establish pili grass as a dominant cover species in upland habitats is underway, and some successful outplanting of pili from experimental plots established in 1998 had been observed prior to a 2015 fire (Cogan et al. 2011). There are additional outplantings of native plants around the visitor center. In August 2015, a wildfire burned approximately 90% of the vegetation within the park. Vegetative recovery has been dominated by buffel grass, with low prevalence of pili grass found in survey plots 12 months post-burn (Ainsworth and Wasser 2016).

### Terrestrial Vertebrate Wildlife

Terrestrial vertebrates encountered in the park are largely nonnative species (Appendix A). Nonnative vertebrates, such as goats (*Capra hircus*), mongooses (*Herpestes javanicus [E. Geoffroy Saint-Hilaire, 1818] Synonym: Herpestes auropunctatus [Hodgson, 1836]),* Norway rats (*Rattus norvegicus*), and Polynesian rats (*Rattus exulans*) are commonly encountered within the park. Herpetological species encountered in the park during a herpetological survey of the west Hawaiʻi National Parks include the common house gecko (*Hemidactylus frenatus*), gold dust day gecko (*Phelsuma laticauda laticauda*), and the blind snake (*Ramphotyphlops braminus*), all of which are nonnative (Bazzano 2007).

Both of the two native mammals that can be seen on terrestrial lands in Hawaiʻi—the ʻilio-holo-i-ka-uaua or Hawaiian monk seal (*Neomonachus schauinslandi*) and the ʻōpeʻapeʻa or Hawaiian hoary bat (*Lasiurus cinereus semotus*)—occur at Puʻukoholā Heiau NHS. There have been multiple surveys for ʻōpeʻapeʻa at Puʻukoholā Heiau NHS, none of which have recorded bats within the park (Jacobs 1994, Fraser et al. 2007). However, Fraser et al. (2007) did record a single bat adjacent to Puʻukoholā Heiau NHS at Samuel M. Spencer County Park and reported that Puʻukoholā Heiau NHS staff often observed bats near the maintenance facility during winter months. A total of 11 sightings of ʻilio-holo-i-ka-uaua have been reported from Puʻukoholā Heiau NHS since 1987 (Mercer 2017).

A species checklist for avifauna in the park lists 41 species (Appendix A). Native species include the ʻio (Hawaiian hawk; *Buteo solitarius*), the ʻaukuʻu (black-crowned night heron; *Nycticorax nycticorax hoactli*), pueo (Hawaiian short-eared owl; *Asio flammeus sandwichensis*), and the kolea (Pacific golden plover; *Pluvialis fulva*). The greatest concentration of wading and waterbirds appears to be located in and around the brackish water body at the mouth of Makeāhua Gulch (Morin 1996, Waddington 2005).

Hawaiian hawk (*Buteo solitarius*; NPS photo, Norman Carlson).

## Marine Life

Marine resources in Pelekane Bay have generally been in decline in the past several decades due to changes in upland land use and reduced circulation associated with construction of the Kawaiahae Harbor in the 1950s (Tissot 1998). Tissot (1998) and Beets et al. (2010) documented changes in algal, invertebrate and fish composition and abundance. The narrow intertidal zone has a rich fauna including urchins (*Echinometra mathaei, E. oblonga*), serpulids and sea cucumbers (Cheney et al. 1977). Mussels and nerites inhabit the small tide pools, and ghost crabs (*Ocypode ceratophthalmus*) inhabit the beach areas (Cheney et al. 1977). The reef off of Puʻukoholā Heiau NHS shores is characterized by turbid inshore waters and silt covered substrate (Beets et al. 2010). More than a third of the substrate is covered by sand or silt (Beets et al. 2010). Biotic substrates are dominated by turf algae, coralline algae, and sediment tolerant corals including *Porites lobata*, *P. compressa*, *Montipora capitata*, and *M. patula* (Beets et al. 2010, Minton et al. 2011).

There is relatively low fish diversity within the waters of Pelekane Bay, and fish numbers and biomass are lower in nearshore waters within the Puʻukoholā Heiau NHS than waters near the mouth of the bay (Beets et al. 2010). Common fish at Puʻukoholā Heiau NHS include black durgon (*Melichthys niger*), convict surgeonfish (*Acanthurus triostegus*), brown surgeonfish (*A. nigrofuscus*), bullethead parrotfish (*Chlorurus sordidus*), and palenose parrotfish (*Scarus psittacus*). Grey reef sharks (*Carcharhinus amblyrhynchos*), blacktip reef sharks (*C. melanopterus*), and whitetip reef sharks (*Triaenodon obesus*) are also commonly seen in park waters (Hoover and Gold 2006).

While green sea turtles and other marine reptiles visit the area, a herpetological survey of the west Hawaiʻi National Parks did not encounter any such species (Bazzano 2007). The Pacific population of green sea turtles (*Chelonia mydas*) is listed as threatened under the Endangered Species Act and are frequently seen in Pelekane Bay and the critically endangered hawksbill turtles (*Eretmochelys imbricata*) have been observed in the shallows of the bay (D. Kawaiaea, NPS, personal communication June 2019).

### 2.2.4 Resource Issues Overview

In Hawaiian cultural tradition, cultural and natural resources are viewed as inseparable. Because cultural resources stem from nature's provision, it follows that natural resources are culturally important and are integrated into the "biocultural" landscape. Throughout Hawaiʻi, including within Puʻukoholā Heiau NHS, these resources face multiple local and global threats and stressors. Key anthropogenic threats (invasive species, overpopulation, unsustainable fishing, and climate change) are chronic stressors to park ecosystems. Although Hawaiian ecosystems have adapted to key natural processes such as island subsidence and episodic events such as hurricane, tsunami, volcanic gas eruption, and large storm swell and wave events, these events can affect park resource status. In particular, the interaction of anthropogenic threats, and natural processes and events can intensify and compound negative effects on park resources. For a detailed discussion of threats, stressors, and resource issues associated with Pacific Island park resources, see Chapter 2 in Haysmith et al. (2006) and the individual resource assessments in this document.

The primary global threats and pressures that can affect park resources and are of concern to park management are global climate change, large-scale environmental pollution, and overpopulation. Local threats and chronic pressures on park resources are adjacent anthropogenic land-use activities; wildfire, anthropogenic, volcanic, and wildfire sources of air pollution; water pollution (particularly from nonpoint sources); increasing local population and visitation; and the spread, persistence, or novel introduction of invasive species or disease associated with the movements of goods and humans around the island, state, and world.

## 2.3 Resource Stewardship

### 2.3.1 Management Directives and Planning Guidance

Management of the park and future park planning are currently guided by the Puʻukoholā Heiau National Historic Site Foundation Document (NPS 2015). Foundation Documents are core planning documents that describe a park's purpose and significance, the reasons for its inclusion in the National Park System, its fundamental resources and values, its special mandates and legal and policy requirements, and key planning and data needs. Prior to the completion of the 2015 Foundation Document, the Development Concept Plan (1989) and the Statement for Management (1988) were the primary guiding documents. A General Management Plan was not written for this park, and the NPS now uses a Foundation Document as a platform upon which to develop management plans. Other management guidance documents are the Interpretive Concept Plan (1997), the Resource Management Plan (1994), the Museum Management Plan (2004), and the Scope of Collections Statement (2010).

An important resource guidance document is a report by Pratt (1998) titled "Vegetation Management Strategies for Three National Historical Parks on Hawaiʻi Island." This document serves as a general vegetation management plan for the park, covering the topics of invasive plant control, native plant management and restoration. The primary goal for vegetation management in Puʻukoholā Heiau NHS is the manipulation of vegetation to reflect the historic / cultural scene as it was in the 1790s. The exception is John Young's Homestead, where the desired condition of the vegetation is a recreation of the historic scene of the 1790s to early 1800s. An additional, important component of park resource guidance is the ongoing communication and consultation with families and descendants of the area and cultural practitioners.

### *2.3.2 Status of Supporting Science*

The NPS is committed to science-based (indigenous and western) learning and management of park resources. Sources of existing data include published journal articles, unpublished reports and data sets, non-peer reviewed literature, and archival manuscripts. Science and data gathering on specific resources and resource issues in the park occurs through the NPS Inventory and Monitoring (I&M) Program (Pacific Island Inventory & Monitoring Network (U.S. National Park Service) (nps.gov) and also through partnerships with universities, non-government organizations and institutions, and federal and state agencies. Reports and data are stored online at the NPS Integrated Resources Management Applications Portal (https://irma.nps.gov/Portal).

Monitoring, data-gathering, and research address environmental processes, habitats, and organisms, with a goal of addressing resource issues. These tasks are undertaken by numerous parties and mechanisms, including the NPS Inventory and Monitoring (I&M) Program (Haysmith et al. 2006), Puʻukoholā Heiau NHS, state and county agencies, federal interagency agreements, and partnerships with traditional practitioners, community members, universities, and non-government organizations. Key agency and institutional research partners are the U.S. Geological Survey, University of Hawaiʻi, U.S. Fish and Wildlife Service, and NOAA Fisheries among others. Partner and interagency research permits are tracked through the online Research Permit Reporting System (https://irma.nps.gov/rprs/).

The NPS I&M Program collects data under strict quality assurance/quality control protocols and analyzes long-term monitoring and trends on selected natural resources—the plants, animals, and ecosystems that can indicate the overall biological health of parks—from 270 parks with significant natural resources across the country. These parks are grouped into 32 "networks" whose boundaries are based on geography and common resources. Puʻukoholā Heiau NHS is one of 10 national park units currently monitored at the time this report was written in the Pacific Island Inventory and Monitoring Network (PACN; Haysmith et al. 2006).

Resources selected for monitoring are termed Vital Signs, a subset of elements and processes of park ecosystems. Vital signs represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values (Haysmith et al. 2006). These data are necessary for park managers, science partners and the public to evaluate the integrity of park ecosystems, to better understand ecosystem processes and to make science-based management decisions. Climate and water quality are the vital signs currently monitored within Puʻukoholā Heiau NHS and are listed in https://www.nps.gov/im/pacn/puhe.htm.

# Chapter 3. Study Scoping and Design

Puʻukoholā Heiau NHS landscape overlooking Pelekane Bay (NPS photo).

## 3.1 Preliminary Scoping

A joint scoping meeting for Puʻukoholā Heiau National Historic Site and Kaloko-Honokōhau and Puʻuhonua o Hōnaunau National Historical Parks was held in November 2014. The meeting included representatives from each of the three parks, the Hawaiʻi-Pacific Islands Cooperative Ecosystem Studies Unit, the NPS Pacific Island Network Inventory and Monitoring Program, the Institute for Wildlife Studies, and the University of Hawaiʹi. During the scoping meeting, NPS staff from each of the three parks provided to the team of experts a general overview of the parks' natural resources, management goals, and cultural context and resources. Park staff gave tours of each of the parks highlighting both the cultural resources that are the primary focus of their enabling legislations and natural resources that were to be focal areas for their respective NRCAs. Focal areas for Puʻukoholā Heiau NHS are 1) native and Polynesian plant populations—population condition in relation to current status, ability to persist in the presence of nonnative plants, nonnative herbivores, climate change, and other perturbations; 2) brackish-pool water quality and ecology—assessment of the physical condition of the hydrology and water quality and the ecological condition of the pool (species diversity, nonnative species, climate impacts and impediments to the pool's natural function, hydrology, and ecology) since the 2006 Puʻukoholā Heiau Watershed Condition Assessment (Hoover and Gold 2006); 3) nearshore marine fish—assessment of the fisheries-independent population condition of several subsistence fisheries target species and the prevailing factors likely affecting the subpopulations of these species in Pelekane and Kawaihae Bays; and 4) watershed and coastal processes—upslope land uses and other factors that affect erosion and sedimentation in the park. Meeting participants agreed that assessment of natural resource conditions would need to be done in the context of two overarching influences: 1) the environmental context of the park as a relatively small area within a heavily impacted landscape, and 2) the cultural context that the park was established to preserve.

The scoping meeting also served to introduce the assessment team to information and data resources stored on the NPS Integrated Resource Management Applications (IRMA) database portal (https://irma.nps.gov/). The team was guided through the web portal to the Data Store and directed where to find reports, published papers, and raw data pertaining to each of the parks. Additional reports and data were provided by NPS staff in additional meetings. Non-NPS sources of information were sought independently through literature searches and professional contacts with other research and land management agencies and NGO resource stewards.

Finally, the scoping meeting provided NPS staff and the assessment team the first chance to discuss the focal areas and their potential Indicators and Reference Conditions. The intensive anthropogenic influences on the park's natural history made it most useful to compare current conditions to multiple reference conditions in some cases. The goals of including multiple reference points are to inform future restoration and management decisions relevant to different historical periods and provide information about how current and future management actions are interacting with out-of-park influences.

## 3.2 Study Design

### *3.2.1 Indicator Framework, Focal Study Resources and Indicators*

This assessment was modeled after the Ecological Framework as described by H. John Heinz III Center for Science, Economics and the Environment (2002), with some variation of the indicators to accommodate the terrestrial and marine resources at the park. The state of the park was assessed by looking at the biological, chemical, and physical components of several resource elements. Six resource elements were chosen: night sky, watershed processes, terrestrial vegetation, terrestrial fauna, brackish water resources, and marine resources (Table 1). Unlike most NRCA reports, air quality was not evaluated due to the lack of data from which to determine air pollution concentrations or resource effects at Puʻukoholā Heiau NHS. The assessment of the night sky examined dark skies and light pollution. The assessment of watershed processes examined natural hydrologic function, coastal dynamics, and sedimentation. The assessment of terrestrial vegetation resources examined native and Polynesian vegetation communities. The assessment of fauna examined birds, native mammals, and invasive mammals. The assessment of brackish water resources examined water quality and the biota of the unnamed brackish water body at the mouth of Makeāhua Gulch. The marine resources assessment focused on water quality, benthic invertebrates, and nearshore fish within Pelekane Bay.

**Table 1.** NRCA Framework, modified after Heinz (2002), used in assessing the condition of focal resources for Puʻukoholā Heiau NHS. Numbers pertain to sections in Chapter 4.

| **4.x Major Reporting Category (broad-scale category modeled after Heinz)** | **Resource Element (major reporting category specific to the park)** | **4.x.x Focal Area (park resources assessed for current condition and trend in Chapter 4)** | **Indicators and Measures** |
|---|---|---|---|
| 4.1 Landscape-scale Physical Environment | Night Sky Resources | 4.1.1 Natural Night Sky | All-Sky Light Pollution Ratio |
| | Water-Related Processes | 4.1.2 Watershed Processes and Coastal Dynamics | Sediment loads entering and flowing through the park, shoreline position, flood frequency and extent, and sediment accumulation into Pelekane Bay |
| 4.2 Terrestrial Ecosystem Integrity | Vegetation Resources | 4.2.1 Terrestrial Plant Communities | Native species richness (number of species), species composition (presence/absence), and structure (percent cover, presence/absence of a canopy) |
| | Vertebrate Faunal Resources | 4.2.2 Birds | Proportion of native species encountered in reference surveys, the National Audubon Society Christmas bird counts Hawaiʻi, and species diversity of native shorebirds |
| | Vertebrate Faunal Resources | 4.2.3 Native Mammals | Number of ʻilio-holo-i-ka-uaua sightings reported in the park and detections of ʻōpeʻapeʻa during acoustic surveys |
| | Vertebrate Faunal Resources | 4.2.4 Invasive Mammals | Abundance (lower abundance indicates better condition) |
| 4.3 Aquatic Ecosystem Integrity | Brackish Water Resources | 4.3.1 Water Quality of Inland Waters | Dissolved oxygen (DO), turbidity, nutrients, chlorophyll *a,* and total suspended solids |
| | Brackish Water Resources | 4.3.2 Brackish Water Biota | Community composition, relative abundance of native and introduced species |
| 4.4 Marine Ecosystem Integrity | Marine Resources | 4.4.1 Marine Water Quality of Pelekane Bay | Dissolved oxygen (DO), turbidity, nutrients and chlorophyll *a* |
| | Marine Resources | 4.4.2 Benthic Invertebrates | Benthic percent cover, coral settlement, coral disease, and invertebrate abundance |
| | Marine Resources | 4.4.3 Nearshore Marine Fish | Mean fish biomass, numerical density, and species richness |

Specific indicators for each resource element and specific focal areas were determined by consensus between the assessment team and NPS staff. Resources to be assessed were chosen based on two criteria: relevancy to park management goals and availability of data from which comparisons could be made between the park's current condition and appropriate reference conditions. Reference conditions were chosen based on availability of historic data and information relevant to NPS management goals (i.e., to recreate the cultural landscape as it was in the 1790s, when King Kamehameha I built the large luakini war temple, keeping an unobstructed view of the archeological temple), and ecological context (e.g., would similar species be expected to occur at a reference site and Puʻukoholā Heiau NHS in the absence of anthropogenic influences). Generally, resources less impacted by human activities after European contact are considered to be in better condition. Indicators and reference conditions for each resource element and focal area are described in Chapter 4.

### *3.2.2 Reporting Areas*

Because of the small area within park boundaries, assessments were done for the entire park. Because of the small area of marine habitats within Puʻukoholā Heiau NHS relative to the biological processes affecting those natural resources in offshore marine habitats integral to both the cultural context and visitor experience at Puʻukoholā Heiau NHS, marine resources were assessed within Pelekane Bay, including waters just outside of the park marine boundary. There were substantial differences in the amount of information available to assess each resource, leading to a more thorough treatment of some resources than others. The length of the subsections in chapter 4 reflects these differences in data availability and does not reflect the relative importance of each resource covered.

### *3.2.3 General Approach and Methods*

This condition assessment was conducted using existing data; no new data were collected as part of the assessment. Data were assembled from a variety of sources. The primary data resource was the collection of peer-reviewed publications, reports, and data sets maintained on the NPS IRMA data portal, https://irma.nps.gov/Portal. Additional publications and reports were gathered through literature searches and communication with NPS staff and researchers conducting recent and ongoing studies within the park and marine zones. In some cases, raw data that were not uploaded to the IRMA data portal were provided to the assessment team by NPS staff. Subject matter experts on the team compiled and summarized data, performing statistical analyses when appropriate to compare values of quantitative indicator metrics to reference conditions.

Chapter 4 describes the data, analysis methods and findings for assessing the current condition of park resources for each of the resource elements and focal areas described above. Each focal area presented generally follows the organization of the Standard NRCA Report Outline and contains the following sections: *Condition Summary* providing a succinct statement of the resource condition, *Description* of the resource, including its relevance and context, *Data, Indicators and Methods* describing data sources, indicator variables, comparisons made and any new analyses conducted as part of this assessment*, Reference Condition(s)* used as a basis for comparison, *Current Condition and Trend* describing the current state of resource condition and recent trends in the resource condition where sufficient temporal data exist, *Data Gaps and Research Recommendations* noting where a lack of information prevented a thorough assessment of the resource condition, *Sources of Expertise* listing the subject expert(s) responsible for determining the condition and additional experts consulted, and *Literature Cited.* When there are significant *Threats and Stressors* to a focal resource, those are presented following the *Condition and Trend* section.

# Chapter 4. Natural Resource Condition Assessment

Aerial view of the park and landscape with Kawaihae harbor and Makahua Gulch to the north (left) and Spencer Beach Park to the south (right), circa 2011 (NPS photo, A. Johnson).

## 4.1 Landscape-scale Physical Environment

In Puʻukoholā Heiau NHS, the landscape-scale physical environment is concurrently the cultural landscape—an enduring expression of the inseparable connections between Hawaiians and their environment. This landscape contains both human-made features and natural features such as night skies, water, and landforms.

### *4.1.1 Natural Night Sky*

*By Brian Hudgens, Institute for Wildlife Studies*

#### 4.1.1.1 Condition Summary

Night skies warrant a moderate level of concern, with significant light trespass reaching the park. Data are not available to assess a trend.

#### 4.1.1.2 Description

The dark night sky is one of the most valued resources in the park. Impacts on the night sky can originate from light sources within the park, such as lighted parking lots or buildings, and adjacent development. Since there is little development within Puʻukoholā Heiau NHS— only two buildings have outside lights at night— the largest light sources impacting the night sky may be expected to originate from development adjacent to the park. For example, lights are on all night at the parking lot at Spencer Beach and at commercial recreational Kawaihae boat harbors north of the park (B. Saldua, NPS, personal communication, D. Kawaiaea, NPS, personal communication, June 2019). For that reason, light pollution provides a good metric for tracking changes in the surrounding landscape from predominantly agricultural to urban uses. Light pollution is a further concern because unnatural nighttime light has been shown to have numerous direct negative effects on many living organisms, including plants, insects, birds, bats, and rodents in terrestrial habitats as well as intertidal invertebrates and marine organisms (see Davies et al. 2013, Gaston et al. 2013 and Gaston and Bennie 2014 for reviews).

#### 4.1.1.3 Data, Indicators and Methods

Measuring the condition of the night sky is challenging because there are both numerous natural phenomena that affect the brightness of the night sky and numerous ways of measuring night-sky brightness. We used the All Sky Light Pollution Ratio (ALR) estimated from upward radiant light observed by satellite to measure the condition of the night sky. The ALR is the average anthropogenic sky luminance presented as a ratio over natural conditions. For this assessment, anthropogenic light was upward reflectance extracted from calibrated VIIRS (Visible Infrared Imaging Radiometer Suite) data. Natural light is determined by simulation model (Duriscoe 2013). This method works well for sites affected by sky glow, but generally does not capture horizontal light trespass from adjacent sources of light pollution. We account for horizontal trespass (i.e., light entering the park from park boundaries rather than from above) in this assessment qualitatively by noting the upward radiance of nearby potential light sources, under the assumptions that 1) upward radiance at the source correlates to the maximum potential brightness of horizontal trespass, and 2) the brightness of horizontal trespass from a single source diminishes with distance approximately proportional to the change in upward radiance with distance from that source. We used ALR data provided by the NPS Natural Sounds and Night Skies Division modeled from VIIRS day/night band monthly cloud free composite data from October 2015.

#### 4.1.1.4 Reference Condition

Natural Night Sky was assessed using the ALR values estimated within the park. For the ALR, lower values indicate a more pristine sky, with a value of 0 corresponding to a sky where natural cycles of light and dark prevail free from artificial glow. National Park Service uses a three-step ranking system based on ALR measures of light pollution depending on the presence of natural or cultural resources that may be impacted by light pollution (Moore et al. 2013). For parks with significant resources, the highest (i.e., most pristine) ranking is assigned to parks with an ALR no greater than 0.33; that is, with measured natural plus anthropogenic light no more than 1/3 brighter than natural conditions. The worst ranking is assigned to parks with an ALR > 2.0, corresponding to anthropogenic light in the night sky twice as bright as natural conditions. All other parks are assigned the middle ranking.

### 4.1.1.5 Current Condition and Trend

Pu‘ukoholā Heiau NHS is located in range of five potential sources of light pollution, though none of these are particularly bright (Figure 9). Two light sources adjacent to the park, Kawaihae north of the park and development associated with the Mauna Kea and Hapuna golf courses south of the park, likely account for most of the artificial light in the Pu‘ukoholā Heiau NHS night sky. The average ALR at Pu‘ukoholā Heiau NHS is between 0.4 and 0.8 (Figure 9), above the threshold for the highest ranking, but well below the threshold for the worst ranking. While Pu‘ukoholā Heiau NHS likely receives horizontal light trespass from Spencer Beach Park (adjacent property to the south), Puako (8 km [5 mi] south) and Waikoloa Village (10 km [6 mi]), the ALR in the center of these developments is still < 2.0, and trespass from these sources at present is unlikely to significantly deteriorate the quality of the Pu‘ukoholā Heiau NHS night sky.

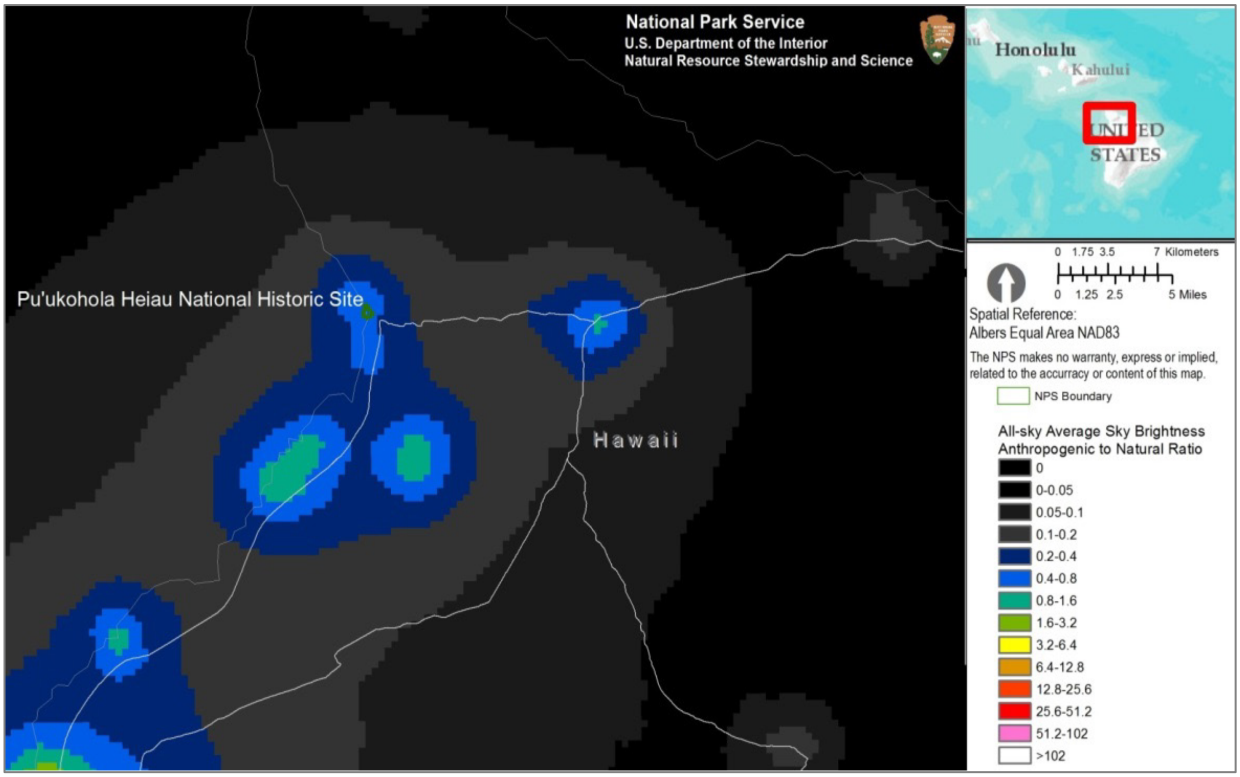


**Figure 9.** All-sky average anthropogenic to natural sky brightness ratio at Pu‘ukoholā Heiau NHS and surrounding lands.

### 4.1.1.6 Data Gaps and Research Recommendations

All of the data on light pollution in Pu‘ukoholā Heiau NHS come from upward reflectance extracted from satellite imagery. However, horizontal trespass is likely to be a major source of light pollution at Pu‘ukoholā Heiau NHS. The simplest method to get a metric of the night-sky brightness is for a dark-adapted observer to make simple qualitative appraisals of the night sky based on celestial features, such as the Milky Way. The most popular qualitative assessment is the Bortle Dark Sky Scale (NPS 2016b). A more comprehensive method, and one less prone to observer bias, uses a light sensor that measures illuminance (the light falling upon a surface) or luminance (the brightness of a surface). A rigorous method used in many parks, including Kaloko-Honokōhau National Historical Park, is described in Duriscoe et al. (2007).

#### 4.1.1.7 Sources of Expertise

- Jeremy White, National Park Service, Natural Sounds & Night Sky Division (at the time of this study)

### *4.1.2 Pelekane Bay and Watershed*

*By Jené Michaud, University of Hawaiʻi at Hilo*

#### 4.1.2.1 Condition Summary

The condition of Pelekane watershed and Pelekane Bay merits high levels of concern because a blanket of land-derived sediment 2–3 m (7–10 ft) deep covers the bottom of Pelekane Bay, smothering benthic ecosystems, degrading water quality, and altering the position of the shoreline. Anthropogenic alternations to the watershed and coastline have altered the hydrologic and coastal processes, resulting in degradation of the marine ecosystem. The sediment thickness is increasing over time as floods deliver new sediment; only a small proportion of the sediment is removed from the bay by wave and current action. Confidence in these assessments is high.

#### 4.1.2.2 Description

Watersheds are a unifying element of the landscape. Streams and overland runoff transport sediment, nutrients, and pollutants downslope through Puʻukoholā Heiau NHS and discharge them at the shoreline. Upon reaching Pelekane Bay, coastal currents and wave action determine where this load is distributed. Interconnected watershed and coastal processes therefore determine the condition of the park's stream channels, shoreline, and bay. Hydrological and shoreline resources are affected by disturbances such as drought, fire, shoreline modification, and sea level rise. Throughout this chapter, the condition of the watershed, shoreline, and coastal waters will be discussed from higher to lower elevations, following the flow of water.

##### *Watershed Features*

Three contiguous watersheds—Makahuna, Makeāhua and Kukui (in part)—comprise the Pelekane watershed. The primary stream channels influencing hydrologic processes in Puʻukoholā Heiau NHS and Pelekane Bay are Makeāhua Gulch, which is the main channel in the Pelekane watershed, and tributary Pōhaukole Gulch, which is a small stream that drains the park itself. The 4,200 ha (10,000 ac) Makeāhua watershed extends from the shoreline to an elevation of 1,600 m (1,700 yd; Figure 10). Annual rainfall varies between 280 mm (11 in) near the coast to 2400 mm (95 in) in the headwaters (Giambelluca 2013). Largely undeveloped, 75% of the watershed is grazed; vegetation is dominated by grass (MKSWCD 2005). There are scattered pockets of scrub, mostly along watercourses; a very small area of forest is found at the top of the watershed. Less than 15% of vegetation is native. The streamflow in Pelekane watershed is ephemeral (flowing briefly after storms[10]). Streams drain southwest along the flanks of Kohala Volcano until they reach the boundary between Kohala and

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[10] Some authors use the terms ephemeral and intermittent interchangeably.

Mauna Kea lava flows, whereupon they turn west, converge into Makeāhua Gulch, and flow along the park's northwestern boundary into Pelekane Bay. The park itself drains into Pōhaukole Gulch or to the ocean on seaside-facing slopes. At the present time, the smaller Pōhaukole Gulch joins Makeāhua Gulch about 160 m from the shoreline (Figure 10). In this report, the channel downstream of the confluence will be referred to as Makeāhua Gulch.

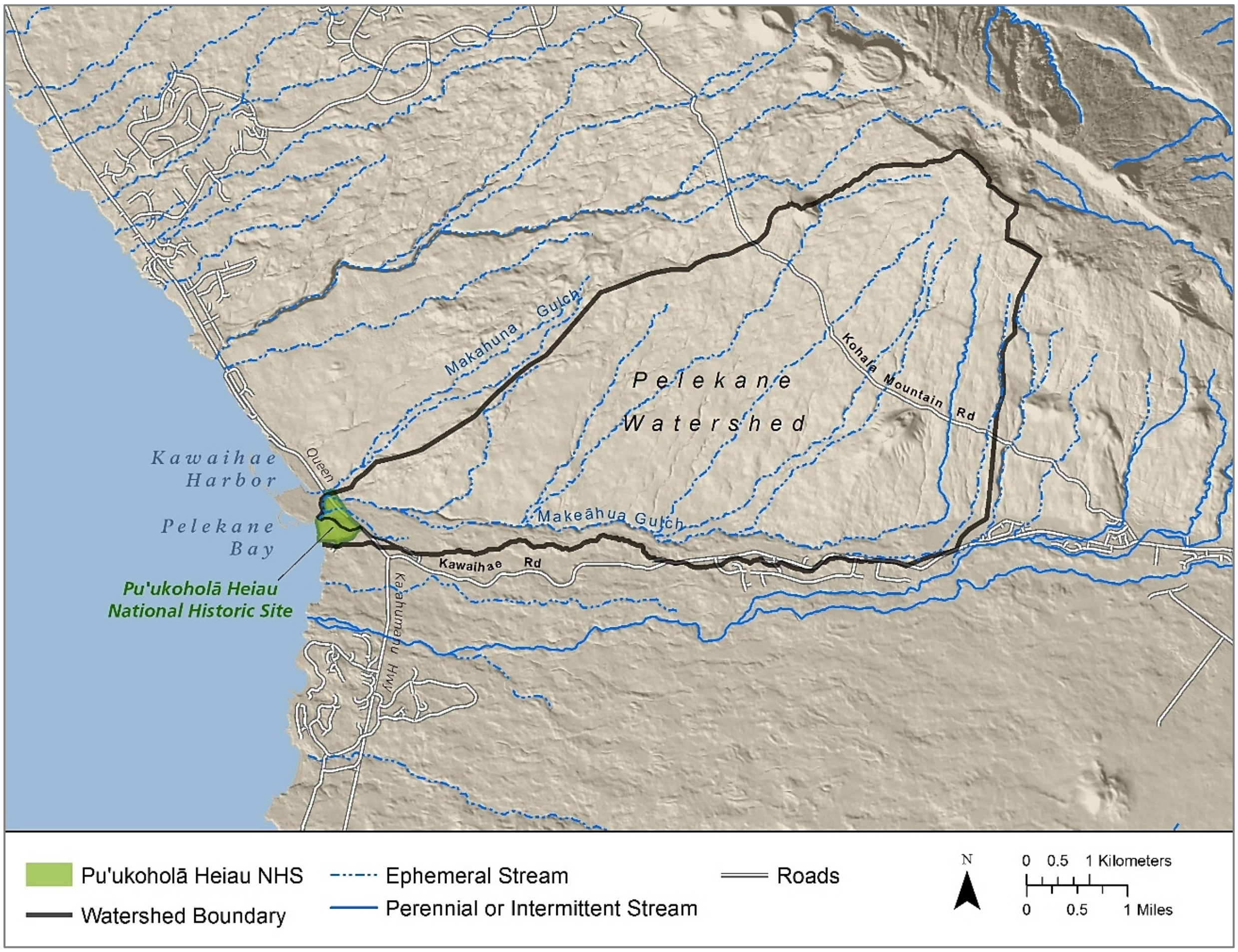

**Figure 10.** Pelekane watershed. The northern half of Puʻukoholā Heiau NHS drains to Pōhaukole and Makeāhua Gulches; the southern half of the Puʻukoholā Heiau NHS drains directly to the ocean. The watershed boundary was derived from NOAA 10 m elevation data by S. Margriter, NPS (unpublished).

The mouth of Makeāhua Gulch is usually blocked by a sand berm that is an extension of Pelekane Beach, creating the "unnamed brackish water body" that extends inland for about 100 m (100 yd) (Figures 11–13). Brackish groundwater is the dominant source of water in this water body, although at other times seawater and streamflow are additional sources. Floods occasionally erode the sand berm so that the channel is open to Pelekane Bay. Once floodwaters subside, tides and marine biota are free to enter the brackish water body until wave action rebuilds the berm. Casual observations suggest that erosion of the sand berm happens on roughly a five-year cycle (D. Kawaiaea, personal communication, 2016). Eventually (roughly several months to ten months) wave action rebuilds the sand berm and closes the connection to the sea. Because of these characteristics it is neither an anchialine pool nor an estuary.

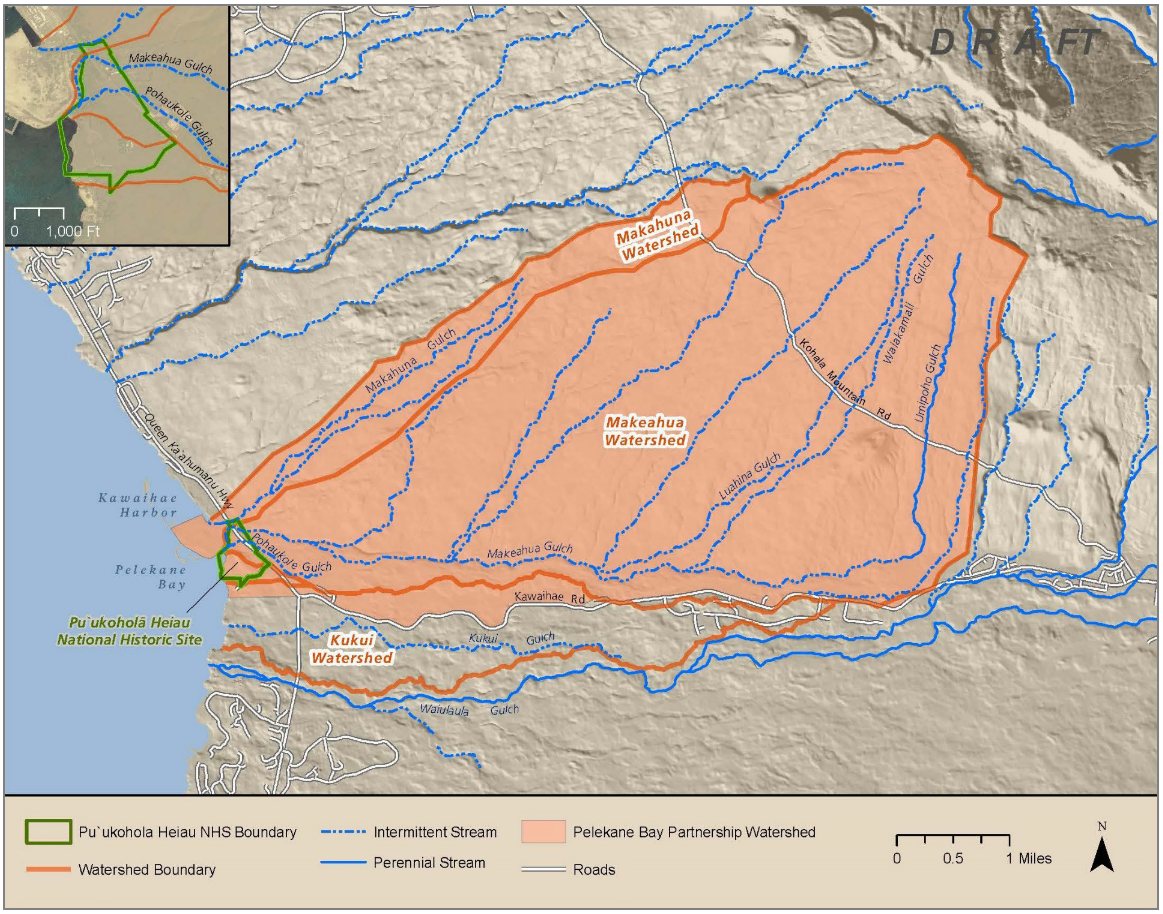

**Figure 11.** Pelekane Bay Partnership watershed area. Watershed basins were delineated based on topography. Makahuna Watershed drains into Kawaihae Harbor and Makeāhua Watershed is also called Pelekane Watershed. Kukui Watershed is south of the park. This watershed delineation is based on where the water should flow based on topography, however the current condition is that Makeāhua flows through a diversion under Akoni Pule Highway and is re-directed by the Kawaihae revetment, around the northwest boundary of the park and into Pelekane bay (10 m elevation data from NOAA 2015, and Margriter, NPS unpublished).

Natural and cultural resources within Puʻukoholā Heiau NHS are also potentially influenced by extreme natural disturbances, such as earthquakes, tsunamis, and sea level rise. Low lying coastal areas are subject to flooding from seasonal high waves, storm-driven overwash, and stream flooding caused by heavy rainstorms (Fletcher et al. 2002, Vitousek et al. 2009).

The geography of Pelekane Bay demonstrates the interaction between anthropogenic and natural landscape processes. Prior to the construction of the Kawaihae Harbor in the late 1950s, there was an open shoreline in the area that is now a protected bay. Construction of the harbor's breakwater blocked wave action and created today's calm water conditions (Storlazzi et al. 2013). During harbor construction, the mouth of Makeāhua Gulch was moved from its original position (further to the north) to its present position inside the park. Floods carry large amounts of sediment down Makeāhua Gulch and into Pelekane Bay, gradually changing the bathymetry of the bay (Storlazzi et al. 2013), smothering benthic ecosystems (Stender et al. 2014), leading to beach accretion (Vitousek et al. 2009), and increasing turbidity in Pelekane Bay. Fine sediment eroded by wind and deposited into Pelekane Bay also contributes to the sediment load.

**Figure 12.** The unnamed brackish water body (NPS I&M photo).

Along the western shoreline of Hawaiʻi Island, near-surface groundwater occurs as a layer of seaward-flowing brackish water (the basal lens) that floats on a deeper layer of saline water (Lau and Mink 2006). The salinity gradually transitions to saltwater with depth (Izuka et al. 2018). Groundwater conditions within Puʻukoholā Heiau NHS are expected to be similar to those in better-sampled locations along the western shoreline of Hawaiʻi Island, except that the freshwater lens would be expected to be especially thin and salty because of upslope aridity. It is likely that there is no true fresh groundwater under the park and that the brackish transition zone extends up to the water table. The aquifer underlying Puʻukoholā Heiau NHS extends from the shoreline to the topographic crest separating windward and leeward sides of the island. Recharge is primarily from rainfall that infiltrates without being evaporated or used by plants (Engott 2011). The park lies within the Mahukona Aquifer System Area, which is one of the driest aquifer systems on the island. Based on water budget calculations, groundwater recharge within and upslope of Puʻukoholā Heiau NHS is low, typically on the order of 3–8 cm $yr^{-1}$ (1–3 in. $yr^{-1}$; Engott 2011). Recharge at the highest elevations, however, is as much as 50–100 cm $yr^{-1}$ (20–40 in. $yr^{-1}$).

**Figure 13.** Shoreline geography and coastal features with detail of area around mouth of Makeāhua Gulch and Pelekane Beach (inset). The brackish waterbody is immediately inland of the sand berm. Yellow and grey indicate the agricultural and urban land use districts, respectively.

Drilling of test holes at the upslope boundary of the park revealed possible perched groundwater at an elevation of about 27 m (30 yd; Hoover and Gold 2006). Some early observers and recent investigators have noted unusually warm groundwater discharging along the shoreline near the park (Hoover and Gold 2006).

*Watershed Processes*

Runoff in semi-arid watersheds with ephemeral streams occurs when rainfall intensity exceeds the infiltration capacity of the soil, creating Hortonian overland flow (Bierman and Montgomery 2014). Surface flow, whether concentrated into rills or present as sheetflow, can erode soil particles if the water velocities are swift enough. The impact of falling raindrops can dislodge soil particles so that they are easier to move. Once flow is concentrated into channels, the bed and banks may be eroded by fast-moving flowing water and saturated banks may slump into the channel. Gully cutting occurs when former rills, swales, and small channels are rapidly eroded to form a deep channel with steep earthen sides. Erosion can be particularly rapid at the head of a gully. Gully cutting and associated headward erosion has occurred in the Pelekane watershed and the stabilization of these sites has been a restoration priority. Debris flows have occurred in the watershed, as evidenced by deposits (C. Cerovski-Darriau, personal communication, 2019).

Several factors affect the generation of runoff and soil erosion. Vegetation is very important because roots stabilize the soil and plants alter soil properties in ways that promote infiltration. Additionally, vegetation catches raindrops that otherwise would dislodge soil particles and slows overland or overbank flow. In short, vegetation reduces erosion and promotes deposition of sediment in transport. The location of intense erosion depends on rainfall intensity and frequency, topographic slope, hillslope length, vegetation, soil erodibility, fire history, and soil crusting. Soil crusting also discourages seed germination and can be a factor in vegetation restoration. Water-repellent soils occur in the watershed but have not been mapped (C. Cerovski-Darriau, personal communication 2019, MKSWCD 2005). Water-repellency tends to increase runoff and erosion.

Sediment undergoing transport by flowing water may be deposited if the flow velocity drops below a critical value. This can occur if runoff is absorbed by (infiltrated into) the soil or channel bed. Deposition tends to occur in places where steep slopes become gentle or where concentrated flow spreads out (e.g., where flow spreads onto a floodplain). In large floods, coarse sediment is deposited just past the mouth of Makeāhua stream, forming a sediment delta in Pelekane Bay. Within the watershed, sediment may be transported short distances in each runoff event, making a gradual approach to the sea.

### *Coastal Features*

Pelekane Bay is an artificial coastal embayment produced by the construction of Kawaihae harbor (Figure 14). Pelekane Beach is the most prominent shoreline feature (Richmond et al. 2008). A small coastal plain is present behind the beach and is bordered on the north by Makeāhua Gulch. In the absence of erosive streamflow, wave action and wave-generated currents build a sand berm across the mouth of Makeāhua Gulch. The sand berm serves to impound brackish groundwater, creating the unnamed brackish water body discussed earlier. The berm is an extension of the wave-dominated beach, which is 1–2 m high and is partially stabilized by trees. Past observers have commented that erosion has exposed roots of the most seaward trees. Sand on Pelekane beach is a combination of sediment of basaltic origin supplied by the stream and biogenic carbonate sediment produced mainly by coral and coralline algae.

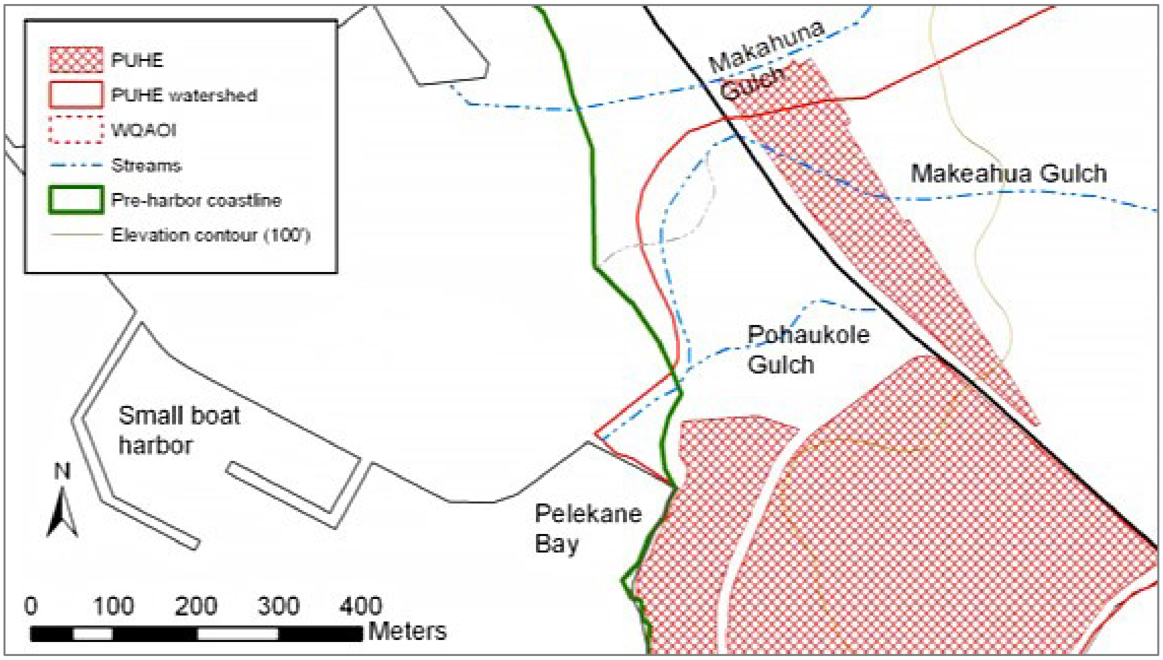

**Figure 14.** Past and present shoreline geography and stream channels. Pre-harbor coastline is derived from aerial photograph in Kelly (1974) and from 1956 coastline trace in Harbors Division documents. The likely pre-harbor outlet for Makeāhua Stream is shown in stippled gray based on aerial photographs from Kelly (1974). Figure from Hoover and Gold (2006; shows the boundary of Puʻukoholā Heiau NHS in the early 2000s).

*Coastal Processes*

Tides on Hawaiʻi Island are mixed semidiurnal with a small range (~0.4 m [~1.3 ft]). At the Kawaihae tide gauge, sea level in Aug–Sept averages 88 mm (3.5 in) higher than in February–April because of persistent trade winds during the summer. Currents in Pelekane Bay are driven primarily by waves, with smaller contributions from wind and tidal forcing (Li et al. 2009). The largest waves at Puʻukoholā Heiau NHS come from the northwest (Vitousek et al. 2009).

Storm waves and associated currents are significant agents of flooding, erosion and sediment transport. Wave runup[11] is a key variable in terms of flooding, erosion, damage to cultural features, and inland transport of sand (Vitousek et al. 2009). The distance that waves travel inland is affected by wave characteristics, tide level, and beach steepness. Tsunamis represent another mechanism for generating large waves that can impact park resources. Even small tsunamis disturb sediment at the bottom of Pelekane Bay.

### 4.1.2.3 Data, Indicators and Methods

The condition of Pelekane watershed, Pelekane Bay, and the shoreline of Puʻukoholā Heiau NHS are assessed based on four indicators: sediment loads entering and flowing through the park, shoreline

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[11] Wave runup is the elevation—relative to the still water level—at the most inland point reached by a wave.

position, flood frequency and extent, and sediment accumulation into Pelekane Bay. Rainfall and sea level are also analyzed because these variables are key to understanding mechanisms of change.

A variety of methods are employed in the condition assessment. These include formal statistical analyses (sea level and rainfall), review of one-time scientific studies, and qualitative assessment and discussion—based on the literature and expert opinion—of key processes.

Tide gauge data for Hilo and Kawaihae harbors were obtained from data portals of the National Atmospheric and Oceanic Administration (NOAA; http://tidesandcurrents.noaa.gov; accessed 10/21/2016). Linear trends were evaluated using linear regression on monthly data. The 95% confidence interval on the long-term rate of rise was calculated by NOAA as 1.96 times the standard error above and below the derived value. Deceleration/acceleration of sea level rise was evaluated by fitting a quadratic curve to annual data using the glm package in program R (Kabacoff 2015). Quadratic analysis is a common method of evaluating acceleration or deceleration, although results may be unduly sensitive to the time period examined and length of record (Rahmstorf and Vermeer 2011). Linear analysis of sub-periods was used to quantify trends in a way that is readily understandable. Precipitation data were obtained from NOAA's National Center for Environmental Information data portal (https://www.ncdc.noaa.gov; accessed 4/19/2017). Differences in mean value between sub-periods were evaluated using the Student's t test (after testing for normality and equal variance) using SigmaStat version 3.5 from Systat Software, Inc., www.systatsoftware.com.

Literature related to oceanographic conditions, sea level rise, shoreline position, and sedimentation were reviewed and synthesized. Literature and reports related to hydrologic process in the Pelekane watershed—and watershed management efforts—were also reviewed. The studies examined are:

- A NPS study on coastal water resources and watershed conditions (Hoover and Gold 2006) and a compilation of historical oral accounts (Greene 1993);
- The Pelekane watershed management plan (MKSWCD 2005), a report on the Pelekane watershed restoration project (The Kohala Center 2011), a study of stream erosion in an adjacent watershed (Sustainable Resources Group International Inc. 2014), a study that modeled soil erosion (Group 70 International 2007), an erosional study by Takesue and Storlazzi (2019), the Kawaihae Harbor master plan (Hawaiʻi Department of Transportation 2011), a fire management study (Witter and Rasmussen 2015), and the South Kohala Community Development Plan (County of Hawaiʻi 2008);
- Studies addressing coastal landforms and coastal hazards (Cochran et al. 2007, Fletcher et al. 2002, Richmond et al. 2008, Thornberry-Ehrlich 2011, Vitousek et al. 2009);
- Studies documenting oceanographic conditions and sedimentation in Pelekane Bay and biological responses to sedimentation (DeMartini et al. 2013, Fabricius 2005, Group 70 International 2007, Li et al. 2009, Koop et al. 2001, Perez et al. 2014, Storlazzi et al. 2013, Stender et al. 2014);
- Flood hazard assessments conducted for the park's shoreline. These include flood maps produced by the Federal Emergency Management Agency (FEMA) and studies that mapped

flooding from high surf, tsunami, exceptionally high tides, and sea level rise scenarios (Caffrey et al. 2018, Marrack and Oʻ Grady 2014, Sweet et al. 2014, Vitousek et al. 2009);

- Studies relevant to recent sea level change in Hawaiʻi (Caccamise et al. 2005, Firing et al. 2004, Ludwig et al. 1991, Merrifield 2011, Merrifield and Maltrud 2011, Nerem et al. 2010, 2018, Zhong and Watts 2002), along with selected studies on methods of data analysis or sea level projections (IPCC 2013, Parris et al. 2012, Rahmstorf and Vermeer 2011, Stammer et al. 2013, Sweet et al. 2017, Watson 2016).

FEMA's Flood Insurance Rate Maps (FIRM) are available at https://www.fema.gov/glossary/flood-insurance-rate-map-firm (accessed 08/13/2019). Panel 0165F of FIRM 155166 covers the streams and shoreline of Puʻukoholā Heiau NHS. FEMA's assessment of coastal flood hazard considers tsunami as the primary agent of coastal flooding but does not consider progressive sea level rise. Details of FEMA's methods are described in the Hawaiʻi County Flood Insurance Study (FIS), volume 1, which is available from FEMA at https://dlnreng.hawaii.gov/nfip/fis/fis-hawaii/ (accessed 03/02/2017).

The Hawaiʻi Commission on Water Resource Management maintains several groundwater monitoring wells upslope of the park. Data on groundwater levels, available from https://dlnr.hawaii.gov/cwrm/groundwater/monitoring, were qualitatively evaluated for trends. There are limited water quality data from several wells located upslope of the park or south of the park (Hoover and Gold 2006). These were deemed inadequate for characterizing water quality within the park itself, however, because of their location or proximity to landscape irrigation.

#### 4.1.2.4 Reference Conditions

The watershed reference condition corresponds to its functionality prior to substantial anthropogenic influences associated with cattle grazing and deforestation. Cattle were introduced in 1793. It is thought that the prehistoric Kohala forests reached nearly to the shore as late as 1815 (Hoover and Gold 2006) and that streams were perennial as late as 1830 (Kelly 1974, as cited in Stender et al. 2014). Eighteenth-century forests would have promoted infiltration, protected soil from rain splash erosion, and prevented wind erosion.

The reference condition for the park's shoreline corresponds to its condition prior to construction of Kawaihae Harbor in the 1950s. Construction of the harbor breakwater created the indentation now known as Pelekane Bay (Figure 14). The area that is now Pelekane Bay would have been subject to stronger wave action, stronger longshore currents, and stronger shore-perpendicular currents, resulting in a greater capacity for removing sediment brought to the shoreline by streams. There are no data documenting coastal sediment accumulation prior to substantial anthropogenic influences, but for the above reasons, very low accumulation rates are expected. A map from the early 20th century (Figure 15) and an air photo from the mid-20th century (Figure 16) show no accumulation of sand in the area that is now Pelekane Beach. A white sand beach began immediately north of what is now Pelekane Beach and extended northward to the area that is now the northern end of Kawaihae Harbor. Much of this sand is above high tide and partly stabilized by vegetation.

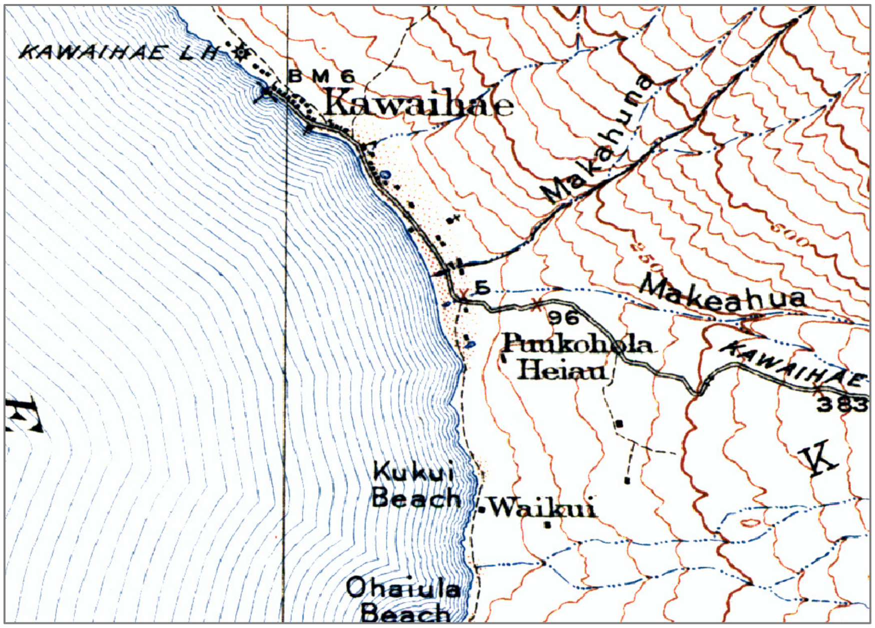

**Figure 15.** USGS Territory of Hawai'i, Kohala Quadrangle topographic 15-minute map. This area was surveyed in 1911 and 1913; the 1916 edition was reprinted in 1932. A tiny waterbody (possibly an anchialine pool) is visible west of Pu'ukoholā Heiau. Contour interval is 50 feet (15 m). The map depicts an area that is 2.0 miles (3.3 km) from north to south.

**Figure 16.** Shoreline before (top) and after (bottom) harbor construction. Puʻukoholā Heiau is visible in the lower right corner of the upper image but is out of view in the lower image. The channel of Makeāhua stream enters the upper image just below the upper right corner but is out of view in the lower image. The upper image shows the position of Makeāhua stream prior to being rerouted towards the south (to the right in this image; MKSWCD 2005). Additional images may be viewed at http://kawaihaereef.org/archives

### 4.1.2.5 Current Condition and Trend

*Watershed Erosion and Sediment Transport*

According to calculations made in the 1990s by the Natural Resources Conservation Service (as cited in MKSWCD 2005), soil erosion from overland flow and rill erosion was 0.6 tons per acre per year (t/a/y) in the invasive kikuyu grass (*Pennisetum clandestinum*) areas above the Kohala Mountain Road, about 2.5 t/a/y in the middle elevations of the watershed, and 9 t/a/y in the lower watershed,[12] which is arid and contains areas damaged by past wildfires. The area below 490 m (1,500 ft) elevation produced the most sediment, but excessive erosion was common up to 760 m (2,300 ft).

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[12] The report does not specify where the "lower watershed" begins. Based on rainfall distribution, it is likely that this refers to approximately the lowest ¼ of the watershed.

Casual observations suggest that dirt roads are particularly susceptible to erosion and are a sediment source (MKSWCD 2005). Fire breaks, which are typically bulldozed road-like features, can also be sediment sources.

The average-annual erosion rate from the watershed was modeled using the N-SPECT model, which focuses on sediment mobilized by rain splash (Group 70 International 2007). The model estimate of 15,000 tons per year was too high given that 1) only 62,000 tons of sediment has accumulated in Pelekane Bay, and 2) the model neglects erosion from gully-cutting and wind erosion. The apparently excessively large estimate of hillslope erosion could be partly explained by sediment deposition prior to reaching Pelekane Bay or flushing of fine sediment from Pelekane Bay during high surf events (Storlazzi et al. 2013) or tsunami (Stender et al. 2014).

Takesue and Storlazzi (2019) compared sediment cores from Pelekane Bay with soils in different parts of the watershed to see where the sediment came from. This was done using geochemical signatures. Results showed that runoff originated predominantly from the lower watershed along a highway corridor. Areas along the northern boundary of the watershed and the southeastern corner of the watershed have a unique geochemical signature and were ruled out as major sediment sources.

The amount of wind erosion in the lower watershed is not documented but is probably substantial given the strong winds, amount of bare soil, and sparse vegetation. Hoover and Gold (2006) noted that airborne dust may be a significant source of sediments to Pelekane Bay. Dust sources include the lower watershed, stockpiled dredge material at Kawaihae harbor, and a quarry located a short distance inland from the park. The quarry has been a major dust source, with plumes observed up to a mile offshore (Hoover and Gold 2006).

Geomorphologists have long noted that sediment eroded from hillslopes may be deposited in lower energy locations such as the base of slopes or floodplains (Bierman and Montgomery 2014). Studies in the conterminous United States and New Zealand have documented an 8× to 310× increase in erosion as the result of clearcutting or conversion of forests into agricultural areas (Reusser et al. 2015, Walling 1999). The corresponding increase in sediment exported by rivers was only 2.2× to 13×, however, with the balance attributed to storage of sediment within the watershed. It is likely that some of the sediment eroded from Pelekane hillslopes is in storage rather than in the ocean. As a result, watershed management projects designed to reduce erosion may not lead to a proportional decrease in marine sedimentation, at least in the short run.

#### *Groundwater*

Groundwater levels have been monitored at five wells in the Māhukona Aquifer System Area (or along the boundary between the Māhukona and Waimea Aquifer Systems; CWRM 2019a). While these wells are generally upslope from the park, the direction of water flow is not known precisely, so it is unknown if the wells are on a flow line that ends at the park. The two wells that are furthest upslope sample “high-level” water that is impounded behind a buried flow barrier, whereas the remaining three wells sample the basal lens closer to the coast. High-level water is more heavily pumped than the basal lens (CWRM 2019a). Data from elsewhere in West Hawaiʻi suggests that high-level groundwater leaks through the flow barrier, but the degree of hydrologic connection between the high-level water and the basal lens is unknown. Between June 2006 and June 2019, water levels at high-level Waiaka Tank well (#8–6141–001) fell by 3.21 m (10.5 ft). The decrease was steady, which is consistent with depletion due to nearby pumping. Water levels at the other high-level well (Kanehoa #8–6144–001) fell by 1.74 m (5.71 ft) between April 2005 and June 2019. At both wells, the rate of decrease has declined over time, with negligible change over the last several years. The reason for the change in rate is not obvious.

Conditions in the basal lens monitor wells are the best available indicator of groundwater trends in the park. The Ouli 1 well (#8–6046–001), which is 4 km (2.5 mi) upslope from the park, has the longest period of record, with data from 1993 onward. Here, water levels have fluctuated without a consistent trend. Fluctuations in the other two basal monitor wells mirror those in the Ouli 1 well.

*Watershed Disturbances*

Prior to the construction of Kawaihae harbor in the late 1950s, Makeāhua and Pōhaukole streams were separate and there was a fishpond at the mouth of Makeāhua Gulch (Greene 1993). During the harbor construction, the outlet of Makeāhua Gulch was redirected from its original position (inside what is now the harbor) to its present position inside the park (Figure 14). After the stream realignment Pōhaukole Gulch became tributary to Makeāhua Gulch. It is very unlikely that the brackish waterbody existed prior to harbor construction. Kawaihae had a significant brackish spring that was apparently destroyed during harbor construction (Greene 1993, Hoover and Gold 2006). Greene notes that the name Kawaihae means “water of wrath”, which has been interpreted to refer to battles over water in the region.

Vegetation and land use are key factors affecting hydrologic processes. As late as 1815, the Kohala forests were reported to reach nearly to the shore (Hoover and Gold 2006). Today, forests are restricted to a narrow strip at the very top of watershed (Figure 11); open grass or grass and shrub covers most of the watershed (MKSWCD 2005). The change in vegetation is attributed to overharvesting for the sandalwood trade, the introduction of non-native plants, and the effects of cattle introduced in 1793 (Hoover and Gold 2006).

Drought reduces vegetation cover, which in turn promotes runoff and erosion. Rainfall in the park[13] was close to the long-term average during 2014 and 2015, but the years 2007–2013 were particularly dry, averaging 120 mm $yr^{-1}$ (4.72 in $yr^{-1}$) in comparison with 284 mm $yr^{-1}$ (11.18 in $yr^{-1}$) during 1978–2006. This difference is statistically significant ($p < 0.01$). Conditions further upslope can be assessed by examining data from the Middle Pen rain gauge, which is slightly north of Pu‘ukoholā Heiau NHS at an elevation of 421 m (1,280 ft) amsl.[14] Here, rainfall averaged 249 mm $yr^{-1}$ (9.80 in $yr^{-1}$) during 2006–2015, which is only half of the average during 1966–2005[15] (504 mm $yr^{-1}$; 19.84

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[13] Rain gauge station Puukohola Heiau 98.1, COOP #518422, elevation 40.5 m (123 ft).

[14] Middle Pen 147.1 station (Network ID GHCND:USC00516270).

[15] Rainfall data begins in 1966 at Middle Pen and 1978 in the park.

in yr$^{-1}$). While both the lower-elevation station and the higher-elevation station experienced drought between 2005 and 2015, there are differences in which years were the driest. Between 1978 and 2015, half of the twelve driest years within the park occurred during 2005–2012. For the same time period, one-third of the twelve driest years at the upslope station occurred during 2008–2015.

On August 8–18, 2015, a human-caused wildfire burned 1,572 ha (3,884 ac) of private and public lands near Kawaihae (Witter and Rasmussen 2015). The fire burned 26 ha (64 ac) of the park (74% of the total park area) and 1,088 ha (2,688 ac) of Pelekane watershed (27% of the total watershed area), including critical erosion areas identified by the Pelekane Bay Watershed Restoration Project. Fires promote overland flow and erosion by exposing soil to raindrop impact, reducing soil anchoring, and, if the fire is hot enough, making the soil water-repellent by volatilizing waxes (DeBano 2000). The risk of excess erosion is greatest immediately after a fire and usually returns to near background levels within several years.

Burn severity within PUHE was not formally sampled/quantified following the 2015 fire. Anecdotal observations post-fire noted that grasses were the primary fuel type and root crowns were still present post-fire, indicating the fire was likely low to moderate in intensity with a very short residence time except in scattered kiawe trees. However, it should also be noted that critical erosion areas identified within the watershed and referenced above occur outside of and upslope from the park. Another much smaller 8.5 ha (21 ac) fire occurred in January 2020 and was confined to the Park. This fire exhibited similar low to moderate intensity behavior and did not prompt the same erosive concerns as the 2015 fire owing to a much smaller fire footprint that did not include critical erosion areas within the watershed (Wasser personal communication).

On August 17, 2015, an intense rainstorm (storm totals of 5–13 cm [2–5 in] at various locations in the watershed) produced floods in Makeāhua and Pōhaukole Streams (Witter and Rasmussen 2015). The return interval for this event was estimated at 25–500 years, depending on location. Flows in Makeāhua Stream rose to the bottom surface of the highway bridge, transported boulders up to 1.5 m (4.9 ft) in diameter and deposited a large sediment delta just offshore of the stream mouth. Trees transported by the flood floated into the bay. Flows in Pōhaukole Stream overtopped the highway bridge. The combination of fire, flood, erosion, and sedimentation damaged cultural features within the park (Witter and Rasmussen 2015). Goat exclusion fences, both at the perimeter of the park and upslope on private land were compromised; these fences are important to recovery of vegetation. In the Pelekane watershed, sediment check dams installed during the watershed restoration project were filled to capacity. Check dams have since been emptied in readiness for the next event, but funding for long-term maintenance remains problematic (J. Merkel, personal communication 2019). Another challenge is preventing remobilization of sediment that has been removed from the cheek dams. Practical methods of minimizing this problem are being researched.

Fires in previous years and non-NPS fire management efforts in Pelekane watershed are described in reports by the Mauna Kea Soil and Water Conservation District (2001, 2005). Fire management goals include education, fuel management through improved grazing (accomplished by building fences and installing water troughs), construction of fuel breaks, fencing people out, making fire hydrants accessible to firefighters, and development of fire response protocols.

*Watershed Management*

The detrimental impact of the Pelekane watershed on the downstream marine ecosystem has been recognized for over two decades. Formal acknowledgement came in 1998 when Pelekane was identified as a Category I watershed by the Hawaiʻi Unified Watershed Assessment process. A Category I watershed is defined as one in urgent need of restoration.

The Pelekane Bay Watershed Management Project (1992–2005) focused on reducing erosion (MKSWCD 2005). Partners in the project included the Mauna Kea Soil and Water Conservation District (MKSWCD), Queen Emma Foundation, Parker Ranch, the Natural Resources Conservation Service, and the University of Hawaiʻi Cooperative Extension Service. Grants funded planning for coordinated resource development, re-vegetation, and fire management. Reducing fire fuel loads and improving cattle grazing rotations were priorities. On-the-ground activities included installing fencing and watering troughs. Stubble height guidelines for grazing were developed in 2001 so that vegetation monitoring could be used to assess effectiveness of grazing rotations.

In 2007 an autosampler was installed in Makeāhua stream under the highway bridge. It automatically collected stormwater for laboratory analysis, but was removed in 2008 due to lack of funding. Data collected by the autosampler is discussed in section 4.3.1.5.

In 2009–2011, the Kohala Watershed Partnership undertook a large restoration project in the Pelekane watershed (The Kohala Center 2011). On-the-ground efforts focused on reducing erosion in two geographical areas. The first is an off-channel critical erosion area in the lower watershed, and the second is the riparian corridor along the main channel. Restoration activities included planting vegetation, installing erosion-control ground cloth, building sediment check dams in small tributaries, and managing feral goats. Goat management was accomplished through a combination of 29 km (18 mi) of exclusion fences and removing goats from inside the fence. Terrestrial monitoring included bare soil mapping and vegetation monitoring. Marine monitoring included turbidity, composition of the benthic community, *porites* growth anomalies, and fish biomass. Monitoring results were not published, however.

In the years since 2011, a variety of grants, organizations (The Kohala Center, South Kohala Coastal Partnership), and agencies (Hawaiʻi Department of Health, Hawaiʻi Department of Land and Natural Resources, U.S. National Oceanic and Atmospheric Administration) have supported watershed management planning efforts or implemented on-the-ground projects. For example, watershed issues are addressed in the South Kohala Conservation Action Plan (The Nature Conservancy 2012). During the period 2017–2020, grants are supporting goat removal, fence construction and repair, tree planting, construction of sediment check dams, and installation of watering troughs. Some of these activities are intended to reduce fuel loads or improve grazing rotations.

*Pelekane Shoreline*

The shoreline in the vicinity of the park has undergone dramatic changes as the result of harbor construction. Prior to the construction of the Kawaihae harbor in 1957–1959, there was an open shoreline while now there is a protected bay (Figures 15 and 17). Construction of the harbor's breakwater blocked wave action, disrupted along-shore currents, and created the calm water conditions present today (Storlazzi et al. 2013). One expert maintains that loss of longshore currents (that previously flushed sediments away) is the primary reason that sediments are now accumulating in Pelekane Bay (MKSWCD 2005).

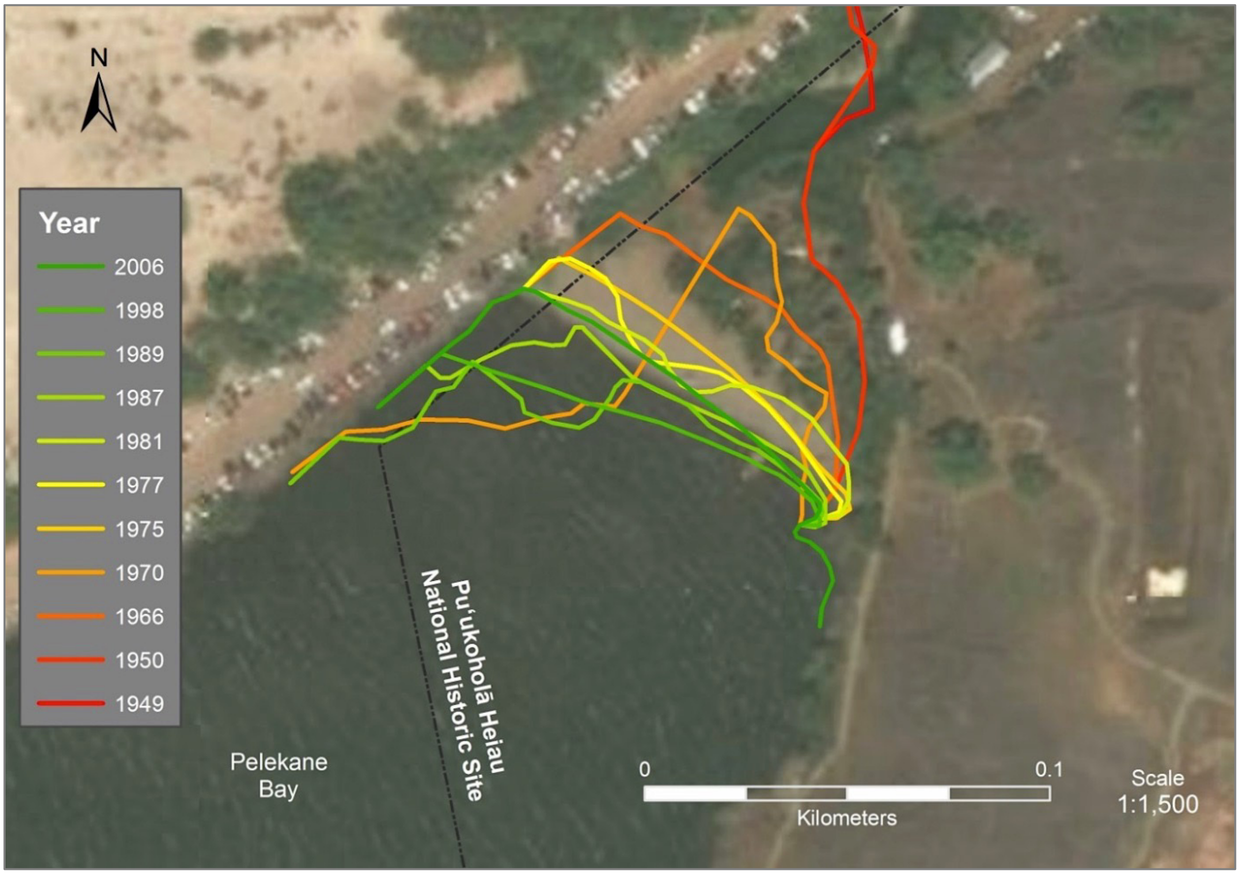

**Figure 17.** Position of shoreline at Pelekane Beach through time. Lines of different color show the shoreline at Pelekane Beach in the corresponding year. Shoreline estimation methods are described in Vitousek et al. 2009. Data provided by S. Vitousek.

The position of the Pelekane Beach shoreline has changed over time, reflecting the effects of harbor construction, sediment deposition, and flood erosion. Vitousek et al. (2009) documented change from 1949–2006 using satellite imagery (Figure 17). High rates of accretion from 1950–1966 reflect dumping of artificial fill during construction of Kawaihae Harbor. After 1966, the shoreline position fluctuated.

### *Flooding and Coastal Hazards*

Low-lying coastal lands can be inundated by stream floods, exceptional high tides, seasonal high surf, tsunami, and rising sea level. Saltwater flooding poisons terrestrial plants and transports marine fauna into the brackish water body. Stream flooding can disturb the waters of Pelekane Bay by reducing salinity, raising turbidity, and altering nutrient levels in the water column. Erosion and associated sediment deposition are additional hazards associated with high surf, stream floods, and tsunami.

Stream floods are known to have occurred in 2003, 2004, 2007, 2010, 2011, 2015, and 2016, but there may be others that have not been documented. Large floods can be expected to inundate the coastal plain behind Pelekane Beach.

On March 11, 2011, a magnitude 9.1 earthquake in Japan produced a tsunami that reached Hawaiʻi. The Kawaihae tide gauge recorded eight waves that reached 0.72–0.95 m (2.19–2.90 ft) above mean sea level. The largest wave was 1.02 m (3.11 ft) higher than the predicted tide. Sediments on the bottom of Pelekane Bay were disturbed (Takesue and Storlazzi 2019). In October 2006, a magnitude 6.7 earthquake in Kiholo Bay (21 km [13 miles] to the southwest) produced a tiny tsunami a few inches high. The largest known tsunami at Kawaihae (3.7 m [12 ft]) was generated by the 1946 Aleutian earthquake (Walker 1994).[16] Geologic evidence north of Kawaihae suggests the occurrence of a prehistoric tsunami with a runup of more than 400 m (1,200 ft; McMurtry et al. 2004). The cause of this megatsunami is believed to be a giant landslide on Mauna Loa that occurred about 120,000 years ago. The risk of tsunami flooding in the park has been quantified by the Federal Emergency Management Agency (FEMA). FEMA's coastal flood zones represent the 100-year inundation (1% annual chance) by tsunami (and streamflow) and are based on hydraulic modeling and historic tsunami runups. FEMA does not consider progressive sea level rise, however.

FEMA considers two areas at risk of both flooding and erosion by fast-moving water. These areas are Pelekane Beach and a narrow zone (about 23–46 m [25–50 yd] wide) along the park's rocky shoreline. In these locations, the expected 100-yr flood elevation is 3.0 m (10. ft) above mean sea level. Makeāhua Gulch up to the highway and the coastal plain behind Pelekane Beach are in the 100-year "floodplain" but outside the high-velocity zone. A 100-yr flood elevation of 1.8 m (5.5 ft) is predicted for the lower end of Makeāhua Gulch. Pōhaukole Gulch is mapped as a lower flood risk (flood depths less than one foot or subject to less frequent inundation). The remainder of the park is designated as zone D (flood hazards possible but not determined).

Vitousek et al. (2009) modeled inundation of the park from storm waves. The modeling processes included analysis of storm swells from different directions, the attenuating influence of island blockage, transformation of deep-water waves to near-shore waves, and various recurrence intervals. The maximum wave heights were then translated to maximum runup elevations using empirical methods that took the effects of the reef into account. According to their results, each year at Pelekane beach there is a 10% chance that runup from storm waves will be at least 1.19 m (3.63 ft).

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[16] Vitousek et al. (2009), citing Lander and Lockridge (1989), give a value of 4.3 m (14 ft).

There is a 1% annual chance that runup will be at least 1.43 m (4.36 ft). Along the park's steep rocky shores, there is a 10% annual chance that runup from storm waves will be at least 1.55 m (4.72 ft) and a 1% annual chance that runup will be at least 1.77 m (5.39 ft). Vitousek et al. (2009) also modeled inundation from the 1946 tsunami and found that waves were amplified in the semi-enclosed Pelekane Bay.

From time to time, unusually high tides can result in nuisance flooding. Such events can be associated with unusual atmospheric conditions coinciding with a particularly high astronomic tide. Data on nuisance flooding are not available for Hawaiʻi Island, but trends on Hawaiʻi Island are likely similar to those in Honolulu because the tidal cycle is similar throughout the state. In Honolulu, the frequency of nuisance flooding has been increasing since 1940, which is consistent with rising sea level (Sweet et al. 2014). The greatest frequency of nuisance flooding in Honolulu occurred in 2003–2004.

Relative sea level (water level relative to a fixed point on shore) at Puʻukoholā Heiau NHS can vary in response to global seawater levels (measured relative to the center of the earth), crustal subsidence or uplift, and regional/local fluctuations in wind (which can push water), atmospheric pressure, oceanic currents, and water density (which is a function of temperature and salinity). Drowned reefs near Kawaihae document crustal subsidence of 2.6 mm $yr^{-1}$ (0.10 in. $yr^{-1}$) over the last 500,000 years (Ludwig et al. 1991, Zhong and Watts 2002). Subsidence is due to the great weight of erupted lava. Satellite measurements provide the most accurate measurements of *global* sea level. From 1993 to 2015, global sea level, as measured by satellite altimetry, has risen 3.3 ± 0.4 mm $yr^{-1}$ (0.13 ± 0.02 in. $yr^{-1}$; Nerem et al. 2010).

Changes to relative sea level during the modern instrumental period are measured with tide gauges. Tide gauge data is available at Kawaihae harbor with a continuous record since 1992 and from Hilo harbor (on the opposite side of the island) with continuous data from 1927–1932 and 1947 to the present. At Kawaihae, sea level rise averaged 7.0 mm $yr^{-1}$ (0.28 in. $yr^{-1}$) from 1992–2015 ($p<0.001$), in comparison with 1.2 mm $yr^{-1}$ (0.05 in. $yr^{-1}$) at Hilo over the same time period ($p=0.02$) (Figure 18). The higher rate of increase at Kawaihae compared to Hilo has been attributed to an abrupt vertical shift of the Kawaihae tide gauge during the 2006 Kiholo Bay earthquake (Yang and Francis 2019). In any case, the period of record at Kawaihae harbor is too short to robustly evaluate sea level trends. The Hilo gauge has a long period of record, however, and during 1927–2015 sea level at Hilo rose 2.95 mm $yr^{-1}$ (95% confidence level 0.31 mm $yr^{-1}$) (0.12 ± 0.01 in. $yr^{-1}$). This is about half of what is expected based on recent measured rates of global sea level rise and average rates of island subsidence.

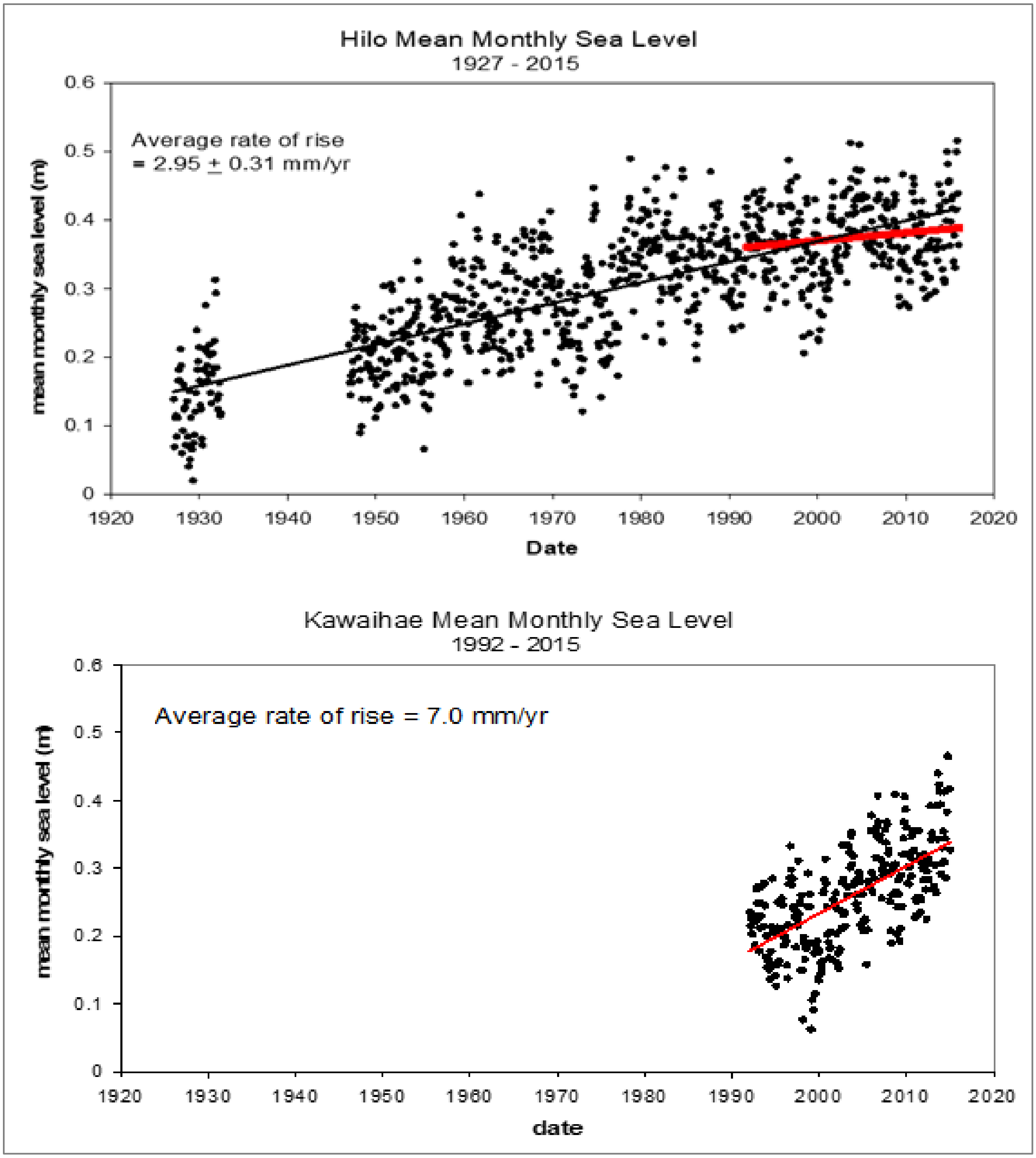

**Figure 18.** Monthly sea level data from the tide gauges at Hilo (top) and Kawaihae (bottom) harbors. The heavy red line in the Hilo graph shows the linear rate of rise (1.2 mm yr$^{-1}$ [0.05 in. yr$^{-1}$] during the Kawaihae period of record (1992–2015). NOAA data from https://tidesandcurrents.noaa.gov/

There are several reasons why trends in regional relative sea level could differ from global trends, with the rate of crustal uplift or subsidence being an important factor. Limited GPS data suggests that the subsidence rate of Hawai‘i Island could be variable over time (Caccamise et al. 2005). While it is not known if Hilo and Kawaihae are subsiding at different rates, the stiffness of the crust provides a certain degree of spatial uniformity. A variety of atmospheric and oceanographic processes can affect regional sea level —but not global sea level—on time scales ranging from months to decades. For example, decadal-scale fluctuations in regional water density have been identified as causes of anomalies in Hawaiian sea level trends (Caccamise et al. 2005). Sea levels around the Hawaiian Island chain experienced an overall decrease since the early 1990s, driven by an increase in the strength of the trade winds in the central and eastern tropical Pacific (Merrifield and Maltrud 2011, Stammer et al. 2013). This resulted in high rates of sea level rise in the western tropical Pacific (beginning in the 1990s) and low (or declining) rates in the eastern Pacific. These changes are not associated with the El Niño–Southern Oscillation events or the Pacific Decade Oscillation, however (Merrifield 2011). Hawaiian sea levels are correlated with the Pacific–North America index, which represents atmospheric connections between the tropical and mid-latitude zones (Firing et al. 2004). Higher (lower) sea level in Hawaiʻi is associated with an increase (decrease) in the strength of the Aleutian low.

**In summary, a variety of natural processes can result in temporary or permanent flooding of the park's coastal lands.** In some cases, anthropogenic activities (overgrazing, wave amplification within Pelekane Bay, warming-related sea level rise) can intensify flooding. Observational data on past floods is very limited. However, the expected severity and frequency of flooding has been quantified by several different research groups working on different mechanisms of flooding.

### *Sedimentation and Impacts to the Ecosystem*

Two surveys have measured the amount of sediment that has accumulated in Pelekane Bay since the harbor was constructed. Group 70 International (2007) compared measurements made in 2006 with a 1953 bathometric chart and found that 35,800 $m^3$ (46,800 cubic yards) of sediment had accumulated. Storlazzi et al. (2013) compared measurements made in 2011 with a 1928 hydrographic survey and found 22,500–37,500 $m^3$ (29,400–49,000 cubic yards) of accumulated sediment. (The range of values represents lack of precision in the 1928 survey and it is likely that little sediment accumulated between 1928 and harbor construction in the late 1950s.) Sedimentation is greatest within 150 m (160 yd) of Pelekane Beach; here, sediment is 2–3 m (7–10 ft) thick. The Hale o Kapuni Heiau is presumed to lie buried under the sediment. Based on measured net sedimentation rates of 0.6 cm $yr^{-1}$ (0.24 in. $yr^{-1}$), it appears that most of the sediment entering the bay has remained there (Storlazzi et al. 2013). However, perhaps 10–15% of the finest material has been removed by wave suspension and subsequent transport by currents (Group 70 International 2007). Bottom sediment is 51% silt and 42% very fine sand, with minor amounts of medium and fine sand (Hoover and Gold 2006).

Both terrestrial and marine processes affect nearshore sedimentation. While Makeāhua Stream is the major sediment source, wind-blown dust and locally-produced carbonate sediment[17] also contribute (Hoover and Gold 2006). Transport processes within Pelekane Bay determine where this sediment comes to rest. Coarse sediment in transport by Makeāhua Stream will be deposited when the forward velocity of the stream drops below a critical value that depends on sediment size. Compared to coarse

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[17] Corals and other shell-producing organisms are the source of carbonate sediment that originates from the fringing reef near the bay.

sediment, fine sediment (silt) remains in suspension longer and is more susceptible to being re-suspended by shoaling waves then flushed out of the bay by currents. This tends to happen during high surf events. Tsunami also suspend and transport bottom sediments.

A flood that occurred in 2010 created a sediment plume that extended more than 500 m (~500 yd) from shore. Three months later, a high surf event re-suspended the sediment, and reef flat sediment was moved outward to the forereef (Storlazzi et al. 2013).

*Conclusions*
Each of the four indicators has been negatively impacted by anthropogenic activity. Upland deforestation and habitat conversion to invasive grasslands has led to soil erosion and subsequent sediment loads flowing into and through the area that is now the park. The construction of Kawaihae harbor changed the position of the shoreline (Vitousek et al. 2009), amplified wave runup, and resulted in a rapid sedimentation that has smothered the benthic ecosystem (Storlazzi et al. 2013). The frequency of shoreline flooding has been intensified by sea level rise associated with global climate change.

#### 4.1.2.6 Threats and stressors

Threats and stressors to the park's watershed and shoreline resources come from natural hazards and land use practices impacting upstream lands.

*Natural Hazards*
Fletcher et al. (2002) compiled a state-wide natural hazard risk map for coastal areas, providing both an overall assessment of risk from any extreme natural disturbance and a breakdown of risk from the seven different types of disturbances. They assessed the overall hazard at Puʻukoholā Heiau NHS as 5 on a scale of 1–7, corresponding to a moderate to high risk of impact by a natural disaster. The assigned risk for each hazard type is shown in Table 2. The greatest risk was assigned to seismic activity. The epicenter of the Kiholo Bay earthquake, which occurred in October 2006, was about 21 km (13 mi) southwest of the park. This earthquake caused severe damage to several heiaus (Richmond et al. 2008).

The risk from volcanic eruptions varies across Hawaiʻi Island. Wright et al. (1992) have therefore divided the island into nine risk zones based on the frequency of lava flows. The park is located near the boundary of zones 8 and 9, which have the least risk. Volcanic activity at Puʻukoholā Heiau NHS ceased at least 65,000 years ago (Richmond et al. 2008); the risk to Puʻukoholā Heiau NHS from active volcanic flows or explosive volcanism is extremely low (Mullineaux et al. 1987, Richmond et al. 2008).

Hurricanes represent the worst-case scenario for shoreline flooding and erosion. Deep offshore waters mean that wave-driven flooding presents more of a threat in Hawaiʻi than wind-driven still-water surge (Kennedy et al. 2012). While no hurricane has made landfall on Hawaiʻi Island in the twentieth or twenty-first centuries, Hurricane Iniki is an example of what is possible. During Hurricane Iniki, the water surface at Nawailiwili harbor (Kauaʻi) reached 6 m (20 ft) above mean sea level (Hall et al. 2016).

**Table 2.** Assessment of natural hazard risk categories. From Fletcher et al. (2002).

| Hazard | Risk Level on a Scale of 1 (low) to 4 (high) | Assessment Criteria for Assigned Risk Level |
|---|---|---|
| Tsunami | Moderately High to High (3–4) | history of tsunami flooding; historical damage; gentle coastal zone slope (<45%) |
| Stream Flooding | Moderately Low (2) | history of nondamaging flooding; streams or highlands with seasonal high rainfall present (>7.9 in per month); coastal slope >20%; or history of fully mitigated flood damage |
| High Waves | Moderately High (3) | seasonal high waves 6–8 ft with hazardous run-up and currents |
| Storms | Moderately High (3) | historical overwash >10 ft on steep slope, and/or high winds; localized (isolated cases) structural damage (~40 mph sustained) |
| Erosion | Moderately Low (2) | long-term stable or minor erosion/accretion cycles; erosion recovered by accretion; low rocky coasts; perched beaches |
| Sea Level | Moderately High (3) | gentle or moderate slope, where rise >0.08 in $yr^{-1}$ or steep slope where rise >0.12 in $yr^{-1}$ |
| Volcanic& Seismic | High (4) | frequent volcanism, Uniform Building Code seismic zone factor ≥ 2 recommended, frequent historic damage |

Observers in 2004 noted that erosion had exposed roots of trees on Pelekane Beach (Hoover and Gold 2006), indicating that progressive erosion of the beach is a concern. Rising sea level is generally perceived as a threat to beaches, although it is possible that the beach, which is built by wave action, will move inland as sea level rises.

Sea level rise is being driven by thermal expansion as the ocean warms and enhanced melting of glaciers and ice caps (Stammer et al. 2013). It is widely anticipated that rising sea level will have a profound effect on the geography, hazards, and ecosystems of coastal zones. For example, higher sea level means that floods from storm waves, exceptional tides, and tsunami will occur more frequently and reach farther inland. The question of whether the rate of global sea level rise has accelerated or will accelerate has important implications for managers anticipating future inundation of coastal lands. Quadratic analysis of 1947–2015 Hilo sea level data shows a statistically significant ($p< 0.001$) deceleration over this period; sea level continued to rise, albeit at an increasingly slower rate over time. This result is corroborated by linear analysis showing a slower rate of rise in 1992–2015 (1.2 mm $yr^{-1}$, $p=0.02$; 0.05 in. $yr^{-1}$) than in 1927–1991 (3.5 mm $yr^{-1}$, $p<0.001$; 0.14 in. $yr^{-1}$; Figure 17). In contrast, analysts of global sea level have noted "strong evidence of a recent acceleration commencing around 1982–1985" (Watson 2016). The satellite altimetry data shows that global sea level is accelerating $0.084 \pm 0.025$ mm $yr^{-2}$ ($0.033 \pm 0.001$ in. $yr^{-2}$; Nerem et al. 2018).

Global mean sea level is expected to rise between 0.2 m and 2.0 m (0.7 to 6.6 ft) by 2100 (Parris et al. 2012, IPCC 2013), with the most credible worst-case scenario being a rise of 2.5 m (8.2 ft) by 2100 (Sweet et al. 2017). These authors also argue that the minimum plausible sea level rise is 0.3 m (1.0 ft) by 2100. Future collapse of the West Antarctic Ice Sheet cannot be ruled out, making the worst-case scenarios of rapid rise more likely (Robel et al. 2019). NOAA has recently published a new projection of global sea level rise and the regional factors that will determine relative sea level rise for the entire U.S. coastline (Sweet et al. 2017). Marrack and OʻGrady (2014) mapped coastal inundation at the park for sea level rise scenarios ranging from 0.5 to 1.9 m (1.6–6.2 ft) plus an additional amount associated with extreme high tides. Coastal subsidence was not considered in these scenarios. Mapping of inundation zones was accomplished using high-resolution LIDAR-derived topographic data, but results for Puʻukoholā Heiau NHS were not included in their report. The National Park Service developed a viewerthat illustrates inundation in the years 2050 and 2100 under moderate (RCP4.5) and high (RCP8.5) global warming scenarios (Caffrey et al. 2018). Coastal subsidence is considered in these scenarios and results show that the area now occupied by the brackish water body will be below high tide by the year 2100 in the RCP8.5 scenario (but not the RCP4.5 scenario). Because the sand berm is built by wave action, it may migrate inland as sea level rises. Groundwater will rise in step with rising sea level, so the brackish water body may also migrate inland.

*Land Use Practices*

Factors that exacerbate flooding and erosion in the Makeāhua watershed are threats that will increase the delivery of sediment to Pelekane Bay. From this perspective, fire, drought, and overgrazing are threats. Changes to vegetation cover or composition may make the watershed more (or less) susceptible to fire or erosion. The incidence of wildfires in Hawaiʻi has increased over the past century, in step with increases in population (Trauernicht et al. 2015). As discussed previously, a variety of watershed management measures have been implemented for the degraded Pelekane watershed. While these efforts have likely reduced sediment loads, the 2015 fire and subsequent flood, which delivered large amounts of sediment to the bay, illustrates that past efforts were not fully sufficient. Past efforts can be undone by drought, fire, and a lack of maintenance. There will be an ongoing need for maintenance of fencing and irrigation systems, [18] clearing of sediment detention structures, terrestrial and marine monitoring, and community education. Financial and organizational resources for these activities will be difficult to sustain over time.

Cattle generally increase runoff, erosion, and sediment yield (Trimble and Mendel 1995). Overgrazing reduces vegetation cover; rotational grazing is likely to be less harmful. Sustained grazing can alter composition of plant communities; trampling compacts soil, promoting runoff. Feral goats have similar effects (Chynoweth et al. 2013). Trampling of stream banks by cattle is a problem in the Waiulaula watershed, which is immediately south of Pelekane watershed. In the Waiulaula watershed, experts have recommended exclusion fences to keep cattle and goats out of the delicate riparian zone (Sustainable Resources Group International Inc. 2014). The Waiulaula watershed contains streams that flow for months at a time, attracting thirsty animals without access to watering troughs. Riparian fences may be less important in the Pelekane watershed because streams do not flow for months at a time.

According to the South Kohala Community Development Plan, the population of the South Kohala district is expected to nearly double between 2000 and 2020 (County of Hawaiʻi 2008). The portion of Pelekane watershed that is upslope of the highway but within about 3–4 km (2–2.5 miles) of the

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[18] Irrigation infrastructure supports improved grazing methods and fire suppression.

shore is designated for urban expansion[19], medium-density urban, and industrial uses, according to the county's Land Use Planning Allocation Guide (County of Hawaiʻi 2008). Further development of this area is probable and poses potential threats in terms of erosion, runoff generation, and polluted runoff. Although mitigation measures can be expected to reduce adverse impacts of new development, there is still reason for concern.

In anticipation of further growth, expansion of Kawaihae Harbor is planned, with the extension of one berth and construction of a new berth. Expansion will require new dredging and removal of the DLNR recreational boat mooring facility (Hawaiʻi Department of Transportation, Harbors Division. 2011). Expansion of land facilities is also planned for the coral flats but not in the area that is immediately adjacent to the park. The Harbor Master Plan gives no indication of plans to mitigate the contribution of the harbor to sedimentation in Pelekane Bay and further states that a channel connecting Pelekane Bay, and the deep draft harbor will not be cut through the coral flats.[20]

#### 4.1.2.7 Data Gaps and Research Recommendations

Several types of data would be useful in analyzing the link between terrestrial watershed processes and the condition of the marine ecosystem. Consistent documentation of flood occurrence would be useful, as would documentation of when the sand berm is breached and when the opening closes. A crest stage gage installed under the highway bridge would be an inexpensive method of documenting the maximum flood level on Makeāhua stream. In Pelekane Bay, periodic measurement of sediment thickness in consistent locations and bathymetry monitoring is needed. Monitoring of benthic invertebrates, fishes, and Pelekane Bay water quality are also worthwhile; these are discussed elsewhere in this report.

There are no observational data on sediment discharge from Makeāhua Stream. Despite efforts to estimate rates of hillslope erosion using models, the sediment budget of Pelekane watershed is uncharacterized. The components of the sediment budget are hillslope erosion by water, erosion by wind, channel and gully erosion, sediment storage, and sediment transported to the ocean. Also uncharacterized is the increase in erosion rates due to human activities since pre-contact times and the rate with which sediment is flushed from Pelekane Bay.

Some of the aforementioned data gaps are being filled by a U.S. Geological Survey investigation of the geomorphology of Pelekane Watershed. Components of this study include mapping of erosive processes and debris flow deposits, mapping the pre-historic edge of the forest, measurement of erosion rates, dust monitoring, and measuring how infiltration rates are affected by animal exclusion. Publication of results is expected in 2020 (C. Cerovski-Darriau, personal communication, 2019).

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[19] "Medium-density urban" is a residential designation; "urban expansion" is a yet-undetermined mix of residential, commercial, industrial, and open designations.

[20] The proposed connecting channel is discussed in the next section.

Groundwater has not been measured in the park, and trends in water level or salinity have not been measured.

Beaches are dynamic, and retreat of the Pelekane Beach storm berm (highest topographic point) should be tracked. Documentation of flood events is also recommended. This could be accomplished by mapping the highest debris lines resulting from significant occurrences of high surf, extreme tides, and tsunami.

Three options for mitigating Pelekane Bay sedimentation have been considered in the past: (1) dredging a channel through the coral flat to connect Pelekane Bay and the Kawaihae deep draft harbor, (2) dredging Pelekane Bay, and (3) building a sediment detention basin on Makeāhua Stream above the highway. It was hoped that the first option would remove sediment from Pelekane Bay. A modeling study showed that while wind setup would move water and sediment from Pelekane Bay towards the harbor, the channel would frequently be clogged by sediment, necessitating frequent dredging (Li at al. 2009). A feasibility study would be needed to evaluate the remaining two options (dredging and sediment detention basin; C. Fletcher, personal communication, 2017).

Over the next 20–100 years, the bathymetry of Pelekane Bay and the geography of the park's shoreline will be affected by rising sea level, coastal subsidence, sedimentation, shoreline erosion, and migration of the sand berm. We recommend a holistic study that predicts the combined impact of these processes.

#### 4.1.2.8 Sources of Expertise

- C. Cerovski-Darriau, U.S. Geological Survey (Menlo Park)
- C. Fletcher, University of Hawaiʻi at Mānoa
- D. Kawaiaea, National Park Service
- J. Merkel, The Kohala Center

## 4.2 Terrestrial Ecosystem Integrity

Anthropogenic activities have degraded or completely altered coastal and lowland ecosystems throughout the state of Hawaiʻi. Before western contact, Hawaiian agriculture was predominant in the uplands, with rain-fed dryland agriculture well-developed in west Hawaiʻi (Ladefoged et al. 2009, Lincoln and Ladefoged 2014). Main crops were sweet potato, dryland taro, yams, banana, sugar cane, and breadfruit (Horrocks and Rechtman 2009, Ladefoged et al. 2009, Lincoln and Ladefoged 2014). Many of these rain-fed systems were abandoned after western contact (Ladefoged et al. 2009). The arrival of westerners led to new types of land use, ultimately including ranching, housing, and other urban developments. The introduction of many invasive species, particularly ungulates, was highly detrimental to the dry forest landscape (Cuddihy and Stone 1990). In addition, invasive grasses have completely altered the disturbance regime, leading to a greater incidence of fire than during pre-human times (Blackmore and Vitousek 2000, Cabin et al. 2002). These ecosystem disturbances greatly affected native bird and insect species. Waterbirds are the only native birds remaining in Hawaiʻi's coastal and lowland ecosystems, and these endangered species are seriously threatened by predatory and competing invasive species, land and water use patterns, pollution, and habitat loss. Similarly, the native mammals, Hawaiian hoary bat and Hawaiian monk seal, are threatened by anthropogenic activities and alterations to their ecosystems.

### ***4.2.1 Terrestrial Plant Communities***

*By Rebecca Ostertag, University of Hawaiʻi at Hilo and Pamela Scheffler, Hawaiʻi Community College*

Pili (grass) restoration near both heiau, north of the Visitor Center, in 2011 (NPS photo, A. Johnson).

#### 4.2.1.1 Condition Summary

The condition of vegetation resources at Puʻukoholā Heiau NHS warrants significant concern because there are few native and Polynesian species. The condition is stable or declining and consists predominantly of non-native species with some plantings and maintenance of native and Polynesian species. The condition assessment is made with a moderate degree of confidence, although the trend is made with low confidence because growth and survival of most native and Polynesian plant outplants are not being monitored and may be short-lived if not continually managed.

#### 4.2.1.2 Description

Little is known about the vegetation before human contact. The earliest reports on the vegetation of this area describe it as treeless landscape, dominated by native pili grass (*Heteropogon contortus*) which was used extensively by the Hawaiians as thatch for housing. While pili grasslands were present, their extent in the area before human settlement is unknown. Hawaiians intentionally practiced burning in many areas to encourage pili seedling establishment, resprouting, and production of new leaves (Cuddihy and Stone 1990). Trees and shrubs were also part of the landscape in some capacity; early land award documents indicate the presence of native trees and useful Polynesian introductions such as niu (coconut; *Cocos nucifera*), hala (screwpine; *Pandanus tectorius*), milo, kou (*Cordia subcordata*) and loulu (palm; *Pritchardia affinis*) growing in this area (Pratt 1998).

In addition, Pratt and Abbott (1996) suggest that wiliwili (*Erythrina sandwicensis*), ‘a‘ali‘i (hopbush; *Dodonaea viscosa*), and ‘ākia (false ohelo; *Wikstroemia* sp.) as well as hala and loulu (*Pritchardia* sp.) were probably found here at the time of contact. They also suggest that ma‘o hau hele (*Hibiscus brackenridgei*), a yellow hibiscus that is the state flower, might also have been in the area.

The current vegetation of Pu‘ukoholā Heiau NHS is predominantly nonnative, with buffelgrass (*Cenchrus ciliaris*) and kiawe (*Prosopis pallida*) dominating the landscape, except in areas where native and Polynesian introduced species have been planted (Figure 19). Pratt and Abbott (1996) denoted four plant associations: dry scrub grassland, closed kiawe forest, a nonnative-dominated halophytic community near a brackish pond, and a disturbed roadside community. This study also noted a narrow strip of native vegetation along the coastal strand and native plantings in the visitor area (Pratt and Abbott 1996). Cogan et al. (2011) classified the Pu‘ukoholā Heiau NHS vegetation into seven vegetation map classes, five of which were dominated by introduced species (Table 3). Overall, 98–99% of the vegetated area of Pu‘ukoholā Heiau NHS consisted of non-native dominated vegetation classes with the most extensive class being the buffelgrass map class at 73% of the vegetated area.

**Table 3.** Summary statistics for the Pu‘ukoholā Heiau NHS Vegetation Inventory Mapping Project. Adapted from Cogan et al. (2011).

| Vegetation Classes within Pu‘ukoholā Heiau NHS | Dominant Species | Acres | Hectares | % of Acres |
|---|---|---|---|---|
| Milo / Sparse Understory | Native/ Polynesian | 1.2 | 0.5 | 1.8% |
| Coconut Palm Strand | Native/ Polynesian | 0.2 | 0.1 | 0.3% |
| **Total Native/Polynesian Dominant** | **–** | **1.4** | **0.6** | **2.2%** |
| Buffel Grass | Non-native | 47.9 | 19.4 | 73.8% |
| Kiawe Coastal Dry Woodland | Non-native | 14.5 | 5.9 | 22.3% |
| Lawn Grass | Non-native | 0.6 | 0.2 | 0.9% |
| Koa Haole Lowland Dry Shrubland | Non-native | 0.5 | 0.2 | 0.8% |
| Planted Pili Mixed Grassland | Non-native | 0.5 | 0.2 | 0.8% |
| **Total Non-native Dominant** | **–** | **64** | **25.9** | **98.6%** |
| **Total Vegetated** | **–** | **64.9** | **26.9** | **100.0%** |

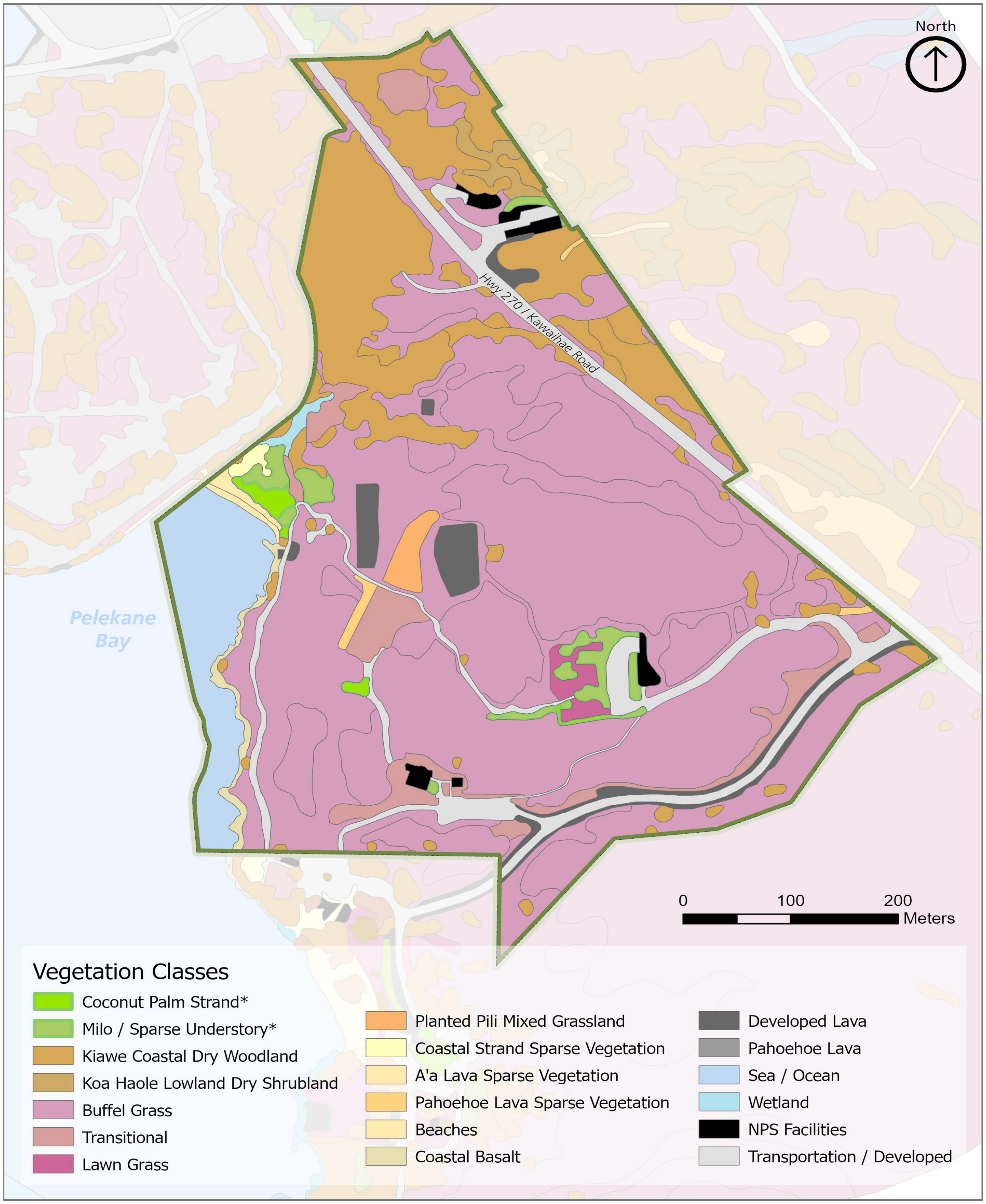

**Figure 19.** Distribution of vegetation classes at Puʻukohola Heiau National Historic Site. Data and nomenclature come from Cogan et al. (2011). The two vegetation classes dominated by native/Polynesian introduced species (Coconut Palm Woodland and Milo/Sparse Understory Woodland) are denoted by an asterisk (*) and are shown in green on the map.

*Definitions of Species' Origins*

For vegetation, we grouped species into two classes:

1. Native and Polynesian introduced:
    a. **Native** species refer to any species that colonized the Hawaiian Islands before people arrived. Native species can be endemic (geographically constrained to Hawaiʻi) or indigenous (found in Hawaiʻi and elsewhere).
    b. **Polynesian introduced** species are those that arrived with the early Hawaiian settlers and thus have been on the landscape for > 1000 years.
2. Nonnative:
    a. **Nonnative** species are those that made it to Hawaiʻi after Western contact.

We followed Wagner et al. (1999) with updates from Wagner et al. (2012) in denoting a species as native or nonnative. The majority of nonnative species do not spread at uncontrollable rates or have devastating impacts. But other nonnative species do have negative effects on native species, and are called **invasive**, which we define here as any naturalized nonnative plant that is included in the Hawaiʻi State Noxious Weed List (http://plants.usda.gov/java/noxious?rptType=State&statefips=15) and/or rated as "High Risk" by the Hawaiʻi Weed Risk Assessment (Daehler et al. 2004, https://plantpono.org). The Hawaiʻi Weed Risk Assessment is a screening tool, and is by far a more comprehensive list, with > 1700 plants screened to date (https://sites.google.com/site/weedriskassessment/home). It consists of a series of 49 questions that are answered and scored for each species; species are considered a likely pest if the score is > 6 (Daehler et al. 2004). Nevertheless, not all invasive plants have been evaluated by the Hawaiʻi Weed Risk Assessment. The Hawaiʻi State Noxious Weed List represents an alternative list, with a more agricultural focus, in which species are chosen by experts. Among those found in the park are koa haole, castor bean (*Ricinus communis*), fountain grass, puncture vine (*Tribulus terrestris*), Sacramento bur *(Triumfetta semitriloba*), buffel grass, and kiawe.

Given the extensive habitat alteration in lowland areas in Hawaiʻi, returning the vegetation to an all native state is not considered feasible. Rather, acceptance of a hybrid ecosystem (Cordell et al. 2016), a mix of native and nonnative species (particularly those of cultural importance and only those which are considered non-invasive) is the suggested reference condition and similar to what was probably in existence in 1790. Below we simplify the vegetation into the three main descriptors that can be used consistently among west Hawaiʻi parks, based on elevation and hydrology.

*Upland Vegetation*

The two dominant upland vegetation types are those that contain buffelgrass (Semi-natural Herbaceous Vegetation) and kiawe (Dry Semi-natural Woodland; Table 3) with patches of koa haole (*Leucaena lucocephala*) near the Homestead site (Pratt 1998, Cogan et al. 2011). The native shrub species ʻilima (*Sida fallax*) and ʻuhaloa (*Waltheria indica*) are found scattered throughout the park, and pili was found localized near the heiau (Pratt and Abbott 1996). The rare native pololei (whiskfern; *Ophioglossum polyphyllum*), was found in the area between the heiau and the highway in very small numbers (Pratt and Abbott 1996) and has not been relocated during annual surveys from 2015–2023 (Wasser personal communication). The majority of the park is upland vegetation.

*Coastal Vegetation*
According to Pratt and Abbott (1996) 12 of the 20 native plants in the park were naturally occurring along the coastline. Common native coastal species include naupaka kahakai (*Scaevola taccada*), milo, pōhuehue (beach morning glory; *Ipomoea pes-caprae*), and ʻākulikuli (sea purslane; *Sesuvium portulacastrum*). Kīpukai (*Heliotropium curassavicum*) and paʻuohiʻiaka (*Jacquemontia sandwicensis*) are less common in the coastal area and more vulnerable to damage. Hala found here was likely planted but is culturally appropriate for the area (Pratt and Abbott 1996). The coastal strand of Puʻukoholā Heiau NHS is the most intact system in the park (Pratt 1998). According to Cogan et al. (2011), the "coastal strand sparse vegetation" class was only mapped in adjacent areas outside NPS lands. Some of the native plants mentioned above were common species within the coconut palm and milo vegetation classes which made up approximately 2% of the vegetated area of the Park.

*Wetland Vegetation*
Nonnative pickleweed (*Batis maritima*) is found at the wetland associated with the brackish water body (Pratt 1998). No other species were reported in the wetland.

#### 4.2.1.3 Data, Indicators and Methods

We evaluate the following indicators in this report: species richness (number of species), species composition (presence/absence), and structure (percent cover, presence/absence of a canopy).

There has been little published on the vegetation at Puʻukoholā Heiau NHS, most likely due to the small size of the park, the homogeneity of the landscape, and the focus on the heiau itself. Four documents contain vegetation data, but for reasons explained below, they are not directly comparable.

Macneil and Hemmes (1977) study is based on numerous field trips during the dry season of May 1975 and the wet season of March 1976. A 31 ha (77 ac) area was divided into four sections and the entire area was surveyed on foot. To monitor roadside plants that could be introduced into the park, an adjacent area was set up with 19 transects (15 m [16 yd] long), spaced at 100 m (109 yd) intervals between State Highway 270 and Spencer Beach Park County Road. Relative abundance was measured using 1 $m^2$ quadrats (1.2 $yd^2$; with 100 marked points) every 2 m (2.2 yd) along the transect line. Pratt and Abbott (1996) report on three park visits between 1992 and 1994. They conducted surveys on foot to create a vascular plant checklist. They searched park trails as well as areas around the heiau and visitor center, the old road to Spencer Beach Park, the brackish water body and stream area, and the John Young house site. An abundance estimate was made for each species (abundant; common, numerous and widespread; occasional, scattered in many localities in the Park; uncommon, infrequent, few plants scattered or localized; rare, one or very few plants seen; or localized).

In contrast to the other two studies that surveyed the whole area, Cogan et al. (2011) subsampled the area using plots. They made a vegetation map from satellite imagery and ground-truthed plots (Cogan et al. 2011). Vegetation mapping included Puʻukoholā Heiau NHS, Spencer County Park, and a 0.5 km (0.3 mi) radius around Puʻukoholā Heiau NHS. The purpose of the plot sampling was to sample replicate plots to represent the landscape variation within each vegetation association. Circular plots (400 $m^2$ [478 $yd^2$]) were used, and cover was estimated into 12 different quantitative classes. The cover data were used to designate the vegetation associations, but the raw cover data were not reported (DataStore - Assemblage - (Code: 2233470) (nps.gov)).

After an August 2015 fire that burned 26 ha (64 ac; 74% of the park), 10 transects of 25 m (27 yd) length were set up in three areas of the park, all within the upland vegetation type (Ainsworth and Wasser 2016). These transects were read at 6 and 12 months post-fire. The point-intercept method was used to estimate cover of each species, and for pili grass, 1 $m^2$ (1.2 $yd^2$) quadrats were placed along the transects to estimate cover, seedling density, and frequency (presence/absence).

Calculations made in this report are frequency (# of plots where a species was detected divided by total number of plots) for both the Macneil and Hemmes (1977) and Cogan et al. (2011) references, and an average of percent cover values for Macneil and Hemmes (1977).

There are difficulties in comparing these four surveys to estimate change. Increases need to be interpreted with caution as these species, especially herbaceous ones, can have temporal fluctuations in presence or abundance, and in between studies, some plantings occurred. The relative abundance numbers, available in Macneil and Hemmes (1977), although quantitative, are for areas outside the park. The abundance estimates in the Pratt and Abbott (1996) survey are subjective categories, and the cover data in the Cogan et al. (2011) report is not comparable to abundance. In addition, the Cogan et al. (2011) and Ainsworth and Wasser (2016) studies did not sample the entire park, so it is difficult to compare to surveys that included more area. These two studies were not focused on estimating total species richness or abundance. Rather, Cogan et al. (2011) defined vegetation associations, while Ainsworth and Wasser (2016) focused on quantifying vegetation response to fire, particularly for pili grass.

#### 4.2.1.4 Reference Condition

The reference condition for the vegetation community at Puʻukoholā Heiau NHS is one with a mixed diversity of plant species, in which the predominant cover is either native species or nonnative species that are culturally important Polynesian introductions. Native species would be those typical of predominantly very old flows in dry habitats and coastal strand forest (Lockwood and Lipman 1987, Lockwood et al. 1988, Trusdell et al. 2006). Culturally important nonnative species would include those mentioned in Hawaiian legends or medicines (Table 4). The conditions referenced here imply a time period of use by Native Hawaiians around the time of contact with European settlers (late 1790s). Species listed in the table are a synthesis from species lists present in Pratt 1998 and Cogan et al. 2011.

**Table 4.** Representative native and Polynesian introduced species that can be used to evaluate the reference conditions (Pratt 1998, Cogan et al. 2011).

| **Group** | **Species Name** | **Hawaiian Name** | **English Name** | **Family** |
|---|---|---|---|---|
| Native | *Cordia subcordata* | Kou | – | Boraginaceae |
| Native | *Dodonaea viscosa* | ‘A‘ali‘i | Hopbush | Sapindaceae |
| Native | *Erythrina sandwicensis* | Wiliwili | – | Fabaceae |
| Native | *Heteropogon contortus* | Pili | – | Poaceae |
| Native | *Pandanus tectorius* | Hala | Screwpine | Pandaceae |
| Native | *Pritchardia* sp. | Loulu | – | Arecaceae |
| Native | *Scaevola taccada* | Napauka kahakai | Beach cabbage, beach naupaka | Goodeniaceae |
| Native | *Sida fallax* | ‘Ilima | – | Malvaceae |
| Native | *Thespesia populnea* | Milo | Portia tree | Malvaceae |
| Native | *Waltheria indica* | ‘Uhaloa | – | Malvaceae |
| Native | *Wikstroemia* sp. | ‘Ākia | False ohelo | Thymelaeaceae |
| Polynesian | *Aleurites moluccana* | Kukui | Candlenut | Euphorbiaceae |
| Polynesian | *Cocos nucifera* | Niu | Coconut | Arecaeae |
| Polynesian | *Cordyline fruticosa* | Kī, Lā‘ī | Ti | Asparagaceae |
| Polynesian | *Morinda citrifolia* | Noni | Indian mulberry | Rubiaceae |

A second reference condition reflects the goal for vegetation management at Puʻukoholā Heiau NHS, which is to recreate the cultural landscape as it was in the 1790s, when King Kamehameha I built the large luakini war temple, keeping an unobstructed view of the archeological temple. This goal will be accomplished by keeping the area before the heiau in an "open, barren condition to conserve the earth colors and protect the dominance of the site when viewed from makai" (Harry et al. 1996 in Pratt 1998). Consequently, current vegetation conditions reflect the management goals of maintaining a minimal canopy in key areas (e.g., around heiau) and fostering culturally important species that are native/Polynesian-introduced where/when possible.

Other goals for the park are to increase pili grass cover. Daehler and Goergen (2005) experimentally showed at Puʻukoholā Heiau NHS that when competition from buffelgrass was reduced via burning, herbicide or hand pulling, pili grass can become dominant over a 3–4 year period. The park has planted hundreds of pili plugs (transplants) following fires in 2015 and 2020. Survivorship data were not quantified but as of 2023 these plantings are persisting (M. Wasser personal communication 9–22–23).

#### 4.2.1.5 Current Condition and Trend

*Species Richness and Species Composition*

The most intact native association is along the coastal strand, but native plantings near the heiau increase the number of native species in the park. The focal native associations in Puʻukoholā Heiau NHS have very few species due to land use patterns in the past that included great alterations of the lowland environments.

The number of species recorded in Puʻukoholā Heiau NHS has ranged from 52 (Macneil and Hemmes 1977) to 104 (Pratt and Abbott 1996). The second survey showed increases in the numbers of both native and nonnative species. However, five native and 11 nonnative species that were found in the first study were not found in the second study (Pratt and Abbott 1996). Changes in species composition need to be interpreted with caution as these species, especially herbaceous ones, can have temporal fluctuations in presence or abundance, and in between the two studies, some plantings occurred.

The Macneil and Hemmes (1977) study, recorded 52 vascular plant species, of which 69% were nonnative, 2% were Polynesian introductions, and 29% were native (Macneil and Hemmes 1977). Pratt and Abbott (1996) found 104 species, of which 67% were nonnative, 13% Polynesian introductions, and 20% native.

Only two of the vegetation classes identified by Cogan et al. (2011), coconut palm woodland and milo/sparse understory woodland, are dominated by native/Polynesian species. Together these vegetation classes covered ~2% of the lands within Puʻukoholā Heiau NHS (Table 3), primarily surrounding the visitor center and immediately southeast of the brackish water body (Figure 19). It is unknown at this time how much area of the different vegetation classes burned in the 2015 fire will transition into different associations.

*Structure: Vegetation Cover and Frequency*

The plant associations at Puʻukoholā Heiau NHS were designated based on their percent cover (Cogan et al. 2011). The four woodlands (Table 3) are described as open stands with 25–60% tree canopy cover or values that exceed shrub, dwarf-shrub, herb, and non-vascular plant cover (*Cocos nucifera* Strand Woodland, *Thespesia populnea* Sparse Understory Woodland, *Prosopis pallida* Coastal Dry semi-natural Woodland, and *Leucaena leucocephala* Lowland Dry Semi-natural Shrubland.). In the two herbaceous associations, herbs usually form > 25% cover or exceed shrub, dwarf-shrub, herb, and non-vascular plant cover. The most frequent (highest occurrence across the landscape) vegetation associations are dominated by buffelgrass and kiawe (Table 3).

The other cover and frequency data reported are from two sources. Macneil and Hemmes (1977) presented cover from the adjacent roadside community. They report that ʻilima was found in 3 of the 120 quadrats sampled, so that across all transects there was an average of 0.09% per quadrat and a frequency of 2.5% (Macneil and Hemmes 1977). After the 2015 fire, 11 species were encountered along the 10 transects at 6 and 12 months post-fire (Ainsworth and Wasser 2016). The invasive buffel grass had the greatest cover (40–50%), while native pili grass had 2–8% cover after the fire. All other species on the transects, including two natives, ʻuhaloa and Pōhinahina (*Vitex rotundifolia*), had less than 5% cover. Cover decreased between the 6 and 12 month samplings, probably due to a dry period. Pili grass frequency (cover) in quadrats was 60% at 6 months and 45% at 12 months, and its frequency decreased from 40% to 4% over the same period (Ainsworth and Wasser 2016).

*Conclusions*

Because Puʻukoholā Heiau NHS has few native and Polynesian species, its vegetation condition is considered poor (Table 5). Management of Puʻukoholā Heiau NHS has included limited planting of native and Polynesian species, justifying an assessment that the vegetation trend may be stable or declining, depending on the outcome of the outplantings.

**Table 5.** Summary of the vegetative resource conditions of Puʻukoholā Heiau NHS based on indicators described in this report.

| **Indicator/Measure** | **Description of the Indicator** | **General Contribution of the Indicator to the Overall Resource Condition** |
|---|---|---|
| Species richness | Number of species | The present-day species richness is likely higher than at any time in the past, due to the continued arrival of nonnative species into Hawaiʻi and some planting of Polynesian species. |
| Species composition (Presence/absence) | Presence of native and Polynesian species in relation to the total number of species | The coastal strand habitat has a higher percentage of native species than the upland and wetland habitats and is considered in the best overall condition among the three vegetation classes. However, a majority (67%) of the plant species documented within the park during the last survey (1992–94) were nonnative. The present composition of nonnative plants is expected to be higher with continued arrival of new introductions and unknown status of native plantings. |
| Structure (Percent cover and frequency) | Percent cover is a measure that accounts for how much space a species occupies and is thus an index of a species' competitiveness; a proxy for abundance; easier to measure in the field than counting all individuals; frequency is the number of plots a species is in across the landscape | There is some tree cover by the Polynesian species *Cocos nucifera,* and the native *Thespesia polpunea* and some native grass cover, but the majority of cover is nonnative; nonnative grasses and the tree *Prosopis* are the most frequent across the landscape. After a fire, there was measurable cover of three native species in the upland vegetation, suggesting that they can survive and resprout or seed after fire if not competing with non-native, fire adapted plants Overall, only ~2% of the land in the park is dominated or co-dominated by native/Polynesian introduced species. |
| Structure (Presence /absence of canopy) | Canopy cover indicates that an area is forest or woodland; under current management absence of canopy cover is desired, particularly around the heiau. | The canopy cover is higher than desired due to presence of nonnative *Prosopis pallida* Coastal Dry Semi-natural Woodland. |

#### 4.2.1.6 Threats and Stressors

Wildfire is a serious and recurring threat to the native vegetation at Puʻukoholā Heiau NHS, but may also be a tool in the maintenance of pili grass. In August 2015, a wildfire burned over 74% of the area of the park (Ainsworth and Wasser 2016). Natural fires are a relatively rare occurrence in Hawaiʻi (Cuddihy and Stone 1990), usually only ignited by lava flows. While native species have been shown to persist following fire (Ainsworth and Kauffman 2009), Hawaiian species have generally not evolved adaptations that lead to enhanced growth or survival in the presence of fire. However, the area surrounding the park has become dominated by invasive grasses, and the fire regime may increase with drier climatic conditions or continued human presence. While fire may be a tool used to enhance pili grass cover, its use must be balanced with the threat of spreading beyond intended borders and with encouraging growth of other invasive species. It is expected that wildfire will remain a threat to the vegetation at this NHS, and probably an increasingly important one, since the landscape beyond is dominated by invasive grasses that are likely to carry fire into the park boundaries. Other threats include ungulates which eat native plants and the possibility of new plant invaders that may outcompete natives.

#### 4.2.1.7 Data Gaps and Research Recommendations

A large data gap is vegetation monitoring. While culturally important Polynesian introduced and native species have been planted, there are no data on their survival, making it difficult to access the effectiveness of outplanting. Furthermore, monitoring is essential to determine if the park is meeting its management goal to increase pili grass cover. Such studies would be extremely valuable, especially because the balance between pili and invasive grass cover will also affect the fire threat. Lack of a reference system of undisturbed dryland habitat also means that it is difficult to decide on appropriate level of cover for the native species. As with other places in Hawaiʻi, Puʻukoholā Heiau NHS will likely be affected by climate change, drought, fire, and continued invasion by nonnative species. Fire will almost certainly favor grasses, but more research is needed to investigate woody native species that may resist fire better than other species in order to break the grass/fire cycle or procedures to increase the cover of pili over invasive grasses after burns. In addition, very little is known about individual species' responses to climate change although none of the species found here are considered highly vulnerable (Fortini et al. 2013).

#### 4.2.1.8 Sources of Expertise

- Alison Ainsworth, National Park Service, Pacific Islands Network

### *4.2.2 Birds*

*By Brian Hudgens, Institute for Wildlife Studies*

#### 4.2.2.1 Condition Summary

The condition of the bird community at Puʻukoholā Heiau NHS warrants moderate concern. Most of the upland species observed in the park are nonnative but there is a diversity of native shore birds, migratory birds, and three Hawaiian endemic species found within the park. Overall, half of the species reported in the park are native (including migratory species), and half nonnative. There are not sufficient data to determine a trend in bird community composition or abundance of native birds.

#### 4.2.2.2 Description

Birds play an important role in both Hawaiian cultural history and modern environmental education. ʻAhu ʻula, or Hawaiian feather capes, were worn as a symbol of high status. Presumably native birds also were formerly a key component of native ecosystems as pollinators, seed dispersers, and transporters of oceanic nutrients (seabirds). At present, most birds commonly encountered by birdwatchers visiting the park are nonnative passerines typical of lowland areas of West Coast Hawaiʻi Island. Most native species encountered are shorebirds, seabirds, or waterbirds (e.g., black-crowned night-heron) (Waddington 2005).

### 4.2.2.3 Data, Indicators and Methods

A general description of the avian community along the west coast of Hawaiʻi Island is provided by the National Audubon Society Christmas bird counts from the North Kona fly-routes centered 1.5 km (0.9 mi) east of the Moanuiahea radio facility on Hualālai.[21] All available data (1996–2001, 2006–2015) were downloaded from the National Audubon Society website (National Audubon Society 2016). Christmas bird counts tally the numbers of identified birds of different species within a circle 15 mi (24 km) in diameter. Because this area is much larger than Puʻukoholā Heiau NHS, we excluded rare birds from analyses as they may not be present in the park. Birds were considered to be rare if they occurred in fewer than seven of the 14 years of counts. Even considering only "common" birds, it would be expected that Christmas Bird counts would reflect a greater diversity in bird species than would be found in Puʻukoholā Heiau NHS, as 15 mi (24 km) is sufficient to go from shore to >1350 m (>4430 ft) elevation, spanning a number of different habitats. The condition at Puʻukoholā Heiau NHS is therefore assessed on two metrics that should be independent of differences in habitat diversity: 1) the proportion of native species among those encountered and 2) species diversity of native shorebirds. The use of these indicators does assume that volunteers participating in the Christmas Bird counts did not tend to favor areas with more native species.

Data on the abundance and species of birds utilizing Puʻukoholā Heiau NHS are sparse. The available data come from baseline surveys done in 1992 and 1993 (Morin 1996), and shorebird surveys conducted in 2003–2004 (summarized in Waddington 2005). Species lists are maintained by the NPS (NPSpecies 2020), which includes any birds ever seen in the park (Appendix A).

### 4.2.2.4 Reference Condition

A natural reference condition would be the avian community in the 1790s, reflecting the management emphasis at Puʻukoholā Heiau NHS to recreate the cultural landscape as it was when King Kamehameha I built the large luakini war temple. However, it is unknown what the avian community composition was in what is now Puʻukoholā Heiau NHS at the time of King Kamehameha I (Morin 1996). While it is quite likely that several now-extinct species, such as extinct flightless rails (*Porzana* spp.), large geese (e.g., *Goechen* spp.), and extinct or fossil species of the finch-billed drepanid genera (e.g., *Telespiza* spp., *Rhodacanthis* spp., *Chloridops* spp., *Loxioides* spp.) once inhabited the area, their presence or numbers in the late 18th to early 19th centuries cannot be confirmed (Morin 1996). Morin (1996) suggested that extant native birds historically present in the park included the "common" ʻapapane (*Himatione sanguinea*) and ʻamakihi (*Hemignathus virens*), pueo (Hawaiian short-eared owl; *Asio flammeus sandwichensis*) and ʻaukuʻu (black-crowned night

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[21] Image of survey circle is available at https://arcg.is/0XDnm1; Moanuahea Radio Facility is located at 3222 ft (982 m) in elevation (USGS 7.5' quadrangle, Kailua 1996) and is about 30 driving miles north of PHNHP, and about 6 miles up Hualālai mountain from the coastline. The summit of Hualālai is 8278 ft (2523 m).

heron; *Nycticorax nycticorax hoactli*). A more tenable reference point for Puʻukoholā Heiau NHS is the contemporary bird community along the West Hawaiʻi coast.

The avian community along the West Hawaiʻi coast is dominated by native wetland/shorebird species and nonnative terrestrial species. Overall, 44% of birds commonly encountered on Christmas bird counts were native, most of which were associated with water. Notable exceptions in upland habitats include the ʻio, or Hawaiian hawk, and amakihʻi, a honeycreeper. There were 10 native wetland and shorebirds commonly encountered on Christmas Bird Counts, including three species listed under the Endangered Species Act: nēnē (Hawaiian goose; *Branta sandvicensis*), aeʻo (Hawaiian stilt; *Himantopus mexicanus knudseni*), and ʻalae kea (Hawaiian coot; *Fulica americana alai*).

### 4.2.2.5 Current Condition and Trend

Morin (1996) found 16 species of birds, only two of which were native, during four surveys conducted from October 1992 to July 1993. She also lists pueo and ʻaukuʻu as being present in the park based on observations by park staff, raising the number of native species to four, or 22.2% of species known from the park. Shorebird surveys conducted from September 2003–May 2004 recorded only six species, four of which were native (67%), during 17 one-hour-long surveys (Waddington 2005). The NPS species checklist for the park lists 41 species of birds: 20 are native, 20 are nonnative, and one observation of a coot species (Appendix A). This is not statistically different from composition of the Christmas Bird Counts.

### 4.2.2.6 Threats and Stressors

Native birds face a number of threats. Habitat loss and degradation, particularly the lack of native trees and shrubs, probably contributed to the extinction and local extirpation of many endemic avian species that once roamed the xeric lowlands at and surrounding Puʻukoholā Heiau NHS (Morin 1996). Predation by nonnative mammals poses another threat. Mongooses were observed during three of the 17 shorebird surveys conducted in 2004–2005 (Waddington 2005). Morin (1996) also cited mongoose control in the park in 1993 as a factor enhancing nonnative grey francolin (*Francolinus pondicerianus*) reproduction. The potential for nonnative predators commonly found in the park, mongooses, feral cats and rats, to decimate native island bird populations has been well documented (Towns et al. 2006, Hays and Conant 2007, Medina et al. 2011, Biteman et al. 2010). Recent evidence of the potential threat posed by nonnative predators comes from nearby Kaloko-Honokōhau National Historical Park, where predator control has been associated with increased breeding success of aeʻo and ʻalae kea at the ʻAimakapā Fishpond (Hudgens et al. *in press*). Other biotic interactions, such as competition with nonnative birds and disease, may also be reducing utilization of the park by native species and impacting the potential for native species to return following restoration of the native vegetative community.

### 4.2.2.7 Data Gaps and Research Recommendations

Bird data for Puʻukoholā Heiau NHS are sparse and poorly replicated. The last formal survey of birds was conducted over 10 years ago. Ideally, regular, standardized surveys should take place that characterize both the breeding and migratory bird communities using the park. This could be accomplished with semi-annual surveys, with the timing of surveys matching peak breeding and migratory seasons. Repeated coverage of the park during surveys—for example, walking survey transects two or three days in a row—is recommended to allow detection probabilities to be estimated, and reduce the uncertainty that unencountered species are present in the park but overlooked by surveyors. Regular surveys would also allow some evaluation of whether or not vegetation restoration efforts have a positive influence on local native avian populations. However, interpretation of bird survey data would need to consider that most birds encountered within Puʻukoholā Heiau NHS spend only part of their lives within the park and will be heavily influenced by the condition of the surrounding landscape.

Historical records such as Winston Banko's compilation of native bird sightings with citations that go back to first western contacts may provide insight to look for original bird fauna for the park and vicinity.

### ***4.2.3 Native Mammals***

*By Brian Hudgens, Institute for Wildlife Studies*

#### 4.2.3.1 Condition Summary

The status of ʻilio-holo-i-ka-uaua (Hawaiian monk seal, *Neomonachus schauinslandi*) and ʻōpeʻapeʻa (Hawaiian hoary bat, *Lasiurus cinereus semotus*) at Puʻukoholā Heiau NHS warrants moderate concern, with insufficient data available to determine trends. The condition reflects concerns over the larger populations of both species throughout their range. This assessment is made with low confidence due to a lack of data on where individuals using the park spend the vast majority of their time, and lack of comparable recent and repeated formal surveys for ʻōpeʻapeʻa in other similar habitats on west Hawaiʻi, and lack of formal surveys for ʻilio-holo-i-ka-uaua within Puʻukoholā Heiau NHS.

#### 4.2.3.2 Description

The only two native mammals that can be seen on lands in Hawaiʻi, the ʻilio-holo-i-ka-uaua or Hawaiian monk seal (*Neomonachus schauinslandi*) and ʻōpeʻapeʻa or Hawaiian hoary bat (*Lasiurus cinereus semotus*), are both found at Puʻukoholā Heiau NHS.ʻIlio-holo-i-ka-uaua live two-thirds of their life at sea, primarily feeding on a variety of prey including fish, cephalopods, and crustaceans. They generally hunt in waters 18–91 m (60–300 ft) deep (NOAA 2016). The entire range of ʻilio-holo-i-ka-uaua is within U.S. waters. The majority of ʻilio-holo-i-ka-uaua live in six main breeding subpopulations in the Northwestern Hawaiian Islands, but breeding populations on Mokumanamana (Necker) Island, Nihoa Island, and the Main Hawaiian Islands comprise an increasingly large part of the total population (NOAA 2016).

ʻŌpeʻapeʻa is mostly a solitary, tree-roosting bat that ranges from sea level to nearly 4,270 m (14,000 ft) in elevation (Bonaccorso 2010). ʻŌpeʻapeʻa may fly distances exceeding 19 km (12 mi) to foraging grounds before returning to its original roost (Bonaccorso 2010, Bonaccorso et al. 2015). ʻŌpeʻapeʻa are particularly active from May through December, corresponding to the period when birthing, lactation and parental care for pups takes place. Little is known about where ʻōpeʻapeʻa roost or breed (Bonaccorso et al. 2015).

4.2.3.3 Data, Indicators and Methods

An indicator of how ʻilio-holo-i-ka-uaua respond to the Puʻukoholā Heiau NHS shoreline and adjacent waters is the correlation between ʻilio-holo-i-ka-uaua activity in the park and population trajectory on the Main Hawaiian Islands. The population trajectory for the Main Hawaiian Islands was summarized from stock assessments reported by National Oceanic and Atmospheric Administration (NOAA) Fisheries division (NOAA Hawaiian Monk Seal Stock Assessments 2006, 2007, 2008, 2010, 2011, 2012, 2013, 2014, 2015 available at: http://www.fisheries.noaa.gov/pr/sars/species.htm)

An indicator for ʻōpeʻapeʻa is consistency of use as foraging grounds, measured as detection rates during acoustical surveys. Fraser et al. (2007) conducted repeated surveys for ōpeʻapeʻa at Hawaiʻi Volcanoes NP, Kaloko-Honokōhau NHP, Puʻukoholā Heiau NHS, and Puʻuhonua o Hōnaunau NHP. Gorresen et al. (2013) conducted repeated acoustic surveys at 23 sites, including Puʻuhonua o Hōnaunau NHP over 5 years. They did not report separate occupancy or detection rate data for individual sites, but data were available from Puʻuhonua o Hōnaunau for 2007.

4.2.3.4 Reference Condition

The overall stock of 'ilio-holo-i-ka-uaua is showing signs of increase after decades of decline (T. Johanos, NOAA, personal communication, September 2019), and observed demographic rates of ʻilio-holo-i-ka-uaua in the Main Hawaiian Islands are consistent with a 6.5% annual growth rate (Baker et al. 2011). However, it should be cautioned that at this time only six individuals are believed to reside in the waters around Hawaiʻi Island (T. Mercer, NOAA, personal communication, June 2017).

ʻŌpeʻapeʻa detection rates at repeated survey points varied among the parks but were typically <5% (Table 6). The average occupancy rate for sites in 2007 was ~75% during June–October, when detection rates are highest (see Gorresen et al. 2013 Figure 5).

**Table 6.** ʻŌpeʻapeʻa detection rates in national parks on Hawaiʻi Island.

| Park | Stations | Surveys | Detections | Detection Rate |
|---|---|---|---|---|
| Hawaiʻi Volcanoes NP [A] | 12 | 41 | 11 | 0.02 |
| Puʻukoholā Heiau NHS [A] | 6 | 12 | 0 | 0.00 |
| Puʻuhonua o Hōnaunau NHP [A] | 4 | 11 | 10 | 0.23 |
| Kaloko-Honokōhau NHP 2007 [A] | 8 | 15 | 2 | 0.02 |
| Kaloko-Honokōhau NHP 2009 [B] | 1 | 5 | 5 | 1.00 |

[A] Fraser et al. 2007.

[B] Bonaccorso and Pinzari undated memo.

[C] Pinzari et al. 2014.

**Table 6 (continued).** ‘Ōpe‘ape‘a detection rates in national parks on Hawai‘i Island.

| Park | Stations | Surveys | Detections | Detection Rate |
|---|---|---|---|---|
| Kaloko-Honokōhau NHP 12 C | 2–4 | 7 | 21 | 0.17 |
| Kaloko-Honokōhau NHP 12 C | 1–2 | 5–7 | 25 | 0.96 |

A Fraser et al. 2007.

B Bonaccorso and Pinzari undated memo.

C Pinzari et al. 2014.

#### 4.2.3.5 Current Condition and Trend

There were 11 sightings of ‘ilio-holo-i-ka-uaua reported from Pu‘ukoholā Heiau NHS from 1987 through 2016, six of which occurred between 2008 and 2012 (Mercer 2017). No ‘ilio-holo-i-ka-uaua were observed during aerial surveys conducted by NOAA in 2000–2001 and 2008 (Mercer 2017).

‘Ōpe‘ape‘a were not detected in surveys at Pu‘ukoholā Heiau NHS (Jacobs 1994, Fraser et al. 2007; Table 6), though bats have been recorded at Spencer Beach (Fraser et al. 2007).

#### 4.2.3.6 Data Gaps and Research Recommendations

No formal ongoing monitoring for either species is currently being done within the park. The anecdotal nature of ‘ilio-holo-i-ka-uaua and small numbers of individuals known from the waters surrounding the Island of Hawai‘i make data from these observations particularly difficult from which to draw any meaningful conclusions. There is also a paucity of data on ‘ope‘ape‘a foraging habitat preferences and roosting areas on western Hawai‘i. Without this basic information about ‘ope‘ape‘a, it is not possible to determine if their relative scarcity in Pu‘ukoholā Heiau NHS is a reflection of the condition of the park, or is to be expected given its location and surrounding habitat. Likewise, information on where individual ‘ilio-holo-i-ka-uaua inhabiting the waters around the island of Hawai‘i spend their time is needed before conclusions can be drawn about activity levels at Pu‘ukoholā Heiau NHS.

### *4.2.4 Invasive Mammals*

*By Brian Hudgens, Institute for Wildlife Studies*

#### 4.2.4.1 Condition Summary

Unlike the other topics presented in this assessment, invasive mammals represent a threat rather than a resource to be protected and conserved. We treat invasive mammals here separately because they represent such a visible and pervasive component of the faunal community at Pu‘ukoholā Heiau NHS, and have significant impacts on both the ecological community and cultural resources within the park. Thus, the commonality of invasive mammals warrants significant concern. There is no trend data available on invasive mammal prevalence in the park.

### 4.2.4.2 Description

Nonnative vertebrates, particularly mammals, have had huge impacts on the Hawaiian landscape, depredating native fauna, decimating native vegetation, spreading invasive nonnative vegetation and facilitating erosion (Nogueira-Filho 2009, Chynoweth et al. 2013, Wehr et al. 2018). Because Hawaiian vegetation and faunal species evolved in the presence of only a single native terrestrial mammal, the ʻōpeʻapeʻa (Hawaiian hoary bat), invasive mammals have an especially high potential to transform Hawaiian landscapes. Predators such as rats (*Rattus exulans*, *R. norvegicus*, *R. rattus*), mongooses (*Herpestes javanicus*), and feral cats are widely implicated in declines of native birds and reptiles on islands (Towns et al. 2006, Hays and Conant 2007, Medina et al. 2011, Biteman et al. 2010a). Rodents are important factors driving native plant declines through seed predation (e.g., Shiels and Drake 2015). Ungulates and livestock may drive native plant declines through overgrazing, trampling, and creating favorable conditions for invasive nonnative plants (Chynoweth et al. 2013), and often also directly damage cultural resources such as the temple structures at Puʻukoholā Heiau NHS and transform the cultural and natural landscape by trampling and other forms of erosion-promoting ground disturbance (Yocom 1967).

The first nonnative mammals reaching Hawaiʻi were brought by Polynesian settlers 1000 years ago. Polynesian rats (*R. exulans*) are believed to have been brought with Polynesians as stowaways (Kirch 1982, Hess and Jacobi 2011). Pig skeletons were found in the earliest archaeological sites of the Hawaiian Islands (Kirch 1982), although pigs currently on the island may be mostly descended from European stock brought by Captain James Cook in 1778 (Stone and Anderson 1988). Other rodents were introduced by Europeans in the 1800s (Hess and Jacobi 2011). Mongooses were introduced to the Hawaiian Islands in 1883 in an attempt to control rodent populations in sugar fields (Hays and Conant 2006). Cattle were introduced to Hawaiʻi as a gift to Kamehameha I by Captain George Vancouver in 1793 (Maly and Wilcox 2000), and goats and sheep were introduced in the same period (Stone and Anderson 1988). Currently, feral pigs, cattle and sheep are found primarily in forested or higher elevation habitats and are rarely observed in the dry lowlands of the West Hawaiʻi coast. This section focuses only on the nonnative mammal species common to West Hawaiʻi coast lowlands and therefore likely to be an issue within Puʻukoholā Heiau NHS: rodents, mongooses, feral cats, and goats.

### 4.2.4.3 Data, Indicators and Methods

Ideally, invasive mammals would be absent from Puʻukoholā Heiau NHS. However, the small size of the park and continual influx of animals from neighboring lands means that park management could expend a large amount of resources trying to reduce the impact of nonnative mammals without eradicating or significantly lowering their densities. We used the density of nonnative terrestrial mammals in the lands surrounding Puʻukoholā Heiau NHS as a point of comparison to gauge the potential effectiveness of existing or future control efforts. We present as reference, condition ranges reported for indices of population abundance where such data are available from the Hawaiʻi Island. When data are available from multiple locations, we used the location that most closely matched the environmental conditions experienced at Puʻukoholā Heiau NHS as the reference condition. If data were not available from an area with similar environmental conditions, we used the average and range of available data. The best available data describing the abundance of invasive island predators (i.e., cats and mongooses) come from trap success per unit effort reported in control projects and from movement studies (Table 7). It should be noted that each of these indices is imperfectly correlated with population size or density: trap success depends on a number of factors including population abundance, density, and trap arrangement; effective population size depends on population abundance, social structure and levels of inbreeding, and annual take depends on population abundance, hunter effort, and animal behaviors.

There are little data on the abundance of nonnative animals inhabiting or using Puʻukoholā Heiau NHS. The best abundance estimate of a nonnative mammal in the park comes from mongoose observations noted during shorebird surveys conducted in 2004–2005 (Waddington 2005). Additional information was taken from qualitative assessments of species abundance reported in the NPS species list and observations reported by park personnel.

**Table 7.** Trap success of invasive mammals on Hawaiʻi Island. Effective population size = the number of individuals in a population that contribute offspring to the next generation. HAVO = Hawaiʻi Volcanoes National Park lowland sites.

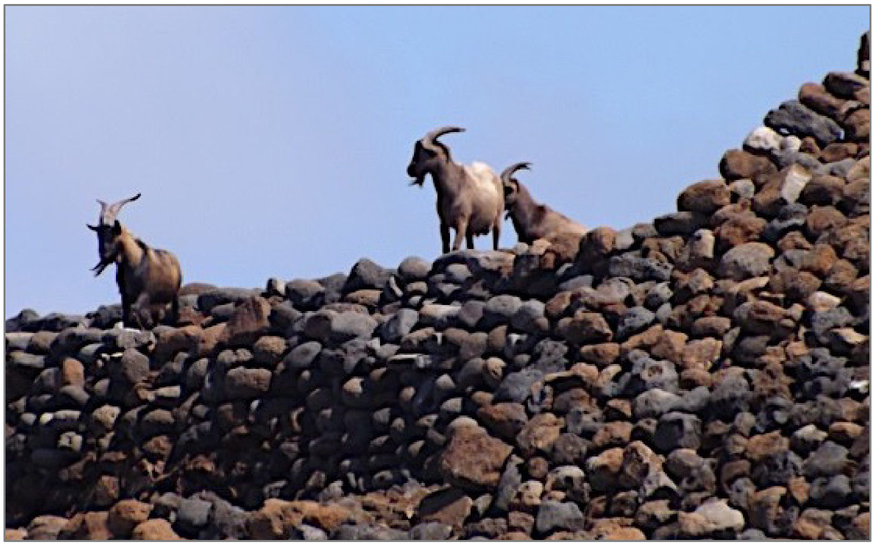
| Species | Location | Metric | Index | Citation |
|---|---|---|---|---|
| mongoose | HAVO | trap success | 0.02 captures/trap day | Hansen et al. 2008 |
| | Hāmākua District | trap success | 0.05 captures/trap day | Tomich 1969 |
| | Hilo | Density | 0.7–3.9 mongoose/ha | Pitt et al. 2015 |
| feral cat | HAVO | trap success | 0.02 captures/trap day | Hess et al. 2008 |
| | HAVO | Number | 24–25 cats | Hess et al. 2008 |
| Polynesian rats | HAVO | trap success | 0.024 captures/trap day | Scheffler et al. 2012 |
| black rats | HAVO | trap success | 0.021 captures/trap day | Scheffler et al. 2012 |
| Norwegian rats | HAVO | trap success | 0 captures in 6400 trap days | Scheffler et al. 2012 |
| mice | HAVO | trap success | 0.99 captures/100 trap days | Scheffler et al. 2012 |
| goats | Kawaihae watershed | Number | eradicated (0) | Kohalawatershed.org unpublished report |

#### 4.2.4.4 Reference Condition

Hansen et al. (2008, in Hess et al. 2008) report trap success for both mongooses and feral cats at two locations within Hawai‘i Volcanoes National Park (Hawai‘i Volcanoes). Hansen et al. (2008) used microsatellite data to estimate an effective breeding population size of 24–25 cats in the same study sites, although it is not clear how large of an area is represented by the genetic sampling compared to the effective trap area. Tomich (1969) reported trap success for mongooses in coastal areas of the Hāmākua District. In his study, initial trap success was up to ten times greater than reported by Hansen et al. in Hawai‘i Volcanoes or in higher elevations on Mauna Kea. However, Tomich reported that his higher elevation site had the highest density of mongooses, and trap success at his low elevation site (0.02–0.07 captures/trap-day) and long-term trap success over the entire site (0.05) was closer to that reported at Hawai‘i Volcanoes. Pitt et al. (2015) reported mongoose densities of 0.7–3.9 mongooses/ha at two sites near Hilo. Reference conditions are summarized in Table 7.

The best information on rodent population size comes from Scheffler et al. (2012) on a five-year trapping study in Hawai‘i Volcanoes (Table 7). Although Polynesian rats are reported to dominate lowland areas (Tomich 1981), in the lowland sites surveyed in Hawai‘i Volcanoes, Polynesian rats comprised 37–45% of the capture, black rats 34–62%, with mice (1–21%) and Norway rats poorly represented. Reproductive seasonality was not seen in any of the species, and it can be assumed that reproduction is occurring year-round. The Hawai‘i Volcanoes site most similar to Pu‘ukoholā Heiau NHS is Kamoamoa, ranging in elevation from 90–180 m amsl. At this site, black rats comprised nearly two-thirds of the capture, mice less than 1%, and the remainder of the capture was Polynesian rats.

Goat and pig population estimates for nearby areas are also lacking in the published literature. The nearest study is a 2015 unpublished draft report by the Hawai‘i DLNR. At the Nāapu‘u Conservation project, approximately 25 km (16 mi) south of Pu‘ukoholā Heiau NHS, they found pigs occurring as low as 762 m (2,730 ft), but they were most commonly found above 1067 m (3,500 ft), likely due to lower precipitation and dry vegetation in coastal areas. Goats were most commonly found in the low elevations below Malamalahoa Highway in the near-coastal habitat. In this same study, pig populations have been declining since 2000 when 200 were taken, while goat take has been increasing since 2004 to a maximum annual take of approximately 450 goats. Goats have been eradicated from 2,700 ha (6,600 ac) of the Kawaihae watershed east of the park by fencing and animal control. (



Goats on historic structures at Puʻukoholā Heiau NHS (NPS photo).

#### 4.2.4.5 Current Conditions and Trend

The species list notes several nonnative species occurring in the park (Appendix A). Most nonnative species in the park are considered common, including feral cats and feral goats. For example, herds of up to 30 feral goats are frequently seen in the park (B. Saldua, NPS personal communication, 2019; Figure 20.).

**Figure 20.** Goat herds at Puʻukoholā Heiau (NPS photo).

Waddington (2005) reported a total of four mongoose sightings were reported on three of 17 bird surveys. Each survey was approximately an hour long, yielding an observation rate of 0.23 mongoose observations/hr. This hourly observation rate is 5–10 times higher than reported daily trapping rates elsewhere on Hawaiʻi. Although observation rates are not directly comparable to trapping rates, the high frequency with which mongooses were observed suggest a relatively high abundance within the park.

### 4.2.4.6 Data Gaps and Research Recommendations

Formal monitoring and quantitative measures of abundance are lacking for all nonnative mammals. Such measures would provide guidance to the potential impact of and efforts required to reduce nonnative species in Puʻukoholā Heiau NHS. Given the impact of nonnative mammals on natural and cultural resources Puʻukoholā Heiau NHS, it generally does not make sense to trap animals without removing them. In some cases, tracking studies of telemetered animals may be useful to determine habitat use, home range size and dispersal patterns to inform where to focus removal efforts. Because telemetered animals can be tracked, they can more easily be removed at the end of the study. Carefully designed removal studies can be used to estimate abundance indices of nonnative mammals while reducing their overall population (Zippin 1958, Williams et al. 2002). Reduction or elimination of nonnative species often requires significant effort. Priority should go to those species that are likely to heavily impact cultural and vegetation resources and may be excluded from the park if eliminated (pigs and goats). Reduction of predators that have large effects on native fauna (rodents, cats and mongoose) will likely require ongoing efforts to counter immigration from surrounding lands.

## 4.3 Aquatic Ecosystem Integrity

Puʻukoholā Heiau NHS contains two ephemeral stream channels: the larger Makeāhua Gulch and the smaller Pōhaukole Gulch, which joins Makeāhua Gulch about 160 m (175 yd) inland from the shoreline (Figure 21). Frequently the mouth of the channel is blocked by a sand berm, creating an unnamed brackish waterbody that occupies the lower reaches of Makeāhua and Pōhaukole Gulches. This waterbody is the only one in the park (Raikow and Farahi 2013, Figure 22). Floods occasionally erode the sand berm so that Makeāhua Gulch is connected with Pelekane Bay; wave action eventually rebuilds the berm.

Classification of the brackish waterbody is complicated by the fact that it is sometimes connected with the ocean and occasionally fed by streamflow. At times it contains marine or estuarine fish and crustaceans (Hoover and Gold 2006, staff observations in 2015). These characteristics give the waterbody estuarine qualities. The waterbody is occassionally used by fishermen. Most of the time the waterbody is fed by brackish groundwater and not by streamflow or seawater, endowing it with some characteristics of an anchialine pool. It is possible that Pōhaukole Gulch once contained perennial or intermittent pools that no longer exist (Hoover and Gold 2006).

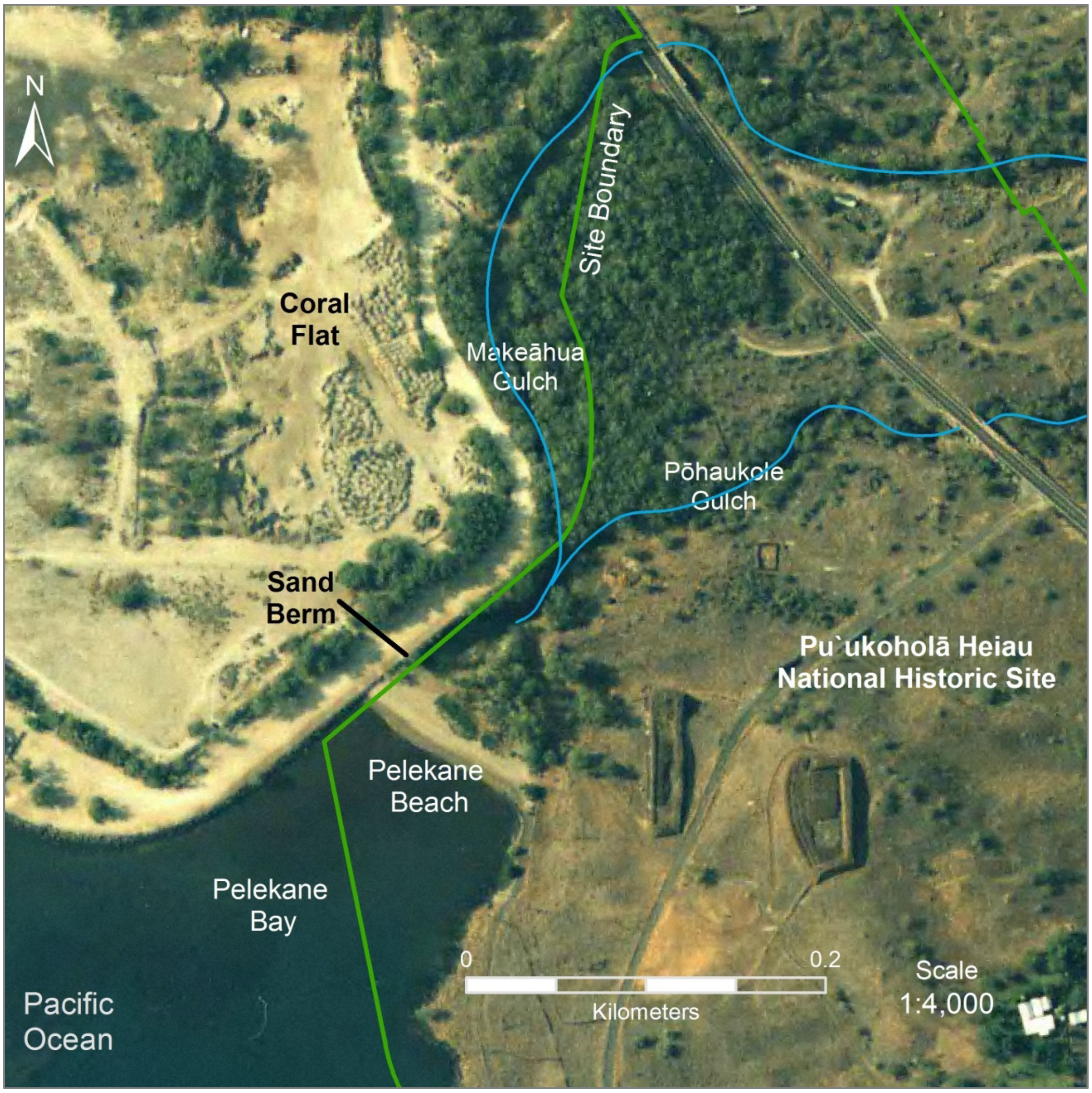


**Figure 21.** Hydrologic features of Puʻukoholā Heiau NHS.

**Figure 22.** The brackish waterbody (NPS I&M photo).

### *4.3.1 Water Quality of Inland Waters*

*By Jené Michaud, University of Hawai'i at Hilo*

#### 4.3.1.1 Condition Summary

The brackish waterbody at the mouth of Makeāhua Gulch merits moderate concern due to algal blooms, elevated nitrate concentrations and high turbidity. Confidence in this assessment is medium because it is unclear what constitutes acceptable water quality. Over the last decade, nutrients and turbidity have fluctuated but there is not a consistent trend. When Makeāhua Stream is flowing, nutrient and turbidity levels can be very high.

#### 4.3.1.2 Description

This section addresses water quality in the Makeāhua Stream (when flowing) and the stagnant brackish waterbody at its mouth. The hydrologic processes influencing water quality in this system are addressed in chapter 4.1.

#### 4.3.1.3 Data, Indicators and Methods

Suspended sediment concentration is an indicator for Makeāhua Stream when it is flowing. Other water quality indicators for the brackish waterbody and Makeāhua Stream (when flowing) are dissolved oxygen (DO), turbidity, nutrients and chlorophyll-*a*. These indicators address the cause (excess nutrients), result (elevated chlorophyll-*a* is a measure of certain algal blooms), and impact (low DO at the bottom of the water column) of eutrophication, which is an ecological threat in

Hawaiʻi and around the world.[22] Chlorophyll—along with nutrients and DO—is an indicator used in all major methods of assessing eutrophication (Ferreira et al. 2011). High turbidity has broad-reaching ecological effects and can result from an algal bloom in the water column, suspended sediments, or uncommon biological or chemical events. High turbidity is the most common cause of Clean Water Act (CWA) impairment of Hawaiian marine waters (HDOH 2014a). Low DO is widely recognized as stressful for aquatic organisms.

Since 2007, the NPS Inventory and Monitoring (I&M) Program has collected nutrient data and measurements of physical parameters on a quarterly basis at three sites in the brackish waterbody using protocols described in Jones et al. (2011). At each sampling site, three samples were collected just below the surface, filtered in the field, preserved, and sent to the laboratory for analysis of nitrate+nitrite[23] (hereinafter simply "nitrate"), total dissolved nitrogen (TDN), and total dissolved phosphorus (TDP). Physical parameters (temperature, salinity, pH, turbidity, and chlorophyll *a*) were measured just below the water surface with a sonde. Data are published in a database (Pacific Island Network 2015) and summarized in reports (Raikow and Farahi 2013, Raikow and Farahi 2016). In this NRCA, data collected between 2008 and 2014 are summarized and compared to reference values. Data collected from 2015 to the present were not yet available for analysis. While there is one sampling date in 2007, those data were excluded because different sampling methods were used.

#### 4.3.1.4 Reference Conditions

Water quality reference values (Table 8 and Table 9) were selected as benchmarks for comparison with monitoring data. Although historic data are not available to serve as a reference condition, a benchmark standard can be used to assess general ecosystem health. Here, benchmarks are based on aquatic ecosystem standards set by the State of Hawai`i under the Clean Water Act (CWA) (HAR §11–54). Reference conditions for the flowing waters of Makeāhua Stream are based on standards applicable to Hawaiian streams during the wintertime. HAR §11–54 contains several sets of stream standards applicable under different conditions (e.g., average and extreme conditions). The standards selected for this NRCA are those that are most appropriate to flood conditions, namely the concentrations that should not be exceeded more than two percent of the time. HAR §11–54 does not establish nutrient and turbidity standards for brackish standing waters, although it does establish standards for estuaries, marine waters, and freshwater streams. Most of the time the brackish waterbody is more like an estuary than a freshwater stream or a marine embayment. Reference conditions for the brackish waterbody are therefore based estuarine standards for average conditions.[24] This choice was made for convenience and does not imply that the brackish waterbody

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[22] Algal blooms can be caused by phytoplankton or benthic macroalgae. Chlorophyll measurements of the water column can detect the presence of phytoplankton but not benthic macroalgae.

[23] Nitrite concentrations are usually much lower than nitrate concentrations.

[24] While the numbers in Tables 8 and 9 are derived from CWA criteria, this NRCA is not determining if CWA standards have been met. The Hawaiʻi Department of Health (HDOH) determines attainment or non-attainment by taking the geometric mean of at least ten measurements taken over two years (HDOH 2014). The HDOH method of data analysis, which is problematic for nutrient values below detection or "zero" chlorophyll or turbidity results, was not used in this NRCA.

is a normal estuary, that it is subject to CWA standards for estuaries, or that water quality is necessarily degraded if reference values are exceeded. Reference conditions were not set for salinity, temperature, and pH because CWA standards are too imprecise to be usable.[25] Temperature, salinity, and pH are nevertheless important environmental variables and monitoring results are reviewed.

**Table 8.** Nutrients and suspended sediments in Makeāhua floodwaters. Values for December 5, 2007 are the average of nine samples collected under the highway bridge and autosampler. However, only five samples were analyzed for suspended sediments and only four samples were analyzed for total dissolved nitrogen. Values for May 2, 2011 are the average of three samples collected between the highway bridge and the ocean. "NA" = measurement not made, "none" = there is no water quality standard for this parameter.

| Parameter | Unit | December 2, 2007 (autosampler) [A] | May 2, 2011 (I&M) | CWA-based Reference Value |
|---|---|---|---|---|
| Nitrate+Nitrite ($NO_3$ + $NO_2$) | mg-N/l | 0.687 | 1.091 | 0.3 |
| Ammonium | mg-N/l | 0.199 | NA | none |
| Total Dissolved Nitrogen | mg/l | 1.317 | 3.03 | none |
| Total Nitrogen (dissolved + particulate) | – | NA | NA | 0.8 |
| Total Dissolved Phosphorus | mg/l | NA | 0.069 | none |
| Total Phosphorus (dissolved + particulate) | mg-l | 2.007 | NA | 0.15 |
| Phosphate | mg-P/l | 0.030 | NA | none |
| Total Suspended Solids | mg/l | 4,060 | NA | 80 |
| Turbidity | NTU | NA | 793 | 25 |

[A] Unpublished data from J. Michaud.

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[25] The CWA standards for Hawaiian estuaries specify that temperature shall not vary by more than 1 degree Celsius from ambient conditions, pH shall not vary more than 0.5 pH units from ambient conditions, and salinity shall not vary by more than 10% from ambient conditions.

**Table 9.** Nutrients and physical parameters measured in the brackish waterbody and Makeāhua Stream (2008–2014). Values are the mean ± the standard deviation across dates. Means which exceed reference values are in bold type. See Table 8 for reference values applicable to flowing conditions. Data are from Pacific Island Network (2015), Raikow and Farahi (2013), and Raikow and Farahi (2016). NA = not applicable.

| Parameter | Unit | CWA-based Reference Value (stream not flowing) | Stream Is Not Flowing | Stream Is Flowing |
|---|---|---|---|---|
| Number of dates | NA | NA | 26 | 1 |
| Number of sites | NA | NA | 3 | 3 |
| Nitrate+Nitrite ($NO_3 + NO_2$) | mg-N/l | 0.008 | **0.097 [E]** ± 133 [A] | **1.091 [E]** |
| Total Dissolved Nitrogen (TDN) | mg/l | 0.20 [D] | **0.81 [E]** ± 0.63 | **3.03 [E]** |
| Total Dissolved Phosphorus (TDP) | mg/l | 0.025 [D] | **0.040 [E]** ± 0.031 [B] | 0.069 |
| Turbidity | NTU | 1.5 | **20.3 [E]** ± 22.9 | **793 [E]** |
| Dissolved Oxygen (DO) | % of saturation | 75 (values less than 75 indicate potentially degraded conditions) | 103 ± 45<br>39% of measurements were below 75 | 104 |
| chlorophyll *a* | µg/l | 2 | **74.3 [E]** ± 113.4 | 16 [C] |
| Salinity | ‰ | NA | 13.0 ± 9.7 | 7.7 |
| Temperature | C | NA | 28.5 ± 2.5 | 25.2 |
| pH | pH unit | NA | 7.94 ± 0.40 | 7.57 |

[A] Fifteen percent of $NO_3 + NO_2$ measurements were below the analytical detection limit of 0.001 µg-N/l. To calculate the mean and standard deviation, values less than the detection limit were set to 0.0005 µg-N/l.

[B] Twenty-four percent of TDP measurements were below the analytical detection limit of 0.015 mg/l. To calculate the mean and standard deviation, values less than the detection limit were set to 0.0075 mg/l.

[C] In Hawai'i, there are no chlorophyll standards for flowing streams.

[D] The water quality standards are written for unfiltered samples, but I&M samples were filtered before measurement.

[E] Means which exceed reference values are in bold type.

### 4.3.1.5 Current Condition and Trend

*Flowing Waters of Makeāhua Stream*

Water quality in Makeāhua Stream has been measured on two occasions when the stream was flowing vigorously. Nutrient concentrations and suspended sediment concentrations (or turbidity) were quite high (Table 8).

In May 2007, an autosampler was installed in Makeāhua Gulch under the highway bridge (unpublished data from J. Michaud). Triggered by rising streamflow, the autosampler took a series of water samples on December 5, 2007. The suspended sediment concentration in the first sample was extremely high (8,300 mg/l [same as PPM/parts per million]) and subsequent samples were in the range of 2,200 to 3,700 mg/l. Total phosphorus was particularly high, with observed values more than an order of magnitude larger than the reference value. Bioavailable phosphate was less than 2% of total phosphorus, however, indicating that particulate and organic forms of phosphorus dominate during flood conditions. The autosampler was removed in 2008 due to lack of funding and the flood in December 2007 was the only event sampled by it.

On May 2, 2011 the regularly-scheduled I&M sampling visit coincided with flood conditions. This is the only time (through 2014) that I&M measurements were made during streamflow conditions.[26] The nitrate concentration was more than three times the reference value, TDN was almost four times the reference value for the sum of dissolved plus particulate nitrogen, and turbidity was thirty times larger than the reference value. These results demonstrate that floodwaters derived from the upslope watershed deliver nutrients to the brackish waterbody and the ocean. Groundwater is also a source of nutrients.

When the stream was flowing vigorously, nutrient and turbidity levels were much worse than under stagnant conditions (Table 9). In comparison with stagnant conditions, flowing water was also slightly colder, less saline, more acidic, and contained less chlorophyll. Average oxygen concentrations were similar but low oxygen conditions were observed more often under stagnant conditions.

*Brackish Water Body*

From 2008–2014, the NPS made measurements in the brackish waterbody on 26 days when the stream was not flowing (Table 9). Under these stagnant conditions average nutrient concentrations exceeded reference values by a factor of twelve for nitrate, four for TDN and two for TDP. Average turbidity exceeded the reference value by one order of magnitude and average chlorophyll concentration exceeded the reference value by 1.5 orders of magnitude. Sixty-one percent of dissolved oxygen measurements met the benchmark for adequate oxygen. Systematic trends in nutrient concentrations were not observed; instead, values fluctuated. High nitrate concentrations did not necessarily correspond with high concentrations of TDN or TDP, and high TDN concentrations did not necessarily correspond with high TDP concentrations. A suspected minor algal bloom was observed in 2009, following a period of slightly elevated nutrient concentrations (Raikow and Farahi 2013). A severe algal bloom was observed in the brackish waterbody in 2013, following a period of elevated TDN concentrations (Raikow and Farahi 2016). Elevated dissolved oxygen, pH, chlorophyll *a*, and turbidity were observed during the 2013 event.

On four dates, both filtered and unfiltered samples were collected so that nutrients in particulate form could be measured. It is likely that phytoplankton make up a significant proportion of the particulate nutrients. Data showed that 78% of nitrogen was in dissolved form and 22% was in particulate form. The corresponding values for phosphorus were 49% dissolved and 51% particulate. Inorganic phosphorus readily attaches to sediment, so the high percentage of the particulate form is not

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[26] Although flood events have not been documented systematically, it is known that other floods occurred 2003, 2004, 2010, and 2016.

surprising. The dissolved inorganic nutrients are the most important ones because they are much more bioavailable than particulate nutrients or organic nutrients. In addition, particulate nutrients can become sequestered in bottom sediments. Nutrient cycling, however, has the potential to transform less bioavailable forms into more bioavailable ones. Thus, it is necessary to consider all forms of nutrients (dissolved inorganic, dissolved organic, and particulate) in a holistic examination of nutrient sources, sinks, and biological interactions.

The persistence of high nutrients, high turbidity, algal blooms, and regular occurrences of low dissolved oxygen demonstrate the generally poor water quality in the brackish waterbody. This is expected given the unusual and stagnant nature of these waters and is not automatically a cause for concern. Casual observations have, however, identified several occurrences of fish kills during the last decade (D. Kawaiaea, personal communication, 2016). The reason for these events is not documented. Casual observations made when the stream is not flowing suggest that water quality is worse when the berm is intact than when there is an opening between the brackish waterbody and the sea (D. Kawaiaea, personal communication, 2016).

Prior to I&M sampling, the only known measurements in the brackish water body were obtained on June 30, 1998 (unpublished data from Wolff, reported in Hoover and Gold 2006; Table 10). The 1998 concentrations of nitrate, TDP, and chlorophyll *a* were lower than the means from 2008–2014, but the difference may not be statistically significant given the inherent variability from one sampling date to the next. Therefore, trends cannot be evaluated.

**Table 10.** Nutrient concentrations in the brackish waterbody on June 30, 1998. These unpublished data are from Wolff, reported in Hoover and Gold (2006). I&M data from Table 9 are provided for comparison. NA = measurement not made.

| Parameter | Unit | Single Measurement from 1998 | I&M (2008–2014) (mean ± SD) (26 dates) |
|---|---|---|---|
| Nitrate+Nitrate | mg-N/l | 0.0028<br>(unfiltered) | 0.097 ± 0.133<br>(filtered) |
| Ammonia | mg-N/l | 0.0036<br>(unfiltered) | NA |
| Total Nitrogen in suspended sediment | mg/l | 299 | NA |
| Particulate Phosphorus | mg/l | 0.053 | NA |
| Total Dissolved Phosphorus | mg/l | 0.019 | 0.040 ± 0.031 |
| Phosphate | mg-P/l | 0.0037 | NA |
| chlorophyll *a* | µg/l | 19.9 | 74.3 ± 113.4 |

A comparison between the brackish waterbody and the groundwater and anchialine pools of Kaloko-Honokōhau NHP is informative. Nutrient levels in the brackish waterbody (2008–2014, stream not flowing) are similar to or less than those in Kaloko-Honokōhau's wells and anchialine pools during the mid-1990s (Brock and Kam 1997). Nutrient levels at Kaloko-Honokōhau NHP have risen since the mid-1990s and are now distinctly higher than those in the brackish waterbody (Hudgens et al. *in press*). Chlorophyll *a* concentrations and turbidity, on the other hand, are much higher in the brackish water body than in the anchialine pools of Kaloko-Honokōhau NHP. These patterns could reflect a longer residence time (resulting in more opportunity for biological uptake) in the brackish waterbody than in anchialine pools. The brackish waterbody responds minimally to tides (Storlazzi et al. 2013), which is consistent with low levels of flushing and a longer residence time.

#### 4.3.1.6 Threats and stressors

Floods bring nutrients and sediment to the brackish waterbody, creating the potential for algal blooms, low oxygen levels in bottom waters, and high turbidity. Factors that exacerbate flooding and erosion in the Makeāhua (Pelekane) watershed therefore are threats to water quality. Wildfire, drought, and overgrazing, which are addressed in section 4.1.2, are among the most notable threats.

Runoff from the highway or spills have the potential to transport toxic pollutants into the Puʻukoholā Heiau NHS.

Most of the time groundwater is the main source of water for the brackish waterbody. Changes to the water balance of the aquifer—or changes to sea level—have the potential to alter the water level or salinity in the brackish waterbody. Urban and agricultural development is expected to increase the demand for groundwater in the Māhukona aquifer system (CWRM 2019b, Appendix H). The 2016 demand of 1.61 million gallons per day (MGD) is expected to increase to 3.11 MGD (without agriculture) or 7.23 MGD (with agriculture) by 2035. Future demand is a sizable fraction of the estimated sustainable yield of 10 MGD (CWRM 2019b, appendix F). There is a risk that increased pumping will lower the water table in the park, leading to less water and saltier water in the brackish waterbody. Conversely, the water table will rise in step with rising sea level. It is likely that the sand berm and brackish waterbody will move inland, with possible increases in salinity.

#### 4.3.1.7 Data Gaps and Research Recommendations

Continued water quality monitoring is recommended. Given the unusual nature of the brackish waterbody, it is unclear what constitutes acceptable water quality. Nutrient loading from various sources (groundwater, seawater, streamflow, litterfall, and atmosphere) and activities has not been quantified. Apart from two single measurements, ammonium and phosphate concentrations have not been characterized. To assist in interpreting the monitoring data, it would be helpful if measurements taken when the berm is closed could be distinguished from those taken when the brackish waterbody is open to the sea. It is therefore recommended to monitor 1) the dates on which the berm is breached, 2) the dates when the berm is re-established (completely closing the opening), and 3) dates on which the stream is flowing. A fixed camera taking still shots once or twice a day could be employed to this end. A shallow pool can become quite warm, and temperature monitoring with a data logger should be considered. A logger is needed because the I&M measurements are too infrequent to capture the diurnal cycle.

In mid-2016, the Hawaiʻi Commission on Water Resource Management began monitoring water levels in a well that is 3 miles (4 km) upslope from the park's shoreline.[27] Water levels in well "Kawaihae 3" (8–6147–001) should be reviewed periodically to look for trends that could affect groundwater flow and salinity at the coastline. Trends at "Kawaihae 3" should be interpreted in view of long-term trends at well "Ouli 1" (8–6046–001). The relationship between the condition of the park's groundwater and rainfall is unknown, as is the relationship with pumping rates.

#### 4.3.1.8 Sources of Expertise

- D. Kawaiaea, National Park Service.

### *4.3.2 Brackish Water Biota*

*By Anne Brasher, Aquatic Ecologist and Barbara Seidel, Technische Universitaet Muenchen*

#### 4.3.2.1 Condition Summary

Based on the limited data available, the condition of the biota within the unnamed brackish waterbody can be classified as of moderate concern, with a low level of confidence. There is insufficient data available to determine a trend in condition. The evaluation of this waterbody is based on the community composition and the relative abundance of both native and introduced species.

#### 4.3.2.2 Description

This section addresses fish, shelled invertebrates, and selected insects.

#### 4.3.2.3 Data, Indicators and Methods

Reference conditions were based on surveys of anchialine pools and other estuarine water bodies by Maciolek and Brock (1974) and Cheney et al. (1977), and species lists generated for Kaloko Fishpond at Kaloko-Honokōhau NHP. Maciolek and Brock (1974) conducted an aquatic inventory of anchialine pools along the Kona Coast in 1972, including the waterbody at Puʻukoholā Heiau NHS. This initial survey included 304 pools, including those with and without a surface connection. They covered approximately 100 miles from Kawaihae to South Point (Ka Lae). Of these, 291 pools were categorized as having no surface connection to the ocean, and thus were considered to be anchialine pools.

The evaluation of this waterbody is based on community composition and the relative abundance of both native and introduced species. The current condition at Puʻukoholā NHS is based on a recent survey by Tango et al. (2012) and casual observation during two visits to the park in 2008 and 2014 (Brasher, personal observation). Tango et al. (2012) used multiple methods to survey for a variety of invertebrates at and adjacent to the brackish waterbody. These methods included baited funnel traps, baited pitfall traps, pan traps, collection of substrate and open water samples, and visual observations.

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[27] Data are available at https://dlnr.hawaii.gov/cwrm/groundwater/monitoring/.

#### 4.3.2.4 Reference Condition

The reference conditions for biota in this system are communities comprised of native species of fish (marine, brackish, and freshwater species), crustaceans, neritid snails, and both damselflies and dragonflies, with relatively few nonnative species. Examples of introduced species expected to be present include the prawn (*Macrobrachium lar*), the mullet (*Valamugil engeli),* damselflies, dragonflies, and thiarid snails, all of which are likely permanently established statewide. During their study, Cheney et al. (1977) observed *Palaemon deblis* (glass shrimp) and small (< 20 cm length [8 in]) introduced Tilapia. Some potential fish and invertebrate species are listed in Table 11, which summarizes fish and invertebrates observed in Kaloko Fishpond at Kaloko-Honokōhau NHP. Invertebrates typical of anchialine pools may also occur. These include the native estuarine shrimp species such as *Marcrobrachium grandimanus* (Hawaiian endemic) and *Palaemon debilis*. Other invertebrate reference biota include the neritid snail (pipiwai) *Theodoxus cariosa,* and Odonata (pinao) species including the endemic dragonfly *Anax strenuous*, the endangered damselfly *Megalagrion xanthomelas,* and indigenous dragonflies, such as the globe skimmer (*Pantala flavescens*) and the green darner (*Anax junius*).

**Table 11.** Native species observed in Kaloko Fishpond located at Kaloko-Honokōhau NHP. Summarized from Chai 1991; Brasher 1996, 1999; and MacKenzie and Bruland 2012.

| Category | Species | Common Name |
|---|---|---|
| Fish | *Acanthurus sandvicensis* | manini |
| | *Canthigaster amboinensis* | puffer |
| | *Arothon hispidus* | puffer |
| | *Caranx ferdau* | papio |
| | *Caranx ignobilis* | ulua |
| | *Scomberoides sanctipetri* | lai |
| | *Trachiurops crumenopththalmus* | akule |
| | *Chaetodon lunula* | butterfly fish |
| | *Chanos chanos* | awa (milk fish) |
| | *Eleotris sandwicensis* | akupa |
| | *Stolephorus purpureus* | anchovy (nehu) |
| | *Bathygobius cocosensis* | goby (oopu) |
| | *Oxyurichthys lonchotus* | goby (oopu) |
| | *Sargocentron xantherythrum* | squirrel fish |
| | *Kuhlia sandvicensis* | aholehole |
| | *Stehtojulius balteata* | omaka (wrasse) |
| | *Thalassoma duperreyi* | hinalea (wrasse) |
| | *Thalassoma* sp. | hinalea (wrasse) |
| | *Mugil cephalus* | ama ama (mullet) |

[A] The introduced mullet is included in this list because it was originally grouped with the native mullet and is apparently well established.

**Table 11 (continued).** Native species observed in Kaloko Fishpond located at Kaloko-Honokōhau NHP. Summarized from Chai 1991; Brasher 1996, 1999; and MacKenzie and Bruland 2012.

| Category | Species | Common Name |
|---|---|---|
| Fish (continued) | *Osteomugil engeli* | introduced mullet [A] |
| | *Mulloides flavolineatus* | weke (goatfish) |
| | *Echidna nebulosa* | eel |
| | *Gymothorax* sp. | eel |
| | *Polydactylus sexfilis* | moi |
| | *Abudefduf abdominalis* | damselfish |
| | *Abudefduf sordidus* | damselfish |
| | *Callydon* sp. | uhu (parrot fish) |
| | *Cepholopholis argis* | roi |
| | *Sphyraena barracuda* | barracuda |
| | *Polydactylus sexfilis* | threadfin |
| Snails and Bivalves | *Nerita picea* | Pipipi |
| | *Isognomen* | Oyster |
| | *Tellina palatam* | Clam |
| | *Theodoxus cariosus* | Hapawai |
| | Thiaridae | Snail |
| | *Serpulorbis variabilis* | tube snail |
| Crustaceans | *Alpheus crassimanus* | snapping shrimp |
| | *Macrobrachium grandimanus* | Prawn |
| | *Palaemon debilis* | glass shrimp |
| | *Metaporgrapsus thukuhar* | Crab |
| Other Invertebrates | *Aiptasia pulchella* | sea anemone |
| | *Haliclona* sp. | encrusting purple sponge |
| | *Eurythoe complanata* | fire worm |
| | *Actinpyga mauritaiana* | sea cucumber |
| | *Holothuria atra* | sea cucumber |

[A] The introduced mullet is included in this list because it was originally grouped with the native mullet and is apparently well established.

Species that Maciolek and Brock (1974) have suggested to be representative species of anchialine pools and brackish waterbodies (Table 12) can be considered the historical reference along the entire west coast of Hawai‘i Island.

**Table 12.** Reference condition species of anchialine pools. Data from Maciolek and Brock (1974) initial inventory along the Kona Coast, Hawai`i Island (n = 291).

| Category | Species | Presence in Number of Pools | Abundance (% of total pools) |
|---|---|---|---|
| Plants | *Ruppia maritima* | 42 | 14 |
| Snails | *Theodoxus cariosa* | 56 | 19 |
| Crustaceans | *Halocaridina rubra* | 182 | 62 |
|  | *Metabetaeus lohena* | 92 | 32 |
|  | *Palaemon debilis* | 64 | 22 |
| Fish | *Eleotris sandwicensis* | 15 | 5 |
|  | *Kuhlia sandvicensis* | 22 | 8 |

### 4.3.2.5 Current Condition and Trend

Tango et al. (2012) observed one species of mollusk, in the near tidal area and not in the pool itself, and two native species of crustaceans (*Macrobrachium grandimanus* and *Palaemon debilis*). They did not observe the native opae ula, *M. lohena* or *H. rubra*. During their surveys, four species of Odonata were observed: the indigenous globe skimmer dragonfly (*Pantala favescens*), the indigenous green darner (*A. junius*), and the introduced black saddlebags dragonfly (*Tramea lacerate*) and damselfly (*Ischnura ramburii).* They did not observe the endangered native damselfly *M. xanthomelas*. In addition, one species of Orthoptera, thirty species of Diptera, five taxa of plankton, and four species of water-associated ants were observed.

Tango et al. (2012) reported the origin (classified as either endemic, indigenous, or adventive) of 22 of the dipteran species found at Puʻukoholā Heiau NHS. The vast majority of these species (17) were adventive, including all species of known origin with more than 10 individuals present in their surveys. Trend analysis cannot be completed because there has been only one survey of fish, crustaceans and molluscs, and one comprehensive invertebrate survey. While visiting Puʻukoholā Heiau NHS during the scoping meeting in 2014, and previously in 2008, Brasher observed mullet and introduced poeciliids in the waterbody. No other data on fish species composition or abundance were available for this assessment.

### 4.3.2.6 Threats and Stressors

Predation and competition for resources by introduced species (Table 13) pose serious threats to native biota in this waterbody (Havird et al. 2013). Maciolek and Brock (1974) estimated that about 15% of the anchialine pools along the Kona coast contain introduced species. Roughly ten years later in 1985, almost 50% of anchialine pools contained introduced species, and in 2000, more than 95% contained introduced species (Brock and Kam 1997, Yamamoto and Tagawa 2000). A recent survey by Marrack et al. (2015) of 398 anchialine pools along the Ala Kahakai National Historic Trail in 2012 and 2013, including 68 pools surveyed by the National Park Service Inventory and Monitoring Program from 2007 to 2009, showed 25% of the pools to contain introduced fishes (tilapia and poeciliids). Recent introductions include jellyfish at the Kaloko Fishpond and tilapia at the Aimakapā

Fishpond (Kaloko-Honokōhau NHP). Tilapia became established in the Royal Fishpond at Puʻuhonua-o-Hōnaunau NHP since at least the 1970s.

**Table 13.** Introduced species, which pose serious threats to native biota in anchialine pools and other brackish water systems on Hawaiʻi.

| Category | Species | Origin | Disturbance |
|---|---|---|---|
| Crustaceans | *Macrobrachium lar* | Guam | prey on native biota, resource competition with native biota |
| Fish | Tilapia | Africa | habitat degradation |
|  | *Poecilia reticulata* and hybrid complex group | Trinidad & Tobago, Venezuela, Guyana and Suriname | resource competition with native biota |
|  | *Gambusia affinis* | Texas, USA | prey on native biota |

Introduced fishes alter the community composition and ecosystem dynamics of this unique environment (Eldredge 2000, Carey et al. 2011, Marrack et al. 2015, Nico et al. 2015, Seidel et al. 2016). For example, Tilapia alter pool habitats by digging pits for brooding and burying rocks under a thick layer of excrement. Algal growth, which is a vital food resource for many native species, is inhibited as the thick layer of sediment prevents light needed for photosynthesis (Seidel et al. 2016). High silt cover may also block access to subterranean passages and restrict movement of shrimp (Marrack et al. 2015). High nutrient levels caused by fish excrement, can create the potential for algal blooms and associated low oxygen levels.

#### 4.3.2.7 Data Gaps and Research Recommendations

A notable gap hindering assessment of the biota in the brackish pool at Puʻukoholā Heiau NHS is the lack of any fish survey data. A second notable gap is a paucity of recent invertebrate surveys. Tango et al. (2012) surveyed for a wide range of invertebrates, but only provided quantitative data on dipteran species abundances. A comprehensive monitoring program including fish and invertebrates should be initiated. It will be important to note if the sand berm is intact or breached at the time of biotic surveys. Additional information is needed on life history characteristics and habitat preferences of native crustaceans and snails. An additional study on the impacts of invasive fish on native biota would be valuable for management decision-making. In addition, an evaluation of how the variability of the water physical and chemical characteristics (currently monitored by PACN I&M) influence the biotic composition over time would also be valuable for management decisions.

### 4.4 Marine Ecosystem Integrity

Marine resources were important to the ancient Hawaiians for subsistence, culture, and survival (Malo 1951, Kahāʻulelio 2006, Friedlander et al. 2013). The vital importance of marine resources to ancient Hawaiians resulted in the development of complex management systems at watershed (ahupuaʻa), district (moku), and island scales. The assessment of marine natural resources at Puʻukoholā Heiau NHS focuses on marine water quality, benthic invertebrates, and nearshore marine fishes. These two ecological communities continue to play significant roles in Hawaiian economic and cultural practices.

There are less than two hectares (five acres) of marine habitats within the boundaries of Pu‘ukoholā Heiau NHS. This area is small and therefore the numbers—and even presence—of a certain species within the park boundaries may be highly variable depending on their mobility and home range size. At such a small scale, the timing of births, deaths, individual movements and small-scale disturbances play a large role in benthic and nearshore fish community composition at any given time. The overall health of marine resources of Pu‘ukoholā Heiau NHS is primarily determined by the conditions present in the surrounding waters of Pelekane Bay and even further north and south along the South Kohala coast. Therefore, to obtain a more robust picture of the benthic and nearshore fish resource conditions, we evaluated a larger area of marine habitat that includes areas adjacent to Pu‘ukoholā Heiau NHS. The marine Pu‘ukoholā Heiau NHS assessment polygon includes nearshore, hardbottom habitat adjacent to the park and extends from the mouth of Kawaihae Small Boat Harbor to just south of Spencer Beach Park (Figure 23).

**Figure 23.** Pelekane Bay and vicinity. Pelekane Bay is an embayment within the larger Kawaihae Bay, which is 8 km (5 mi) from north to south. The survey boundary encloses the marine assessment polygon.

### *4.4.1 Marine Water Quality of Pelekane Bay*

*By Jené Michaud, University of Hawai'i at Hilo*

#### 4.4.1.1 Condition Summary

Water quality in the marine waters of Pelekane Bay warrant moderate to significant concern because they are listed as impaired under the Clean Water Act (CWA) due to high nutrient concentrations and high turbidity. Confidence in this assessment is medium. The period of measurement is too short to determine if there are any trends in marine water quality. It is likely, however, that water quality deteriorated after construction of Kawaihae harbor in the 1950s.

#### 4.4.1.2 Description

The ephemeral Makeāhua Stream empties into the head of Pelekane Bay, which is located between the "coral flat" (artificial fill comprising the southern portion of the Kawaihae harbor) and Spencer Beach Park. Groundwater seeps and occasional floodwaters give the bay estuarine characteristics and fishes typical of estuarine habitats (*Osteomugil engeli, Kuhlia xenura, Herklotcichthys quadrimaculatus, Selar crumenophthalmus*) are prevalent in the bay. Pelekane Bay habitats have been strongly degraded by sediment delivered by Makeāhua stream. Kawaihae Harbor, which protrudes from the natural shoreline, has contributed to the problem by disrupting waves and currents that would otherwise remove stream sediments.

Water quality is addressed below, and sedimentation is considered in section 4.1.2.

#### 4.4.1.3 Data, Indicators and Methods

Water quality indicators for the park's marine waters are dissolved oxygen (DO), turbidity, nutrients and chlorophyll-*a*. These indicators address the cause (excess nutrients), result (elevated chlorophyll-*a* is a measure of certain algal blooms), and impact (low DO at the bottom of the water column) of eutrophication, which is an ecological threat in Hawai'i and around the world.[28] Low DO is widely recognized as stressful for aquatic organisms. High turbidity has broad-reaching ecological effects and can result from algal blooms in the water column, suspended sediments, or uncommon biological or chemical events. High turbidity is the most common cause of CWA impairment of Hawaiian marine waters (HDOH 2014).

It is possible that construction of the Kawaihae Harbor, which has decreased exchanges between Pelekane Bay and the open ocean, has slightly increased temperatures and reduced salinity in Pelekane Bay. Shallowing of the bay due to sedimentation would have similar effects. The discharge of floodwaters from Makeāhua Stream may sometimes alter the bay's temperature, salinity, and pH. There are several reasons that temperature, salinity, and pH were not selected as indicators, however. First, there are no monitoring data, nor are there historic data. CWA standards are not precise enough to serve as a point of reference.[29] The HDOH has not measured temperature salinity, or pH as part of the 303(d) monitoring program, presumably ranking these parameters as a lower priority among management concerns.

Beginning in approximately 2011, the HDOH conducted CWA monitoring at Pelekane Bay (station HI738158) as part of an ongoing effort to determine locations that should be included on the 303(d) list of impaired water bodies (HDOH 2014). HDOH measurements were made on at least ten days over a two-year period. The monitoring dates are not published. Measurements were made at multiple locations along a transect that begins at the shoreline; data were summarized as a geometric

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[28] Algal blooms can be caused by phytoplankton or benthic macro algae. Chlorophyll *a* measurements of the water column can detect the presence of phytoplankton.

[29] The following CWA standards apply to the park's marine waters: temperature shall not vary more than 1 degree Celsius from ambient; salinity shall not vary by more than ten percent from natural or seasonal changes; pH shall not be less than 7.6 (7.0 if influenced by terrestrial fresh water) nor more than 8.6.

mean along the transect and across measurement dates. The State publishes biennial 303(d) assessment reports that describe whether standards were attained; data values are not published, however. Reports published in 2012 and 2014 were examined for this assessment (HDOH 2012, 2014). Results of several studies and one-time surveys were also examined. Storlazzi et al. (2013) and Stender et al. (2014) measured salinity, temperature, turbidity, and pH in Pelekane Bay on several dates in 2010–2012. In 2003, the HDOH measured nutrients, turbidity, and chlorophyll at three shoreline locations (MKSWCD 2005). Results of these studies are reviewed and summarized. While there are water quality data from Spencer Beach Park (mostly from 1990–1997; Hoover and Gold 2006), these data are not reviewed because they are from outside the park and are not recent.

#### 4.4.1.4 Reference Conditions

Because there are no historic data that can be used to establish reference conditions, a benchmark standard was used to assess ecosystem health (Table 14). Benchmarks were based on water quality standards set for the nearshore marine waters of the Kona coastline by the State of Hawai`i under the Clean Water Act (HAR §11–54). Reference conditions were not set for salinity, temperature, or pH, because they fluctuate naturally, and there is no indication that they have been subjected to anthropogenic alteration.

**Table 14.** Results of HDOH water quality monitoring at Pelekane Bay. Dissolved oxygen, phosphate and ammonium were not measured. At present, Pelekane Bay is held to the standards that prevail in the nearshore waters (shoreline to 1000 m depth) along the Kona Coast.

| Parameter | CWA Water Quality Standard | Observations Reported in the 2012 303(D) List | Observations Reported in the 2014 303(D) List |
|---|---|---|---|
| Total Dissolved Nitrogen (TDN) | 0.100 mg/l | Standards exceeded | Standards exceeded |
| Nitrate plus Nitrite ($NO_3$+$NO_2$) | 0.0045 mg-N/l | Standards exceeded | Standards exceeded |
| Total Dissolved Phosphorus (TDP) | 0.0125 mg/l | Standards exceeded | Standards exceeded |
| Chlorophyll | 0.3 µg/l | Standards exceeded | Standards exceeded |
| Turbidity | 0.1 NTU | Not measured | Standards exceeded |
| Enterococci bacteria | 130 cfu/100 ml | Standards exceeded | Standards met |

#### 4.4.1.5 Current Condition and Trend

The waters of Pelekane Bay were assessed as "impaired" under the CWA and placed on the state's 303(d) list in 2012 and 2014 (Table 14; HDOH 2012, 2014). Standards were exceeded for all nutrients measured, as well as turbidity and chlorophyll *a*. Oxygen levels were not measured. Standards for enterococcus bacteria were exceeded in the 2012 assessment; this could indicate either sewage contamination or the presence of soil bacteria. Because of the short measurement period, trends in water quality at Pelekane Bay could not be determined. CWA monitoring at nearby sites, however, have a longer period of record. At Spencer Beach Park (immediately south of the park) and inside Kawaihae Harbor (immediately north of the park), turbidity standards were exceeded in the 2006, 2008/2010, 2012, and 2014 303(d) assessments. Bacterial standards were met; nutrients were not measured.

Stender et al. (2014) measured turbidity in Pelekane Bay on June 23, 2012. Measurements were taken by a diver with a sonde who swam along three transects that were 50 m (55 yd) long. The transects were over hard bottom habitat and located southwest of the sand berm. Average turbidity was 1.8 NTU on the transect that was approximately 270 m (290 yd) from the sand berm and 0.8 NTU on the transect that was approximately 310 m (330 yd) from the sand berm. These values exceed CWA standards by approximately an order of magnitude. Average pH was 8.11. Turbidity near the shoreline is often higher than offshore. Based on a shoreline measurement, turbidity was 26.5 NTU at Pelekane Beach on November 2, 2003 (MKSWCD 2005). On the same date, turbidity was 9.2 NTU 300 m (300 yd) west of Pelekane Beach along the coral flat, and 3.2 NTU near the southern end of the park's shoreline.

Storlazzi et al. (2013) measured temperature, salinity and turbidity at three locations in Pelekane Bay (Table 15). Data were collected every five minutes over 81 days during fall and winter of 2010–2011. As expected, temperatures were warmest in shallow water, and salinity was depressed close to shore. Turbidity maximums, which were larger near the seafloor and decreased with distance from shore, were associated with a large flood that occurred on November 19, 2010 (Panel B in Figure 24). Elevated turbidity was also associated with large wave conditions (panel D in Figure 24). Waters were relatively clear during normal wind and wave conditions. The turbidity reference value (0.1 NTU) was exceeded by 2–3 orders of magnitude during the flood event. Two meters (7 ft) below the water surface, the minimum observed turbidity was less than the reference value in moderately deep water (5 and 15 m [16 and 49 ft]). Just above the seafloor, the minimum observed turbidity was less than the reference value at the deepest site (15 m [49 ft]), but not at the shallower sites (2 and 5 m [7 and 16 ft]).

**Table 15.** Temperature, salinity, and turbidity in Pelekane Bay during fall and winter 2010–2011. Data (from Storlazzi et al. 2013) were measured along a transect that began at the head of Pelekane Bay and extended seaward. Means and extremes were affected by a flood event.

| | **Temperature (C)** | | **Salinity (PSU)** | | **Turbidity $^A$ (NTU)** | |
|---|---|---|---|---|---|---|
| **Sensor Location** | **Mean** | **Range** | **Mean** | **Range** | **Mean** | **Range** |
| Just above the seafloor; water depth is **2 m** (7 ft). | 26.3 | (23.9–29.0) | 31.0 | (25.0–33.2) | 7.4 | (1.6–1524) |
| Just above the seafloor; water depth is **5 m** (16 ft). | 25.8 | (24.2–27.1) | 34.7 | (32.8–35.1) | 13.5 | (0.4–232) |
| Two m (7 ft) below the water surface; water depth is **5 m** (16 ft). | 25.9 | (24.6–27.3) | 34.9 | (32.9–35.2) | 20.7 | (0.0–102) |
| Two m (7 ft) below the water surface; water depth is **15 m** (49 ft). | 25.8 | (24.5–27.0) | 34.9 | (34.0–35.2) | 1.7 | (0.0–45) |
| Just above the seafloor; water depth is **15 m** (49 ft). | not measured | not measured | not measured | not measured | 7.3 | (0.1–205) |

$^A$ Data from 30 days were excluded due to biofouling.

On November 2, 2003, the HDOH conducted a one-time water quality sampling at three locations along the Pelekane Bay shoreline (MKSWCD 2005). Measured values of nutrients and chlorophyll were much higher than the water quality standards (Table 16). Nitrate concentrations were particularly high, and it is possible that nitrogen-fixing trees near the brackish waterbody are a source of excess nitrogen. The measured concentrations are also higher than concentrations in the marine waters of Kaloko-Honokōhau NHP. The samples at Kaloko-Honokōhau NHP were collected just outside the surf zone, and it is known that nutrient concentrations decrease with increasing distance from shore.

**Figure 24.** Surface turbidity in Pelekane Bay during different wind, wave, and flood conditions. *A*, Typical trade-wind conditions. *B,* Flood conditions in November 2010. *C,* After the flood (trade-wind conditions). *D.* Large-wave conditions in February 2011. From Storlazzi et al. (2013).

**Table 16.** Nutrients and chlorophyll along the Pelekane Bay shoreline. Data were collected by the HDOH on November 2, 2003 (MKSWCD 2005).

| Location | Nitrate (mg-N/l) | Total Nitrogen [A] (mg/l) | Total Phosphorus [A] (mg/l) | Chlorophyll-*a* (µg/l) |
|---|---|---|---|---|
| Pelekane Beach | 0.046 | 0.348 | 0.041 | 3.19 |
| 300 m (300 yd) west of Pelekane Beach along the coral flat | 0.020 | 0.234 | 0.020 | 3.76 |
| near the southern end of the park's shoreline | 0.015 | 0.137 | 0.010 | 0.85 |
| CWA standards for Kona waters | 0.0045 | 0.100 (for filtered samples) | 0.0125 (for filtered samples) | 0.3 |

[A] It is likely that samples were filtered, but this is not known for sure.

Concerns about water quality in Pelekane Bay are driven by potential impacts to ecosystems, particularly coral reefs. There is abundant evidence from around the world that sediment and nutrients in terrestrial runoff degrade coral reefs (Fabricius 2005). Nutrients affect marine ecosystems indirectly through eutrophication. In addition, as demonstrated by Koop et al. (2001), excessive nutrients can harm corals directly. Koop et al. investigated *in situ* effects of nutrient additions at 12 patch reefs in Australia. Adding small amounts of inorganic nitrogen and phosphorus did not affect coral mortality, but at high doses mortality increased for sensitive species. Nitrogen additions stunted coral growth, and phosphorus additions increased the calcification rate but made the corals more susceptible to breakage. Sediment near river mouths can smother benthic communities, kill exposed coral tissue (especially if sediment is fine-grained or organic in origin), reduce photosynthetic yields, and increase metabolic costs. In addition to sedimentation killing established corals, another concern is that a silt-covered bottom surface will inhibit coral recruitment. Perez et al. (2014) evaluated the effect of sediment (collected in a Hawaiian watershed) on the survival and settlement of coral larvae on Petri dishes. There was no recruitment on surfaces with more than 0.9 mg/cm$^2$ of sediment. The main impact of the sediment was on successful settlement rather than on mortality.

At Pelekane Bay, several studies have documented the effects of terrestrial runoff. Sediment deposition has destroyed habitat that is closest to Pelekane Beach. Further from shore, reef degradation increased as the amount of deposited sediment increased (DeMartini et al. 2013). Longitudinal studies at Pelekane Bay have documented a rapid decline in habitat from 1977 to 1996; this was followed by slight improvement in coral cover over 1996–2012, accompanied by increases in fish diversity (Stender et al. 2014). These patterns and trends are discussed in more detail in sections 4.4.2 and 4.2.3.

It is very likely that water quality in Pelekane Bay was degraded during dredging of the Kawaihae Harbor in 1957–1959 and dredging/blasting of the Small Boat Harbor in 1969–1970. The effects on water quality were not documented, however. The breakwater of the Small Boat Harbor was finished in 1998 but the facility did not host boats until November 2014, when twenty-five berths were completed. The U.S. Army Corps of Engineers investigated the possibility of dredging a channel between the head of Pelekane Bay and the interior of the harbor to increase circulation and flush sediment out of the bay (Li et al. 2009). This idea was abandoned when models showed that the channel would frequently become filled with silt.

#### 4.4.1.6 Threats and stressors

Kawaihae Harbor, which supports commercial shipping and has ten berths for recreational boats, is immediately north of Puʻukoholā Heiau NHS. It has the potential to generate nutrients, metals, and other contaminants. Spills from the fuel depot are always possible, and sewage from boat holding tanks might be released accidentally or intentionally. Tributyltin antifouling paints are known to be especially toxic to marine life; while these paints were banned in 2008, it is likely that some boats or ships still have tributyltin paints. Polluted water or sediment from the commercial harbor could potentially be transported by currents into the marine waters of the park. The Kawaihae Small Boat Harbor, which is very close to the park, is also a potential source of pollutants.

The Kawaihae breakwater is itself a significant stressor. It disrupts wave action and longshore currents, reducing water circulation and promoting sediment accumulation.

Activity at the Kawaihae Small Boat Harbor will likely increase when its boat ramp is completed in 2019 or 2020. Expansion of the commercial harbor is planned, with the extension of one berth and construction of a new berth. This will require new dredging (HDTHD 2011). Surfers and swimmers from Spencer Beach Park may introduce sunscreen containing oxybenzone and octinoxate into marine waters near the park. Recognizing that these compounds are harmful to corals, Hawaiʻi has banned them starting in 2021.

Insofar as Pelekane Bay is affected by terrestrial runoff, upslope threats must be considered. For example, runoff from the highway or spills from accidents have the potential to transport contaminants into the Puʻukoholā Heiau NHS. As discussed in section 4.1.2.6, future urban development may occur within a few kilometers of the highway; further upslope, changes in land use practices could increase loading of nutrients and sediment.

#### 4.4.1.7 Data Gaps and Research Recommendations

There are no data to indicate whether pollutants or polluted sediment from Kawaihae Harbor are being transported into the marine waters of Puʻukoholā Heiau NHS.

The HDOH has identified Pelekane Bay as needing a Total Maximum Daily Load (TMDL) study but assigned a low priority to such an effort (HDOH 2014). A TMDL study would quantify nutrient loads and identify sources but would not quantify the effect of the harbor breakwater on degraded water quality.

I&M monitoring should be conducted in Pelekane Bay, and efforts should be made to obtain HDOH data in order to evaluate trends.

### 4.4.2 Benthic Invertebrates

*By Megan J. Donahue, University of Hawaiʻi at Mānoa and Megan Ross, University of Hawaiʻi, West Oʻahu*

#### 4.4.2.1 Condition Summary

This condition assessment was initiated in 2014, before the 2014–2017 worldwide bleaching event (Skirving et al. 2018) resulted in extensive coral bleaching and subsequent mortality in the West Hawaiʻi region in 2015 (Maynard et al. 2016). **The data available for this condition assessment ends in 2014; it does not include data during or after the 2015 bleaching event. As such, this condition assessment serves as a pre-bleaching baseline for this area.** Before the 2015 bleaching event, the condition of coral reefs in the waters of Puʻukoholā Heiau NHS warranted significant concern due to the impacts of sedimentation on coral abundance and recruitment. During the 2015 bleaching event, 38–92% of all coral colonies bleached at sites across West Hawaiʻi (Maynard et al. 2016), including extensive bleaching at two sites near Puʻukoholā Heiau NHS (>83% of corals experienced bleaching at Kawaihae and >76% at ʻŌhae ʻula). The lack of long-term data in Puʻukoholā Heiau NHS marine area precludes an assessment of trends.

#### 4.4.2.2 Description

The benthic habitats in Pelekane Bay consist of uncolonized sand, aggregate reef, and aggregate patch reef dominated by coral and coralline algae (Cochran et al. 2007). Much of the sediment found on reefs offshore of Puʻukoholā Heiau NHS originates from dredging of Kawaihae small boat harbor and terrigenous input by the ephemeral Makeāhua Stream and impeded circulation due to the physical structures built for the harbor (Cochran et al. 2007, Demartini et al. 2013). Benthic community composition is structured primarily by (i) the availability of hard substrate for colonization, (ii) wave exposure, (iii) sedimentation, and (iv) light availability (Jokiel et al. 2004). The benthic community in the Puʻukoholā Heiau NHS assessment area is dominated by uncolonized substrate and crustose coralline algae. Corals, primarily *Porites lobata* and *P. compressa*, macro-algae and turf algae are also significant components of the benthic community, which is clearly impacted by the high turbidity and sedimentation rates within Pelekane Bay (Beets et al. 2010). The 2015 bleaching event had widespread impacts in West Hawaiʻi (Maynard et al. 2016), including extensive bleaching at two sites near Puʻukoholā Heiau NHS.

#### 4.4.2.3 Data, Indicators and Methods

For coral reef communities in the Puʻukoholā Heiau NHS study area, we considered three indicators of current condition; (i) benthic percent cover of coral, macroalgae, crustose coralline algae (CCA), turf algae, and other substrate categories, (ii) coral recruitment, and (iii) coral disease. Indicators were selected based on the NPS I&M Benthic Marine Community Monitoring Protocol (Brown et al. 2011) and recommendations made by the NPS for the parks along the West Hawaiʻi coast. These three indicators were compared between the Puʻukoholā Heiau NHS assessment polygon and the surrounding West Hawaiʻi reference region. The Puʻukoholā Heiau NHS assessment polygon extends from the mouth of Kawaihae small boat harbor to just south of Spencer Beach Park (Figure 25). The West Hawaiʻi reference region extends from ʻUpolo Point (20.2°N, 156.8°W) to South Point (18.9°N, 155.7°W).

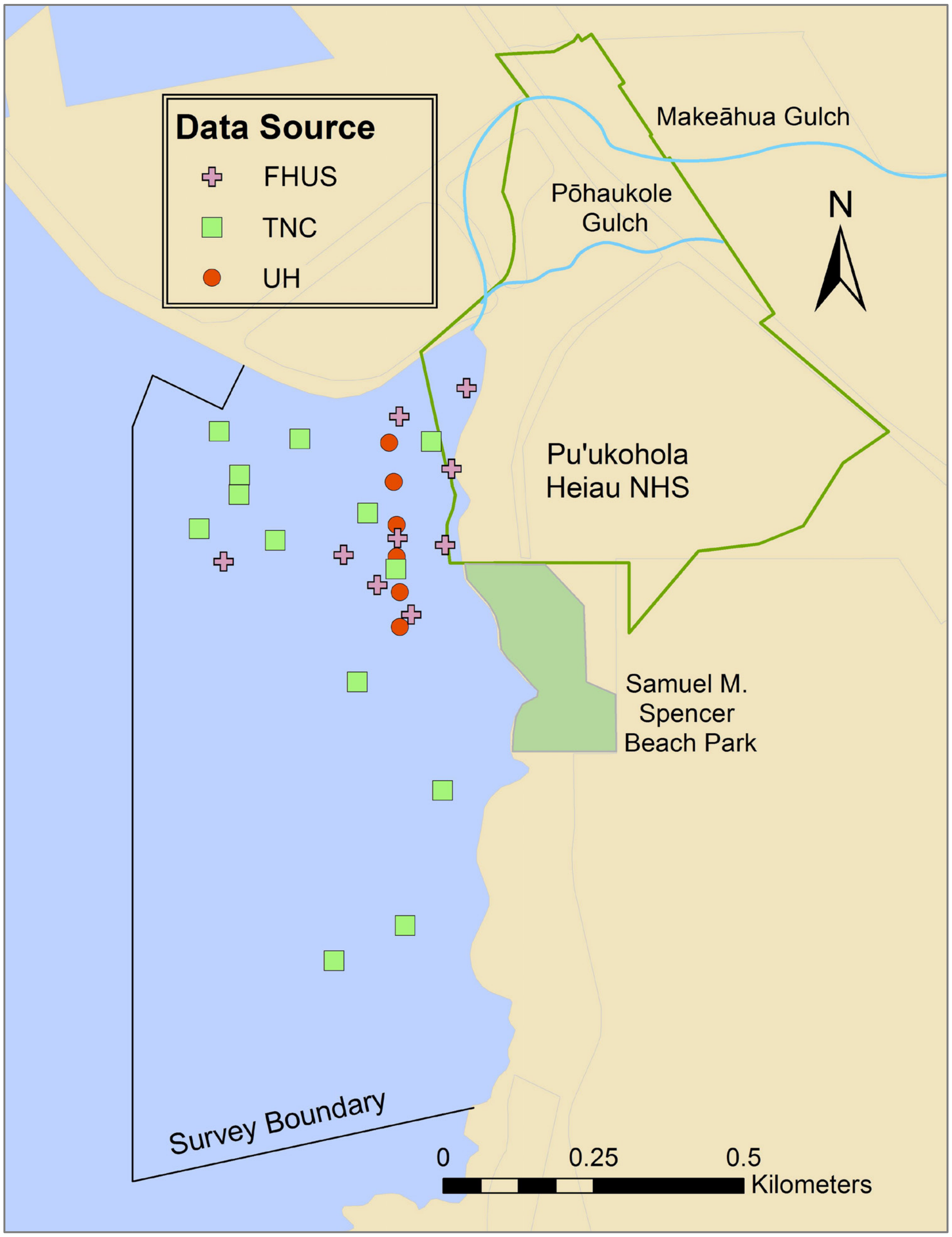

**Figure 25.** Location of benthic and coral disease surveys in the Puʻukoholā Heiau NHS marine assessment polygon. The benthic surveys (FHUS, TNC, UH) are identified by data source and described in the text. All data sources are listed in Table 17.

**Table 17.** Benthic invertebrate assessments along the west Hawai‘i coast used to assess reference conditions as well as resource conditions with the Pu‘ukoholā Heiau NHS assessment polygon.

| Project | Citation | Years | Benthic Cover | Coral Disease | Coral Recruitment | Methods Summary |
|---|---|---|---|---|---|---|
| WHRP | Basch et al. 2009, Martin & Walsh 2012 | 2004–2012 | – | – | WHRR: n=9 | Terracotta recruitment tiles were used to estimate coral recruit density from April 2004 to March 2012 at 9 sites in West Hawai‘i. Tiles were replaced every 6–11 mos. Summarized site data were available from the published report. |
| DAR WHAP | Walsh et al. 2013 | 2007, 2011 | WHRR: n=26 | WHRR: n=62; | – | Benthic cover was assessed using photoquadrats on transects at each of 26 WHAP sites located within WHRR. Raw data was available through the Hawai‘i Monitoring and Research Collaborative (HIMARC).<br>Coral Disease was assessed on 62 1 × 25 m belt transects at 26 sites in the WHRR. All colonies on the 1 × 25 m transect were assessed for disease and diseased colonies were recorded; colony density was assessed on a 1 × 10 m transects overlapping the disease transects; prevalence was estimated by dividing the density of diseased colonies on the 25 $m^2$ belt transects by total density of colonies on the 10 $m^2$ belt transect. Raw data was available from HICORDIS (Caldwell et al. 2016a). |
| Cornell University | Couch et al. 2014, Couch 2014 | 2010–2011 | – | WHRR: n=42 | – | Coral disease was assessed on 42 10 × 2 m belt transects in the WHRR. All colonies within the belt were counted, identified to species and observed for signs of diseases. Prevalence was calculated by dividing the density of diseased colonies by the total density of colonies on the belt transect. Raw data was available through HICORDIS (Caldwell et al. 2016a). |
| NOAA CRED | Heenan et al. 2014; Ayotte et al. 2015 | 2007–2010, 2014 | WHRR: n=56 | WHRR: n=25 | – | Benthic cover was assessed using analysis of 0.7 $m^2$ photoquadrats taken along 30 m transects at stratified random sites within the WHRR. Coral disease was assessed on 25 of these transects. Raw data was available from HIMARC. |
| CRAMP | Rodgers et al. 2004; 2015 | 2002, 2004 | WHRR: n=28 | – | – | Benthic cover was assessed using the analysis of 0.35 $m^2$ photoquadrats taken along 20 10 m long Rapid Assessment Transects (RATS) within the WHRR. Benthic cover was also assessed using photoquadrats taken along eight permanently marked 10 m long transects at four long-term monitoring stations located within the WHRR. Raw data was available from CRAMP and HIMARC. |
| EPSCoR | Caldwell et al. 2016a, Burns 2016 | 2011–2012 | – | WHRR: n=36 | – | Line-point intercept surveys on 25 m transects, where each colony on the transect was characterized by species, size, morphology, and disease presence and severity at five sites (Kahuwai, Kailua Kona, Kaloko, Waiopae, Waaiuli) stratified by three depth zones. Raw data was available from HICORDIS (Caldwell et al. 2016a) |

**Table 17 (continued).** Benthic invertebrate assessments along the west Hawaiʻi coast used to assess reference conditions as well as resource conditions with the Puʻukoholā Heiau NHS assessment polygon. WHRR = West Hawaiʻi Reference Region; PHNHS = Puʻukoholā Heiau National Historic Site

| Project | Citation | Years | Benthic Cover | Coral Disease | Coral Recruitment | Methods Summary |
|---|---|---|---|---|---|---|
| NPS PICRP | Marrack et al. 2014; Weijerman et al. 2014 | 2005–2007 | WHRR: n=85 | – | – | Fixed transects were established at 61 sites in Kaloko-Honokōhau NHP, 14 sites in Puʻuhonua o Hōnaunau NHP, and 10 at a reference site within the WHRR. Benthic cover was assessed using photoquadrats along 10 m transects at each site. |
| NPS I&M | I&M benthic habitat database: https://irma.nps.gov/DataStore/Reference/Profile/2231928 | 2007–2010, 2014 | WHRR: n=90 | – | – | Benthic cover was assessed using photoquadrats taken along 25 m transects. |
| FHUS | Beets et al. 2010 | 2005 | • WHRR: n=353<br>• PHNHS: n=9 | – | – | Benthic cover was assessed at 353 transects in four parks, including 9 within the Puʻukoholā Heiau NHS marine area using the *in-situ* planar point intercept quadrat method along a 25-m transect. |
| UH | DeMartini et al. 2013 | 2010 | • WHRR: n=6<br>• PHNHS: n=6 | – | • WHRR: n=35<br>• PHNHS: n=6 | Benthic cover was assessed using both quadrats and line point counts at 6 fixed stations at Puʻukoholā Heiau NHS. These are included as part of the WHRR. Recruitment was measured from May–Nov along a 6 station array starting at Makeāhua Stream in 2010 and 2011; in 2011, an additional 29 offshore stations were measured. Based on the description of the methods, we assume that each station has an available surface area of 0.54 $m^2$. |
| TNC | Minton et al. 2011 | 2010, 2013 | • WHRR: n=479<br>• PHNHS: n=13 | • WHRR: n=8<br>• PHNHS: n=8 | – | Benthic cover was assessed using analysis of 0.25 $m^2$ photoquadrats at 479 transects across 40 sites. Eight of the transects included coral disease surveys: all colonies within a 10 × 2 m transect were sized and any observed disease states were recorded. The survey area was stratified into two depth categories, shallow (1–3 m) and deep (>3–20 m). Raw data was accessed through HIMARC. |

Descriptions of the three indicators follows:

- *Benthic percent cover of coral, macroalgae, CCA, turf algae, and other substrate:* Benthic community composition is the most widely collected monitoring data for coral reef ecosystems in Hawai‘i and changes in community composition are often used as an indicator of effective management (e.g., Kahekili Herbivore Fisheries Management Area, Ka‘anapali Maui, Williams et al. 2016). Long-term monitoring of benthic community structure, along with targeted studies investigating particular stressors, can help identify causes of reef composition change (Brown et al. 2011). Benthic cover has been listed as an indicator for the NPS monitoring of the Marine Benthic Community Vital Sign (Brown et al. 2011a).
- *Coral Recruitment*: Coral recruitment can be an indicator of resilience to disturbance. Recruitment data from settlement plates were used to assess the relative contribution of small, newly recruited coral populations. Coral recruitment is listed as an indicator for NPS monitoring of the Marine Benthic Community Vital Sign (Brown et al. 2011b).
- *Coral disease*: The NPS Coral Reef and I&M programs currently collect presence/absence data on coral disease and bleaching (Brown et al. 2011a). We reported on the prevalence of the three most commonly observed diseases in West Hawai‘i (Walsh et al. 2013, Couch et al. 2014), which have distinct etiologies: *Porites* Growth Anomalies (GA), *Porites* trematodiasis (TRE), and tissue loss diseases (TL).
    - *Porites* growth anomalies are a chronic condition characterized by protuberant growth of skeleton accompanied by aberrant calyx formation overlaid by normally pigmented to colorless tissues (Aeby et al. 2011a). *Porites* GA have been shown to reduce colony growth and fecundity (Cheney 1975, Bak 1983, Domart-Coulon et al. 2006, Work et al. 2008, Stimson 2010, Yasuda et al. 2012) and increase mortality (Stimson 2010, Yasuda et al. 2012); it is associated with human population density (Aeby et al. 2011a, Walsh et al. 2013), light irradiance (Aeby et al. 2011a), bleaching stress (McClanahan et al. 2009), and nutrient input (Kaczmarsky and Richardson 2011, Couch 2014).
    - *Porites* trematodiasis is an infection by the digenetic trematode *Podocotyloides stenometra* (Aeby 1991). Trematodiasis has been shown to reduce the growth rate of infected corals (Aeby 1991). However, trematodiasis is not generally associated with mortality or anthropogenic factors.
    - Tissue loss diseases have been associated with widespread losses of coral cover resulting in phase shifts from coral to algal dominated communities on reefs in the Caribbean (Aronson and Precht 2001, Walton et al. 2018). Although tissue loss diseases are less prevalent in the Main Hawaiian Islands (MHI) than in other regions in the world, several outbreaks have been observed in the MHI and North Western Hawaiian Islands (NWHI; Aeby 2005, Aeby et al. 2010, Aeby et al. 2011b, Caldwell et al. 2018).

*Data Sources*

The resource conditions and reference conditions for this assessment were based on a compilation of available benthic survey data, coral disease survey data, and coral recruitment data collected in the West Hawaiʻi reference region from 2004 (after the last assessment, Hoover and Gold 2006) to 2014, when this assessment was initiated. Data sources and methods for all surveys conducted in the West Hawaiʻi reference region are listed in Table 17. Three of these studies include benthic surveys that fall within the Puʻukoholā Heiau NHS assessment polygon (Figure 25); they are described in detail below. The benthic survey data include a combination of one-time measures from randomly selected points and repeated measures from fixed transects. For repeated measures, only the most recent data points were included to assess the current condition.

Percent benthic cover data are available for a total of 1123 transects in the West Hawaiʻi reference region from 2004–2014 (Table 17). This includes 28 transects with benthic cover data from the Puʻukoholā Heiau NHS assessment polygon from three studies, which are summarized below (see also Table 17 and Figure 25).

*Benthic Cover*

- FHUS: In 2005, the NPS I&M in collaboration with the University of Hawaiʻi (UH) conducted benthic surveys at NPS sites in Hawaiʻi as part of a baseline inventory of marine vertebrates and a Fish Habitat Utilization Study (FHUS; Beets et al. 2010). Nine transects were located within the Puʻukoholā Heiau NHS assessment polygon.
- UH: In spring 2010, Hawaiʻi Institute of Marine Biology (HIMB) and the United States Geological Survey (USGS) collaborated to conduct benthic surveys at six fixed stations in Pelekane Bay from Makeāhua stream southward toward Spencer Beach Park (DeMartini et al. 2013).
- In August 2010, The Nature Conservancy (TNC) conducted benthic cover surveys at 40 sites from the Kawaihae breakwater to south of Pelekane Bay (Minton et al. 2011). Thirteen of these transects fall within the Puʻukoholā Heiau NHS assessment polygon.

Data collected within the West Hawaiʻi Reference Region, but outside of the Puʻuhonua o Hōnaunau NHP marine area, include surveys by the Division of Aquatic Resources West Hawaiʻi Aquarium Project (DAR WHAP), the National Oceanographic and Atmospheric Administration Coral Reef Ecosystem Division (NOAA CRED), NPS Inventory and Monitoring Program (NPS I&M), the University of Hawaiʻi (UH), and The Nature Conservancy (TNC). All data sources are listed in Table 17.

Compiled data were used to conduct a Permutational Multivariate Analysis of Variance (PERMANOVA) comparing average benthic cover of coral, macro-algae, substrate, turf algae and CCA between and among sites.

*Coral Recruitment*

As part of the West Hawaiʻi Recruitment Project (WHRP; Basch et al. 2009; Martin and Walsh 2012), NPS and the Department of Land and Natural Resources, Division of Aquatic Resources (DAR) monitored coral recruitment at nine sites in West Hawaiʻi. Terracotta recruitment tiles were deployed starting in April 2004 and used to estimate coral recruit density (coral recruits $m^{-2}$ $y^{-1}$ [square meters {1.2 $yd^2$} per year]); tiles were replaced every 6–11 months. None of the DAR/WHRP sites were located in Puʻukoholā Heiau NHS assessment polygon, but all nine sites are included in the West Hawaiʻi reference region; the closest sites were Waiakaʻilio Bay, approximately 8 km (5 miles), to the north and Puakō, approximately 5 km (3 miles) to the south of Puʻukoholā Heiau NHS.

From May to November 2010 and May to November 2011, UH and HIMB deployed settlement arrays at 6 inshore stations inside the Puʻukoholā Heiau NHS assessment polygon (DeMartini et al. 2013). From May to November 2011, a second set of arrays were deployed at 29 additional sites offshore of Pelekane Bay.

TNC conducted coral size frequency surveys in August 2010. These data can be used to infer age structure of coral populations (Minton et al. 2011).

*Coral Disease*

Data were available from coral disease surveys conducted at 173 transects in the West Hawaiʻi reference region (Caldwell et al. 2016a; Table 17); this included eight surveys conducted within the Puʻukoholā Heiau NHS assessment polygon in August 2010 by TNC (Minton et al. 2011).

### 4.4.2.4 Reference Conditions

*Benthic Cover*

Hawaiʻi Island has the largest area of intact accreting reefs in the MHI (Jokiel et al. 2004). Coral cover in the West Hawaiʻi reference region is high relative to the statewide average and dominated by *Porites* spp. (Rodgers et al. 2004). CCA is the most common benthic cover after coral; macro-algal cover was very low (Rodgers et al. 2004).

Based on a compilation of all available data collected along the West Hawaiʻi coast from 2004–2014 (Table 17), mean benthic percent cover was comprised of turf algae (41.6 ± SE 0.8%), coral (25.2 ± SE 0.6 %), CCA (8.1 ± SE 0.31%), and macro-algae (3.0 ± SE 0.3%), as well as 8.3% (± 0.61%) of "bare" substrate with no conspicuous cover. Note that these results are summarized prior to the 2015 bleaching event (Maynard et al. 2016).

*Coral Recruitment*

The average annual recruitment rates on the West Hawaiʻi coast from 2004–2012 was 25 ± 23 (SD) recruits $m^{-2}$ $year^{-1}$ based on recruitment plates at nine sites in the WHRP study (Martin and Walsh 2012).

*Coral Disease*

Prevalence of the three most widespread coral diseases in the West Hawaiʻi reference region was 10.7 ± SE 1.9% for growth anomaly, 8.7 ± SE 2.1% for trematodiasis, and 2.5 ± SE 0.7% for tissue loss for *Porites* spp. (Aeby et al. 2011b, Walsh et al. 2013, Couch et al. 2014). In general, disease prevalence within the West Hawaiʻi reference region was low (Walsh et al. 2013). Note that the prevalence of growth anomalies in *Porites* spp. is eight times higher in West Hawaiʻi than in the MHI (Couch et al. 2014). Prevalence of growth anomaly is positively correlated with higher host abundance (Williams et al. 2010, Aeby et al. 2011a, Couch 2014), and the high prevalence of *Porites* growth anomaly in West Hawaiʻi is largely explained by higher percent coral cover of *Porites* spp. (Couch et al. 2014).

### 4.4.2.5 Current Condition and Trend

*Percent Benthic Cover*

Based on 28 transects surveyed in 2005, 2010, and 2013, benthic habitats in the Puʻukoholā Heiau NHS assessment polygon had lower coverage of corals and turf algae and higher coverage of CCA, macro-algae, and bare/silt-covered substrate than the West Hawaiʻi reference region (PERMANOVA; $R^2$=0.019; p < 0.001, Figure 26).

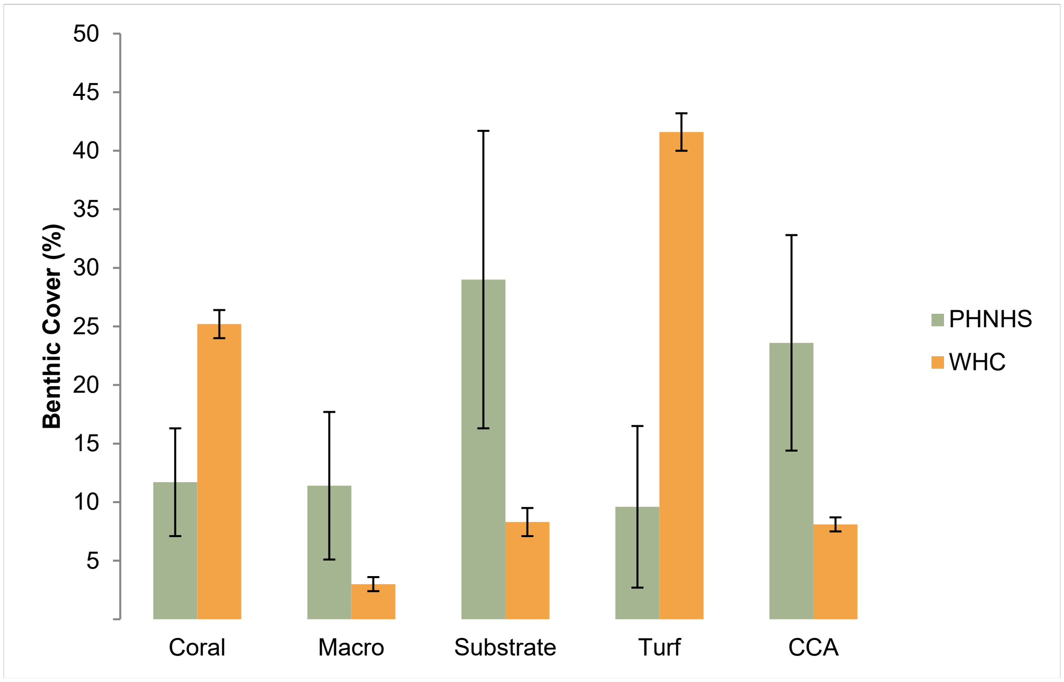

**Figure 26.** Mean percent benthic coverage (± 95% CI) of coral, macro-algae, uncolonized substrate, turf algae, and crustose coralline algae (CCA) in Puʻukoholā Heiau NHS assessment polygon (PHNHS; n=28) and along the West Hawaiʻi Coast (WHC; n=1096). Based on compilation of all available data.

Beets et al. (2010) describe the reef in the Puʻukoholā Heiau NHS assessment polygon as "highly degraded with turbid inshore waters and silt covered substrate." The dominant benthic cover within the Puʻukoholā Heiau NHS assessment polygon was silt covered substrate followed by turf algae, coral, CCA and macro-algae (Beets et al. 2010).

DeMartini et al. (2013) found that *Porites lobata* and *P. compressa* were the most common coral species found within the Puʻukoholā Heiau NHS assessment polygon, and that coral cover increased with distance from the stream mouth, presumably due to decreased sediment accumulation rates.

Within the Puʻukoholā Heiau NHS assessment polygon, Minton et al. (2011) found similar benthic communities at both shallow (1–3 m) and deep (>3–20 m) survey sites. The benthic community was dominated by CCA with the exception of five sites in shallow water near an area that experiences chronic turbidity. These five sites, all close in proximity, were dominated by abiotic substrate (silt and rubble) with biotic cover dominated by *Porites* corals rather than CCA. Minton et al. (2011) found no significant correlation between coral cover and turbidity. They did, however, find that coral species richness and diversity, and mean colony size of *P. lobata* were all negatively correlated with increasing turbidity.

Given the limited data available in the Puʻukoholā Heiau NHS assessment polygon (28 transects), a quantitative assessment of trends within this area is not possible. However, given the widespread bleaching and mortality across the WHRR in 2015 (Maynard et al. 2016), including documentation of severe bleaching (>70%) at nearby sites, it is likely that there were significant negative impacts on coral cover in the resource area.

*Coral Recruitment*

Coral recruitment rates in the Puʻukoholā Heiau NHS assessment polygon were generally lower than the West Hawaiʻi reference region average of 25 recruits $m^{-2}$ $year^{-1}$ (Martin and Walsh 2012, Table 18): at the six inshore stations, recruitment averaged 2–4 recruits $m^{-2}$ $y^{-1}$ and no recruits at the three stations closest to the stream in 2010. Recruitment was higher (20 recruits $m^{-2}$ $y^{-1}$ ± 21 SD) at the 29 offshore sites (outside the assessment polygon; DeMartini et al. 2013). Coral settlement was negatively correlated with turbidity at the stations observed in 2011 (DeMartini et al. 2013).

**Table 18.** Annual recruitment rates and standard deviations from 2004–2012 for nine sites in West Hawaiʻi outside of the Puʻukoholā Heiau NHS assessment polygon (Martin and Walsh 2012).

| Site | Recruits per $m^2$ per Year | Std Dev. | Range of Recruitment Rates |
|---|---|---|---|
| *Waiakaʻilio Bay* | 72 | 101 | 0–176 |
| *Puakō* | 56 | 116 | 0–411 |
| *Kaʻupulehu* | 18 | 15.4 | 0–49 |
| *Honokōhau* | 19 | 22.1 | 0–71 |
| *N. Keauhou* | 4 | 4.54 | 0–16 |
| *Keʻei* | 8 | 12.6 | 0–41 |
| *Hoʻokena* | 16 | 19.8 | 0–67 |

**Table 18 (continued).** Annual recruitment rates and standard deviations from 2004–2012 for nine sites in West Hawai‘i outside of the Pu‘ukoholā Heiau NHS assessment polygon (Martin and Walsh 2012).

| Site | Recruits per $m^2$ per Year | Std Dev. | Range of Recruitment Rates |
|---|---|---|---|
| *Miloli‘i* | 17 | 22.6 | 0–64 |
| *Manuka* | 10 | 16.3 | 0–44 |
| **Average** | **25** | **23.3** | – |

Overall, rates of coral growth and settlement, colony maximum diameter and the percentage of live tissue on an individual colony increased with distance from the stream mouth (De Martini et al. 2013). Areas nearer the stream mouth contained high amounts of terrestrially derived sediment, leading to high turbidity (see section 4.4.1 Marine Water Quality of Pelekane Bay). Despite low growth rates of coral colonies associated with turbid waters, low recruitment of new corals in turbid waters reduces the number of small colonies there, leading to a positive correlation between mean colony size and turbidity (Minton et al. 2011).

*Coral Disease*

The Pu‘ukoholā Heiau NHS assessment polygon has higher mean prevalence of *Porites* GA and lower prevalence of *Porites* TRE and tissue loss than the West Hawai‘i reference region (Figure 27). Trematodiasis is associated with high host density (Aeby et al. 2011b), therefore, the lower prevalence of trematodiasis in the Pu‘ukoholā Heiau NHS assessment polygon can be attributed to the lower density of *Porites* in this region.

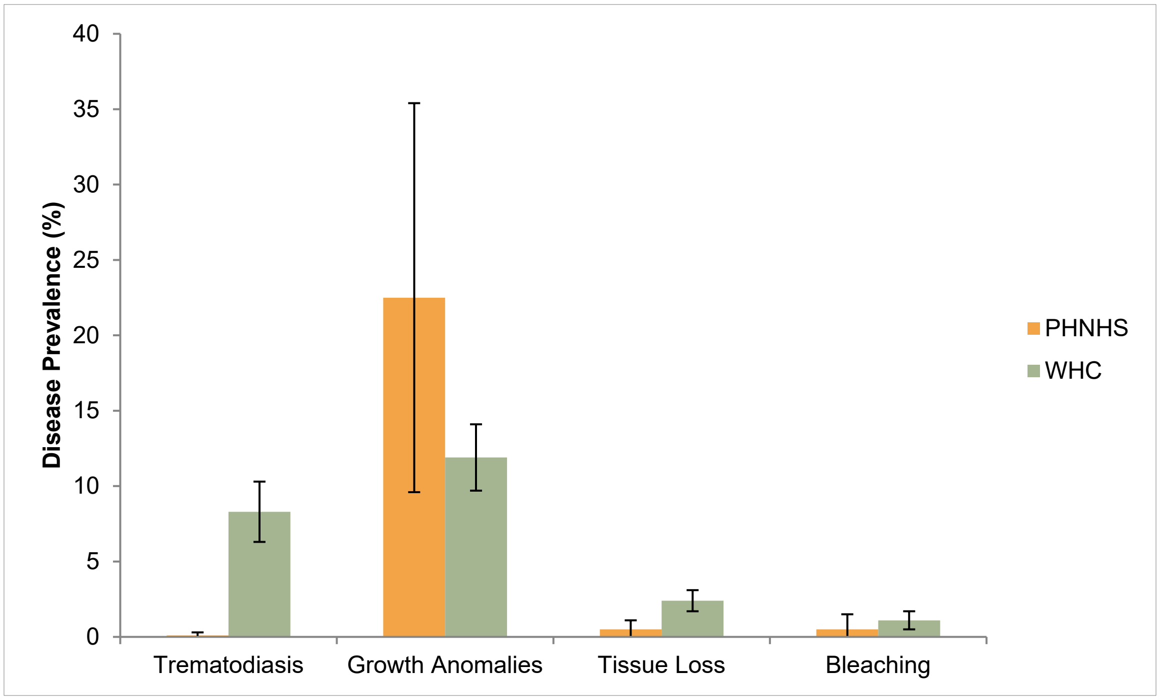

**Figure 27.** Mean prevalence (± 95% CI) of *Porites* trematodiasis, *Porites* Growth Anomalies, tissue loss disease, and bleaching in the Puʻukoholā Heiau NHS assessment polygon (PHNHS; n=5) and along the West Hawaiʻi Coast (WHC; n=168). Based on compilation of all available data prior to 2015.

Given the limited data, a quantitative assessment of trends in disease prevalence within the resource area is not possible. However, given the widespread bleaching and mortality across the WHRR in 2015 (Maynard et al. 2016), and the association of tissue loss diseases with thermal stress (McClanahan et al. 2009, Caldwell et al. 2016b, Muller et al. 2018, Brodnicke et al. 2019), it is likely that the resource area experienced significant bleaching in 2015 and a subsequent increased risk of disease.

### 4.4.2.6 Threats and Stressors

*Coral Bleaching*

Coral bleaching is a stress response of corals that results from a breakdown of the symbiotic relationship between the coral and the algae (zooxanthellae) that live within its tissues. When stressed, the coral expels the pigmented zooxanthellae, leading to a pale/white or "bleached" appearance of the coral and the loss of significant nutritional resources for the coral. Mass coral bleaching events are associated with elevated sea surface temperatures and have been increasing in extent and severity worldwide (Hughes et al. 2018, Eakin et al. 2019, Sully et al. 2019). In Hawaiʻi, coral bleaching events have been documented in 1996, 2002 (Jokiel and Brown 2004), 2014 (Neilson et al. 2014), 2015 (Maynard et al. 2016), and 2019. The effects of the 2015 bleaching event were documented at 20 sites from south Kohala to north Kona by The Nature Conservancy (Maynard et al. 2016), at 8 WHAP monitoring sites by Kona DAR, and at sites around the MHI by the Hawaiian Islands Humpback Whale National Marine Sanctuary in collaboration with the Papahānaumokuākea Marine National Monument. Maynard et al. (2016) report that 68% of shallow water corals (6–7 m

[20–23 ft]) and 60% of deeper water corals (11–12 m [36–39 ft]) were partially or severely bleached across twenty sites in West Hawaiʻi, 50–60% of the two most abundant species (*Porites lobata* and *P. compressa)* partially or fully bleached, and bleaching related mortality was “considerable” for many of the dominant reef-building species. Thermal stress events that cause coral bleaching will pose a significant continued and accelerating threat to the reefs of West Hawaʻi, including Puʻukoholā Heiau NHS. Although thermal stress events will continue to threaten West Hawaiʻi reefs, local management of coastal water quality can mitigate the increased risk of coral bleaching and disease (Vega-Thurber et al. 2014, Wiedenmann et al. 2013).

*Predation*

At high densities, the crown-of-thorns sea star (*Acanthaster planci*; COTS) can cause substantial loss in coral cover (Lourey et al. 2000, De’ath et al. 2012), and COTS outbreaks have been associated with an increase in coastal eutrophication (Fabricius et al. 2010, Hughes et al. 2014). COTS density has been monitored in West Hawaiʻi since the start of DAR WHAP monitoring in 1999. Walsh et al. (2013) report an overall increase in COTS abundance from 2000–2005 and decrease from 2005–2009, as well as an outbreak event resulting in dramatic loss of coral cover at Kanahena Point in 2005. In the available data, no observations were recorded within the Puʻukoholā Heiau NHS polygon. This is not surprising given the normally low density of COTS in West Hawaiʻi. COTS will continue to pose a moderate but unpredictable threat to West Hawaiʻi reefs, including Puʻuhonua o Hōnaunau NHS.

*Water Quality*

Terrigenous sediment deposition and resuspension poses a significant limitation to coral cover in the Puʻukoholā Heiau NHS area. DeMartini et al. (2013) found that sediment accumulation declined away from Makeāhua stream mouth, where the sediment is finer and more terrigenous. Minton et al. (2011) found turbidity to be greatest along the north side of Pelekane Bay and decreased away from Makeāhua stream. Coral growth, recruitment, and species richness were all negatively impacted by increasing turbidity and sedimentation (DeMartini et al. 2013, Minton et al. 2011). While some sedimentation is expected near a stream mouth, the restricted water motion due to harbor infrastructure increases the risk of deposition and resuspension due to wind and wave action, exacerbating the effects of poor watershed management upstream. Marine water quality issues are discussed in more detail in section 4.4.1, and upstream watershed water quality issues are discussed in section 4.1.2.

*Invasive Species*

In Hawaiʻi, 19 species of macroalgae have been introduced both intentionally and accidentally since 1950. Of these, five have become established (Smith et al. 2002). Invasive algae are found on all of the MHI but are most abundant on the islands of Maui and Oʻahu. Macroalgal cover is low along the West Hawaiʻi Coast (Figure 26). Hoover and Gold (2006) reported that during 2005 algal surveys Cheryl Squair detected no nonnative species within Puʻukoholā Heiau NHS (unpublished data). No new data are available on the presence of invasive algae within the Puʻukoholā Heiau NHS assessment polygon.

#### 4.4.2.7 Data Gaps and Research Recommendations

For the decade of 2004–2014, there were just 28 benthic surveys, including 8 coral disease surveys, limited to three years (2005, 2010, 2013) in the Puʻukoholā Heiau NHS assessment polygon, allowing only limited assessment of conditions and no assessment of trends over that time. The mass coral bleaching in West Hawaiʻi in 2015 and increasing risk of thermal stress events further highlight the need for ongoing monitoring within the resource area. While substantial research efforts were undertaken to understand sedimentation in Pelekane Bay in 2010–2011, only an ongoing monitoring program can adequately assess trends. We recommend that survey stations be re-established and monitored as part of the NPS Pacific Island I&M Network.

Coral size structure data and coral growth data are useful for inferring age structure and disturbance history of coral communities and can give more detailed information about coral reef resilience than coral cover alone. We recommend including coral size and growth components as part of the benthic monitoring program to better understand processes underlying long-term changes in benthic cover; these are also monitoring objectives of the NPS Pacific Island I&M Network.

Coral recruitment data for two years were available from DeMartini et al. (2013) and contextualized by the WHRP (Martin and Walsh 2012). However, coral recruitment is highly variable both spatially and temporally and is a critical component of reef resilience. We recommend that Puʻukoholā Heiau NHS be included in the NPS I&M Network, which includes recruitment of hard corals to standard substrates as one of its monitoring objectives.

Outbreaks of disease or episodic bleaching events require both long-term monitoring and rapid responses to detect. The establishment of rapid response protocols specific to disease and bleaching events seem particularly critical, given the increasing risk of thermal stress event that result in bleaching and may increase the risk of disease outbreaks. Rapid response protocols would also be appropriate for use with COTS outbreaks. Prompted by the 2014–2015 bleaching events, there has been increased activity statewide to establish and coordinate rapid responses to bleaching and other episodic events, providing an opportunity for Puʻukoholā Heiau NHS to align its rapid response protocols with these broader efforts.

In discussions with the NPS staff prior to this analysis, three other taxa were considered as potential indicators. Urchins: Grazing by herbivorous urchins (e.g., species in the genera *Diadema, Echinothrix, Heterocentrotus, Tripneustes*) helps maintain low macro-algal cover, thereby reducing competition with adult coral colonies, and providing clean substrate for the recruitment of juvenile corals (Hughes et al. 2007a, b). Octocoral: The octocoral *Sarcothelia edmondsoni* has been proposed as an indicator of poor water quality (Hernandez-Munoz et al. 2008, Walsh et al. 2013, Marrack et al. 2014, Weijerman et al. 2014). However, its distribution is patchy, limiting its value as an indicator (Rodgers et al. 2015; Walsh et al. 2013). Sea cucumbers: In response to an emerging fishery, the Department of Land and Natural Resources (DLNR) adopted new rules in 2016 prohibiting commercial harvest of sea cucumbers for food and applying limits to non-commercial take and to the Hawaiʻi aquarium fishery. The available data were inadequate to include any of these taxa as indicators in this condition assessment.

Rapidly changing technology is creating new opportunities for automation in benthic monitoring (Dornelas et al. 2019, Williams et al. 2019). In Hawaiʻi, researchers at NOAA, University of Hawaiʻi at Hilo, and Hawaiʻi Institute of Marine Biology are actively investing in technology to automate reef monitoring (Bryson et al. 2017, Fukunaga et al. 2019, Williams et al. 2019). We recommend that Puʻukoholā Heiau NHS develop partnerships with these researchers to help develop and maintain an effective and sustainable benthic monitoring program.

Recommendations:

1. Establish Puʻukoholā Heiau NHS as part of the NPS Pacific Island I&M Network
2. Develop a rapid response protocol for coral bleaching, coral disease outbreaks, COTS, or other episodic events
3. Identify partners to leverage new technologies for benthic monitoring

### ***4.4.3 Nearshore Marine Fish***

*By Alan Friedlander, University of Hawaiʻi at Mānoa and Megan Ross, University of Hawaiʻi, West Oʻahu*

#### 4.4.3.1 Condition Summary

The condition of the nearshore fish assemblage in the waters adjacent to Puʻukoholā Heiau NHS warrants significant concern and is deteriorating. Fish species richness, biomass and trophic complexity is lower in Pelekane Bay than both the overall West Hawaiʻi Coast and in Kalaupapa NHP. The condition assessment is made with a high degree of confidence. While Kalaupapa NHP resides in a different ecological regime compared to Puʻukoholā Heiau NHS (Donovan et al. 2018), it has one of the healthiest fish populations in the MHI (Friedlander et al. 2018, Friedlander et al. in press) and therefore serves as a benchmark for comparisons with more impacted ecosystems and can help gauge the effectiveness of management at Puʻukoholā Heiau NHS and other locations around the state.

#### 4.4.3.2 Description

Nearshore fisheries in Hawaiʻi comprise a mix of commercial, recreational, and subsistence fisheries (Pooley 1993, Schug 2001, Friedlander et al. 2013). Commercial fish in Hawaiʻi reported from Pelekane Bay are: ʻūʻū (*Myripristis berndti*), moana (*Parupeneus multifasciatus*), and weke ʻula (*Mulloidichthys plfugeri*) (see sections 4.4.3.3 and 4.4.3.5). Reef fish found in and adjacent to Puʻukoholā Heiau NHS include several species important in the aquarium trade such as: goldring surgeonfish (*Ctenochaetus strigosus*), brown surgeonfish (*Acanthurus nigrofuscus*), yellow tang (*Zebrasoma flavescens*), orangespine unicornfish (*Naso lituratus*) and Achilles tang (*A. achillies*) (see sections 4.4.3.3 and 4.4.3.5). Three nonnative fish, taʻape (*Lutjanus kasmira*), toʻau (*Lutjanus fulvus*), and roi (*Cephalopholis argus*), have also been recorded in Pelekane Bay (see sections 4.4.3.3 and 4.4.3.5).

Throughout the Pacific, increased fishing pressure has led to declines in biomass and shifts in the assemblage composition of nearshore fishes (Friedlander and DeMartini 2002, Houk et al. 2015, Williams et al. 2015). Low abundance of top predators is of particular concern because it can lead to further shifts in community structure, a shortened food chain, and a loss of resilience (Heithaus et al. 2008, Estes et al. 2011).

Loss of herbivorous fishes is also of particular concern (Bellwood et al. 2004, Heenan et al. 2014). Herbivorous fishes, especially large parrotfishes, are vital to the maintenance of benthic community structure (Hughes et al. 2007, Ledlie et al. 2007, Bellwood et al. 2011). Decreased herbivory allows both native and nonnative algae to overgrow on corals, which can lead to a phase shift from a coral- to an algal-dominated benthic community (Bellwood et al. 2004, Mumby et al. 2006, Hughes et al. 2007, Mumby 2009). This changes the function of the reef structure, which can in turn lead to further changes in marine fish assemblage composition (Syms et al. 2000, Graham et al. 2007). This negative feedback loop can allow an algal-dominated benthic community to persist, preventing the recovery of the coral reef ecosystem (Knowlton 2004, Norström et al. 2009, Nyström et al. 2012).

Invasive species are a growing concern for marine biodiversity, particularly in Hawaiʻi with its large proportion of endemic species (Hourigan et al. 1987, Kay and Palumbi 1987, Bowen et al. 2013). The majority of introduced species in Hawaiʻi are invertebrates (Eldridge and Smith 2001); however, many are cryptic, and their distribution is limited to the site of their introduction (Smith et al. 2004). Introduced vertebrates such as nearshore reef fish are visible and have received much attention due to concerns over their effects on native fisheries species (Friedlander et al. 2002, Schumacher and Parrish 2005, Dierking et al. 2009). Two introduced species, taʻape, or blueline snapper (*Lutjanus kasmira*), and roi, or peacock grouper (*Cephalopholis argus*), are relatively abundant and of special concern within the West Hawaiʻi reference region (Friedlander et al. 2008, Giddens et al. 2014) and will be used as the focal species for this assessment.

Taʻape were intentionally introduced to Hawaiʻi from French Polynesia for food and sport fishing in 1955 (Randall 1987). Taʻape have since spread throughout the Main Hawaiian Islands (MHI) and the Northwest Hawaiian Islands (NWHI; Oda and Parrish 1982, Randall et al. 1993). Concerns have been raised regarding the competitive ability of taʻape over native fish with similar foraging behaviors (Friedlander et al. 2002, Schumacher and Parrish 2005). Fishers believe that the non-native taʻape compete with native fish species for habitat and prey, and that taʻape consume eggs, larvae and juveniles of preferred native species resulting in declines of important food fish.

Roi were introduced to Oʻahu and Hawaiʻi islands, along with six other species of groupers in 1956 (Maciolek 1984, Randall 1987). Roi now occur in all MHI and up to French Frigate Shoals in the NWHI (Friedlander et al. 2008). Roi are one of the most common large piscivores in Hawaiʻi Island reefs, and there are concerns regarding the effects of roi on the smaller reef fish which they target as food (Dierking et al. 2009, Giddens et al. 2014).

The aquarium fishery is one of Hawaiʻi's most lucrative nearshore fisheries (Walsh et al. 2013). In 1998, the West Hawaiʻi Regional Fishery Management Area was established by Legislative Act 306 (Hawaiʻi Revised Statutes §188F) and includes a system of nine Fish Replenishment Areas (FRA) comprising 35.2% of the coastline (Hawaiʻi Administrative Rules §13–60.4). These FRAs, which are situated along the entire length of the coast, were established to protect against the depletion of reef fishes by the aquarium trade (Tissot and Hallacher 2003; Appendix B). The FRA system was also created to reduce conflict between aquarium fishers and other marine resource uses (Tissot 2005).

Ancient Hawaiians relied heavily on nearshore fisheries for subsistence, which led to a complex management system (Titcomb 1972, Kahāʻulelio 2006). This system changed dramatically following Western contact due to the introduction of new technologies, increased human population, and changes in the value system and worldview (Schug 2001). Seafood remains an important component of the diet of the people of Hawaiʻi today. Commercial landings for a number of nearshore fishes have declined by more than 90% since the 1900s (Friedlander et al. 2015).

In Hawaiʻi, subsistence fishing is culturally and economically important in many communities (McGregor et al. 1998, 2003, Kikiloi and Graves 2010, Poepoe et al. 2007, Friedlander et al. 2013). Non-commercial fishing, including subsistence, recreational, and cultural fisheries dominate the nearshore fish catch in Hawaiʻi (Geslani et al. 2013, Kittinger 2013). The non-commercial nearshore fisheries catch is an order of magnitude higher than the reported commercial catch in the MHI (McCoy 2015). Declines in near-shore fisheries have resulted from habitat destruction, and overfishing associated with a growing population, as well as improved efficiency of fishing technologies that have resulted in shifts in fish abundance and community composition (Smith 1993, Shomura 1987, 2004, Friedlander et al. 2003).

### 4.4.3.3 Indicators, Data and Methods

*Overall nearshore fish community*

Three indicators were used to assess nearshore marine fish communities: (i) mean fish biomass, (ii) numerical density, and (iii) species richness. In addition to the nearshore fish community as a whole, five focal groups were assessed: consumer group, species origin (i.e., endemic, indigenous or introduced), commercial fisheries, aquarium trade fishery, and recreational and subsistence fisheries. Different indicators were used to assess the different focal groups depending on available data (Table 19)

**Table 19.** Indicators used to assess nearshore marine fish communities in total and by focal group (i.e., consumer group, species origin, commercial, aquarium, and recreational & subsistence fisheries). An X designates that the indictor was used to assess that focal group.

| Focal Group | Biomass | Numerical Density | Species Richness |
|---|---|---|---|
| Overall | X | X | X |
| Consumer Group | X | – | – |
| Species Origin | – | – | X |
| Commercial Fisheries | X | – | – |
| Aquarium Trade Fishery | – | X | – |
| Recreational & Subsistence Fishery | X | – | – |

Assessments were made based on comparisons to two reference regions. For the fish community as a whole, consumer group and species origin comparisons were made to West Hawaiʻi Coast from Upolo Point (20.2°N, 156.8°W) to South Point (18.9°N, 155.7°W), and to Kalaupapa NHP, located on the Kalaupapa Peninsula on Molokaʻi Island. The West Hawaiʻi reference region was included as a point of reference because it serves as a point of comparison with more similar marine habitats, environments, and history of exploitation. Comparison to the West Hawaiʻi reference region also allows inference about the impacts of ongoing exploitation of nearby fisheries to the fish community adjacent to Puʻukoholā Heiau NHS. Differential impacts between the Puʻukoholā Heiau NHS and the West Hawaiʻi reference region were further examined through comparisons of the aquarium trade, commercial, and recreational and subsistence fisheries.

Kalaupapa NHP was used as a baseline reference area because it has considerably lower fishing pressure, visitation, and recreational use than Puʻukoholā Heiau NHS and boasts some of the highest reef fish biomass and abundance of top predators found anywhere in the Main Hawaiian Islands (MHI; Friedlander, et al. 2017, 2019). Despite differences in the marine habitats and environments between Kalaupapa and Puʻukoholā Heiau NHS and the West Hawaiʻi Coast in general, comparisons among different regimes provides valuable insight into the complex dynamics of these ecosystems and how best to manage them (Donovan et al. 2018, Jouffray ey al. 2019).

*Data Sources*

Data were compiled from five monitoring programs conducted along the West Hawaiʻi coast and Kalaupapa NHP (Table 20). Three of the programs included survey transects within the Puʻukoholā Heiau NHS assessment polygon. All five monitoring programs included survey transects within the West Hawaiʻi reference region. Only one of the monitoring programs included survey transects within Kalaupapa NHP. The data sources include a combination of one-time measures from randomly selected points and repeated measures from fixed transects. For repeated measures, only the most recent data points were included. Twenty transects included in summary analysis did not include data on species diversity so sample sizes will vary between indicator metrics (Table 21).

The monitoring programs used in this assessment were conducted after the publication of the assessment conducted by Hoover and Gold (2006), which summarized work conducted by Cheny et al. (1977), Ball (1977), and Tissot et al. (2004). Hoover and Gold (2006) acknowledged that much of the work had been conducted further from shore where reef degradation and turbidity was lower and therefore may not be representative of the area directly adjacent to Makeāhua stream. The following three programs within the Puʻukoholā Heiau NHS assessment polygon (Figure 28) quantified reef fish species richness, density, and biomass within the area of interest adjacent to Puʻukoholā Heiau NHS but were not included in the 2005 assessment (Table 20).

- The Hawaiʻi Coral Reef Assessment and Monitoring Program (CRAMP) surveyed six transects within the Puʻukoholā Heiau NHS assessment polygon in 2002 (Rodgers et al. 2004).
- The Fish Habitat Utilization Study (FHUS), a collaboration between the University of Hawaiʻi and the National Park Service Inventory and Monitoring Program (I&M), surveyed

nine inventory sites for near-shore marine fish in the Puʻukoholā Heiau NHS assessment polygon in 2005 (Beets et al. 2010).

- The Nature Conservancy (TNC) conducted fish surveys at 40 sites within an area 1500 m to the north and south of Pelekane Bay in 2010 (Minton et al. 2011). Of these, 15 fell within the Puʻukoholā Heiau NHS assessment polygon.

Sources and methods for all surveys conducted within the West Hawaiʻi and Kalaupapa NHP reference regions are summarized in Table 20.

The identity of species comprising the three fisheries was determined from the avialable catch records for each fishery. The commercial fisheries focal species were selected to be the ten inshore taxa with the highest representation in terms of total biomass caught from 2004–2013 within commercial reporting zones 101 and 102 (the two nearshore zones along the West Hawaiʻi reference region) (Table 22). The aquarium fisheries focal species were selected to be the top 10 most collected aquarium fishes in fiscal years 2013–2014 (Table 23, Walsh et al. 2013). The list of species valuable to subsistence and recreational fisheries in Hawaiʻi used in this assessment was compiled based on Beets and Tom (unpublished data 2009–2010; Table 24), creel surveys and recommendations by NPS personnel.

**Table 20.** Nearshore Marine Fish assessments conducted within the West Hawaiʻi reference region (WHRR, including the Puʻukoholā Heiau NHS assessment polygon), Kalaupapa NHP (KNHP), and the Puʻukoholā Heiau NHS assessment polygon (PHNHS) used to assess reference conditions as well as resource conditions since Hoover & Gold 2006. * signifies inclusion in the Puʻukoholā Heiau NHS assessment polygon. An X designates that the measure was used in the project.

| Project | Report/Publication | Year Data Used Collected | # of Transects in West Hawaiʻi Reference Region | # of Transects in KNHP | # of Transects in PHNHS | Fish Abundance | Consumer Group | Endemism | Methods |
|---|---|---|---|---|---|---|---|---|---|
| DAR WHAP | Walsh et al. 2013 | 2006–2013 | n=46 | n=0 | n=0 | X | X | X | Fish biomass is assessed quarterly at 23 sites along the WCHI. Four 25 × 4m belt transects are surveyed at each site. Species and TL to nearest 5 cm are recorded in 5 cm bins are recorded for each fish observed. |
| NOAA CRED | Heenan et al. 2014; Ayotte et al. 2015 | 2012–2013 | n=34 | n=0 | n=0 | X | X | X | Nearshore fish biomass and density were assessed using the stationary point count method. Species and total length are recorded for all fish within two 15 m diameter cylinders along each 30 m transect (site). |
| CRAMP | Rodgers et al. 2004; 2015 | 2002 | n=47 | n=0 | n=6 | X | – | – | Fish abundance was assessed along six 25 × 5 m belt transects within the PUHE buffer area in 2002. All fish were identified to the lowest possible taxon and total length was estimated to the nearest cm. |
| TNC | Minton et al. 2011 | 2010 | n=575 | n=0 | n=15 | X | X | – | Fish surveys were conducted at 40 sites between points 1500 m to the north and south of Pelekane Bay. Fifteen of these fall within the PUHE buffer. All fish within a 25 × 5 m belt transect were identified to the lowest possible taxon and total length was estimated to the nearest 5 cm and placed in 5 cm bins. |
| FHUS | Beets et al. 2010 | 2004–2005 | n=141 | n=53 | n=9 | X | X | – | – |
| NPS I&M | Brown et al. 2011; Friedlander et al. 2018 | 2009–2010, 2014 | Biomass n=423 | n=120 | n=0 | X | X | X | Biomass and density of nearshore fishes were assessed using visual belt transects 25 × 5 m. All fish within the belt were identified to the lowest possible taxon and total length of each fish was estimated to the nearest 1 cm. |

**Table 21.** Number of transects available for summary analysis in the West Hawaiʻi Reference Region (WHRR), the area of interest adjacent to the Puʻukoholā Heiau NHS (PHNHS), and Kalaupapa NHP (KNHP).

| **Spatial Extent** | **# of Transects** | **# of Transects Including Species Level Data** |
|---|---|---|
| WHRR outside PHNHS | 1083 | 1063 |
| PHNHS | 30 | 30 |
| KNHP | 173 | 173 |
| Total | 1286 | 1266 |

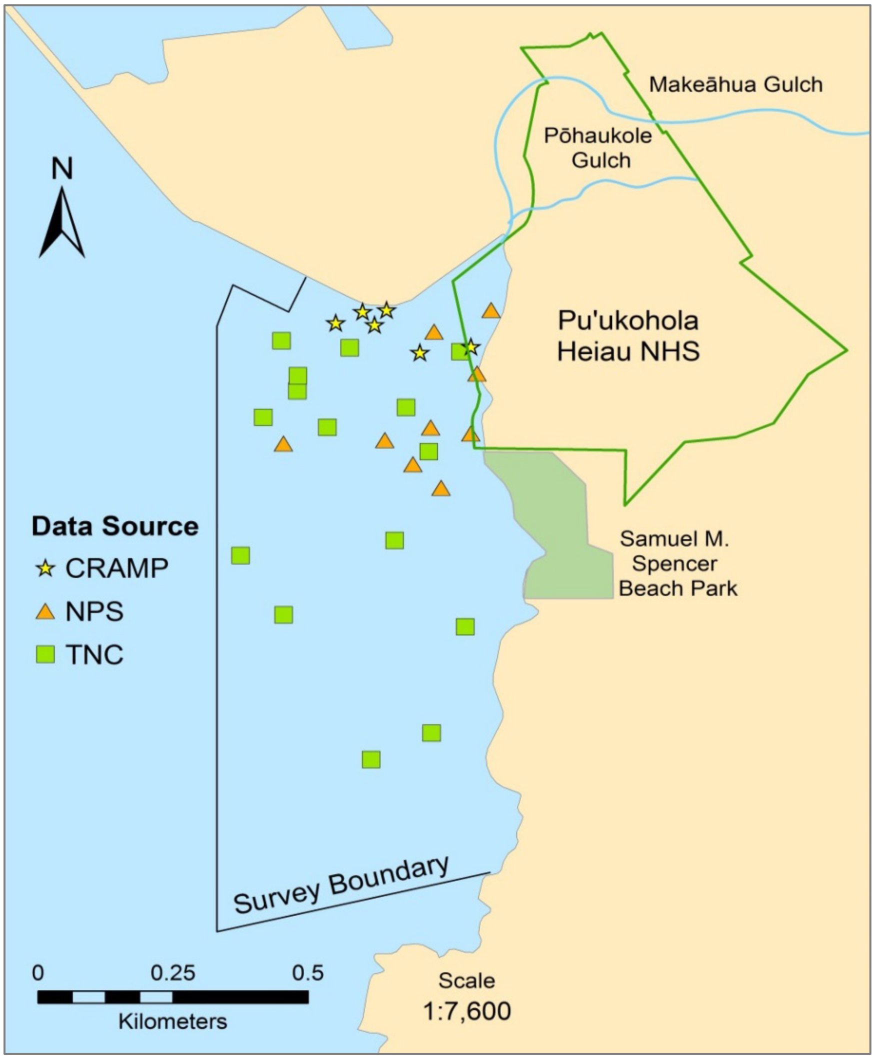

**Figure 28.** Locations of all fish transects within a polygon modified from Beets et al. (2010). Color coded by data source. Data sources within the polygon include the Hawaiʻi Coral Reef Assessment and Monitoring Program (CRAMP; Rodgers et al. 2004), the NPS/UH Fish Habitat Utilization Study (NPS; Beets et al. 2010), the University of Hawaiʻi (UH; DeMartini et al. 2013), and The Nature Conservancy (TNC; Minton et al. 2011).

**Table 22.** The top ten commercially landed species in the DAR commercial fisheries reporting blocks 101 and 102 based on 10-year sum (2004–2013) of total weight of commercial landings (kg). Commercial landings (kg) below are the sum of commercial landings in the two commercial fisheries reporting blocks within the West Hawaiʻi reference region (WHRR, blocks 101 and 102). Mean biomass (g 100 $m^{-2}$ ± 95% CI) of top 10 species were calculated using all available survey data in the West Hawaiʻi reference region (WHRR) since the last assessment (Table 20), but outside of the Puʻukoholā Heiau NHS assessment polygon. Percentage of total density of top 10 species in parentheses.

| **Hawaiian Name (Species)** | **Commercial Landings (kg) Blocks 101 & 102** | **Commercial Landings (% of total catch of 10 species) Blocks 101 & 102** | **WHRR (g 100 $m^{-2}$) n=1050** | **WHRR (% of total catch of 10 species) n=1050** |
|---|---|---|---|---|
| ʻŪʻū<br>(*Myripristis* spp.) | 25960 | 51.0 | 73.7 ± 20.4 | 12.1 |
| Palani<br>(*Acanthurus dussumieri*) | 4619 | 9.1 | 170.3 ± 75.7 | 28.0 |
| ʻŌpelu Kala<br>(*Naso hexacanthus*) | 4149 | 8.1 | 168.5 ± 56.5 | 27.7 |
| Manini<br>(*Acanturus triostegus*) | 3381 | 6.6 | 42.8 ± 13.8 | 7.0 |
| Taʻape<br>*(Lutjanus kasmira*) | 2877 | 5.7 | 53.1 ± 36.4 | 8.7 |
| Laenihi<br>*(Iniistius* spp.) | 2637 | 5.2 | 0.1 ± 0.2 | 0.02 |
| Mu<br>(*Monotaxis grandoculis*) | 2402 | 4.7 | 61.2 ± 29.5 | 10.1 |
| Kumu<br>(*Parupeneus porphyreus*) | 2237 | 4.4 | 2.9 ± 2.4 | 0.5 |
| ʻĀweoweo<br>(*Priacanthus* spp.) | 1609 | 3.2 | 0.1 ± 0.1 | 0.01 |
| Weke ʻAʻa<br>(*Mulloidichthys flavolineatus*) | 1011 | 2.0 | 35.1 ± 14.5 | 5.8 |

**Table 23.** The top 10 most collected aquarium fish species based on average number caught in FY 2013–2014. Mean density (# ha$^{-1}$ ± 95% CI) within the West Hawaiʻi reference region (WHRR) outside of the Puʻukoholā Heiau NHS assessment polygon (PHNHS) based on analysis of all available survey data collected within the West Hawaiʻi reference region since 2005 (Table 20). Percentage of mean numerical density of top 10 species in parentheses. * = endemic species.

| **Species** | **Catch FY 2013–2014 (Walsh et al. 2013)** | **Catch FY 2013–2014 (% of average number caught; Walsh et al. 2013)** | **WHRR** | **WHRR (% of average number caught)** |
|---|---|---|---|---|
| Yellow Tang (*Zebrasoma flavescens*) | 273,778 | 85.2 | 759.6 ± 48.1 | 32.4 |
| Goldring Surgeonfish (*Ctenochaetus strigosus*)* | 28,407 | 8.8 | 1085.7 ± 67.1 | 46.3 |
| Achilles Tang (*Acanthurus achilles*) | 7,073 | 2.2 | 14.7 ± 4.1 | 0.6 |
| Chevron Tang (*Ctenochaetus hawaiiensis*) | 4,045 | 1.3 | 27.9 ± 5.8 | 1.2 |
| Orangespine Unicornfish (*Naso lituratus*) | 4,026 | 1.3 | 92.56 ± 8.6 | 3.9 |
| Forcepsfish (*Forcipiger flavissimus*) | 1,045 | 0.3 | 44.0 ± 4.6 | 1.9 |
| Potter’s Angelfish (*Centropyge potteri*) | 945 | 0.3 | 49.5 ± 7.8 | 2.1 |
| Ornate Wrasse (*Halichoeres ornatissimus*)* | 724 | 0.2 | 115.9 ± 8.6 | 4.9 |
| Fourspot butterflyfish (*Chaetodon quadrimaculatus*) | 699 | 0.2 | 41.8 ± 4.3 | 1.8 |
| Orangeband Surgeonfish (*Acanthurus olivaceus*) | 698 | 0.2 | 113.5 ± 19.0 | 4.8 |

**Table 24.** Mean biomass (g 100 m$^{-2}$ ± 95% CI) of fishes commonly targeted by subsistence and recreational fisheries within the West Hawaiʻi Reference Region (WHRR) outside of the Puʻukoholā Heiau NHS assessment polygon. Species were selected based on Beets & Tom (unpublished data) and recommendations by NPS personnel. Analysis was conducted using all available survey data collected within the West Hawaiʻi reference region since the last assessment (Table 19).

| **Hawaiian** | **Common** | **Scientific** | **Biomass (g 100 m$^{-2}$)** |
|---|---|---|---|
| ʻŪʻū | Menpachi, Soldierfishes | *Myripristis* spp. | 73.4 ± 20.4 |
| Taʻape | Blueline snapper | *Lutjanus kasmira* | 53.1 ± 36.6 |
| ʻĀweoweo | Bigeye | *Priacanthus* spp. | 0.07 ± 0.1 |

**Table 24 (continued).** Mean biomass (g 100 m$^{-2}$ ± 95% CI) of fishes commonly targeted by subsistence and recreational fisheries within the West Hawaiʻi Reference Region (WHRR) outside of the Puʻukoholā Heiau NHS assessment polygon. Species were selected based on Beets & Tom (unpublished data) and recommendations by NPS personnel. Analysis was conducted using all available survey data collected within the West Hawaiʻi reference region since the last assessment (Table 19).

| **Hawaiian** | **Common** | **Scientific** | **Biomass (g 100 m$^{-2}$)** |
|---|---|---|---|
| Kole | Goldring surgeonfish | *Ctenochaetus strigosus* | 318.5 ± 25.6 |
| Uhu | Parrotfishes | *Scarus* spp., *Chlorurus* spp., *Calotomus* spp. | 823.2 ± 65.6 |
| Weke ʻula | Yellowfin goatfish | *Mulloidichthys vanicolensis* | 13.3 ± 7.9 |
| Manini | Convict tang | *Acanthurus triostegus* | 42.8 ± 13.8 |
| Palani | Eyestripe surgeonfish, Pone | *Acanthurus dussumieri* | 170.3 ± 75.7 |
| Pākuʻikuʻi | Achilles tang | *Acanthurus achilles* | 10.0 ± 7.4 |
| Pualu | Ringtail or yellowfin surgeonfish | *Acanturus blochii, A. xanthopterus* | 76.5 ± 28.7 |
| Maʻo maʻo | Hawaiian sergeant | *Abudefduf abdominalis* | 41.3 ± 19.9 |
| Kūpīpī | Blackspot sergeant | *Abudefduf sordidus* | 23.2 ± 12.6 |
| ʻAmaʻama | Mullet | *Mugil cephalus* | 0 ± 0 |
| Āholehole | Hawaiian flagtail | *Kuhlia sandvicensis* | 0 ± 0 |
| Weke ʻaʻā | Yellowstripe goatfish | *Mulloidichthys flavolineatus* | 35.1 ± 14.5 |
| Weke nono | Moilua, Aka Weke, Red goatfish | *Mulloidichthys pflugeri* | 8.9E-03 ± 0.02 |
| Kūmū | White Saddle goatfish | *Parupeneus porphyeus* | 2.9 ± 2.4 |
| Munu | Doublebar goatfish, Joe Louis | *Parupeneus insularis* | 28.5 ± 15.0 |

*Statistical Analyses*

Measures of the overall nearshore fish community abundance and diversity were analyzed using ANOVA with data transformed for normality. Biomass and numerical density were transformed using cube root functions and richness was transformed using a square root function. Measures of the proportional composition of different consumer groups or species origins were assessed using a PERMANOVA. Data for individual species in the three fisheries were zero inflated and not suitable for statistical analysis. When summed the numerical density of aquarium trade fishery focal species, and biomass of commercial fisheries or the recreational and subsistence fisheries focal species were positively skewed but no longer zero inflated, and comparisons were made using a Mann-Whitney test.

### 4.4.3.4 Reference Conditions

*Overall nearshore fish community*

Mean biomass was lower (t-test; $t = 11.14$; $p<0.001$) and species richness was higher (t-test; $t = -2.01$; $p = 0.045$) in the West Hawaiʻi reference region than in Kalaupapa NHP. Numerical density was similar between the West Hawai‘i reference region and Kalaupapa NHP (Table 25; t-test; t = 1.34; p = 0.18).

**Table 25.** Backtransformed mean overall fish biomass (g m$^{-2}$ [95% CI]), numerical density (number m$^{-2}$ [95% CI]), and species richness (number of species 125 m$^{-2}$ [95% CI]) for all data sources within the West Hawai‘i Reference Region outside of the Pu‘ukoholā Heiau NHS assessment polygon (WHRR), and within Kalaupapa National Historical Park (KNHP) based on analysis of all available survey data collected along the west Hawai‘i coast since the last assessment (Table 20). n represents the number of transects used for analysis; p was calculated using t-tests conducted using data transformed for normality (biomass$^{(1/3)}$, Numerical Density$^{(1/3)}$, Richness$^{(1/2)}$).

| Measure | WHRR n=1086 | KNHP n=173 | p-value |
|---|---|---|---|
| Biomass | 42.1 [40.3, 43.1] | 121.2 [103.5, 140.8] | <0.0001 |
| Numerical Density | 0.97 [0.94, 1.01] | 1.1 [0.94, 1.2] | 0.18 |
| Richness | 28.2 [27.5, 29.0] | 26.0 [24.0, 28.0] | 0.045 |

*Consumer Group*

Mean biomass was higher for all consumer groups in Kalaupapa NHP than in the West Hawai‘i reference region. The percentage of biomass in the top predator and primary consumer groups were higher and the percentage in the secondary consumer group was lower in Kalaupapa NHP than in the West Hawai‘i reference region (Table 26; PERMANOVA; $R^2$= 0.005; p = 0.005).

**Table 26.** Mean (± 95% CI) biomass (g m$^{-2}$) of fish by consumer group for all data collected within the West Hawai‘i Reference Region outside of the Pu‘ukoholā Heiau NHS assessment polygon (WHRR), and in Kalaupapa National Historical Park (KNHP) based on analysis of all available survey data collected within the West Hawai‘i reference region since the last assessment (Table 20). n represents the number of transects used for analysis. Planktivores were not observed in the available survey data and are therefore not included in the table.

| | Biomass (g m$^{-2}$) | | Percentage of Biomass | |
|---|---|---|---|---|
| Consumer Group | WHRR n=1066 | KNHP n=173 | WHRR n=1066 | KNHP n=173 |
| Top Predator | 3.4 ± 7.0 | 13.7 ± 7.0 | 6.2 ± 0.6 | 7.0 ± 2.0 |
| Secondary Consumer | 20.6 ± 1.5 | 52.9 ± 10.4 | 43.0 ± 1.2 | 38.5 ± 3.4 |
| Primary Consumer | 26.8 ± 1.7 | 95.9 ± 14.7 | 50.8 ± 1.3 | 54.5 ± 3.6 |

The biomass of corallivores (those species that consume live coral directly), planktivores, and sessile invertebrate feeders has not changed substantially in West Hawai‘i over the past 14 years (1999–2013; Walsh et al. 2013). During this same time period, biomass of herbivores and detritivores has increased, while biomass of piscivores and mobile invertebrate feeders, commonly targeted for food by fishers, has decreased (Walsh et al. 2013).

*Introduced Nearshore Marine Fish Species*

The mean percentages of indigenous species is lower and the percentage of introduced species is higher in Kalaupapa NHP than in the West Hawai‘i reference region (Table 27; PERMANOVA; $R^2 = 0.037$; $p = 0.001$).

**Table 27.** Percentage of species in the West Hawai‘i Reference Region (WHRR, n=1043 transects), and in Kalaupapa National Historical Park (KNHP, n=170 transects) that are endemic, indigenous, and introduced based on analysis of all available survey data collected in the West Hawai‘i reference region since 2005 (Table 20).

| Category | WHRR n=1063 | KNHP n=170 |
|---|---|---|
| Endemic | 26.0 ± 0.6 | 26.6 ± 1.8 |
| Indigenous | 73.6 ± 0.6 | 69.5 ± 1.7 |
| Introduced | 0.3 ± 0.08 | 3.9 ± 0.5 |

Belt transect and free swim surveys conducted annually along the West Hawai‘i coastline since 1999 show a declining trend in ta‘ape and roi biomass following a peak in 2004 (Walsh et al. 2013). Walsh et al. 2013 hypothesized that the decline in roi abundance was associated with a fish die off event in 2006. Several species of fish including *Mulloidichthys* sp., *Acanthurus dussumeiri*, *Acanthurus olivaceus*, and *Chlorurus sordidus* were observed dead on the beach, or struggling underwater or at the surface (Walsh et al. 2013). While affected fish were observed to have distended swim bladders, the cause of this condition is unknown (Walsh et al. 2013). The cause of roi mortality was not identified. No proximate cause was provided for changes in ta‘ape biomass.

One of the concerns regarding roi is that they may be responsible for declines in two fish important in the aquarium trade, yellow tang (*Zebrasoma flavescens*) and goldring surgeonfish (*Ctenochaetus strigosus*), in West Hawai‘i. No correlation was observed between the long-term trends in yellow tang or goldring surgeonfish and roi, suggesting that roi are not responsible for changes in the abundance of these two fish species (Walsh et al. 2013).

*Commercial Fisheries*

Total biomass was calculated for the top 10 commercially landed taxa based on DAR commercial landings reports (Table 22). Fisheries independent data based on compiled surveys from the West Hawai‘i reference region were zero inflated and inappropriate for statistical analysis. Qualitative comparison between the percentage of catch (commercial landings) and percentage of biomass (fisheries independent survey data) shows different patterns. ‘Ū‘ū (*Myripristis* spp.) was most abundant based on commercial landings reports while palani (*Acanthurus dussumieri*) and ‘Ōpelu Kala (*Naso hexacanthus*) were the two most abundant species based on the fisheries independent data (Table 22).

The summary analysis presented above does not include longitudinal data. A discussion of trends in the population dynamics of resource fishes within the West Hawai‘i reference region is provided by

Walsh et al. (2013). DAR WHAP monitoring collects data on resource fishes commonly targeted by commercial, recreational, and subsistence fishers. Resource fishes include “food” fish such as jacks (Carangidae), goatfishes (Mullidae) and uhu (parrotfishes (Scaridae); Walsh et al. 2013). Walsh et al. (2013) reported that resource fish have increased in WCHI over the last 14 years of WHAP monitoring.

### *Aquarium Trade Fishery*

The aquarium catch for FY 2013–2014 was used to rank the top 10 most collected species (Table 23). Qualitative assessment of the ranking of species by abundance varies between fisheries dependent and independent surveys (Table 23). The 10 most collected aquarium species were identified based on DAR reports for Fiscal Year (FY) 2013–2014 (Oct 1, 2013–Sep 30, 2014; Walsh et al. 2013). The mean numerical density for the 10 most collected species were assessed for the West Hawaiʻi reference region. Mean numerical density was calculated for each species based on all available survey data collected in the West Hawaiʻi reference region since 2015 (Table 23). Fisheries independent data based on compiled surveys from the West Hawaiʻi reference region were zero inflated and inappropriate for statistical analysis. Qualitative comparison between the percentage of catch (number of aquarium fish) and percentage of numerical density (fisheries independent survey data) shows different patterns. Yellow tang (*Zebrasoma flavescens*) was the most commonly caught species based on catch reports. Fisheries independent data showed that Goldring Surgeonfish (*Ctenochaetus strigosus*) and Yellow tang (*Z. flaveescens*) were the two most commonly-observed species (Table 23).

The analysis presented here does not include longitudinal data. A discussion of trends in the population dynamics of resource fishes within the West Hawaiʻi reference region is provided by Walsh et al. (2013). Based on current DAR WHAP monitoring data, numerical density of fishes collected for the aquarium trade have increased over the past 14 years (Walsh et al. 2013). Numerical densities of three of the most commonly collected aquarium species, yellow tang, goldring surgeonfish, and forcepsfish (*Forcipiger flavissimus*) increased markedly from 2000 to 2014 suggesting that the implementation of the Fish Replenishment Area network in 2000 was having a positive impact on fish populations along this coastline (Walsh et al. 2013).

### *Recreational and Subsistence Fisheries*

Mean biomass was calculated for a group of fishes commonly targeted by subsistence and recreational fishers using all available survey data collected in the West Hawaiʻi reference region since the last assessment (Table 24).

The summary analysis presented above does not include longitudinal data. A discussion of trends in the community dynamics within the West Hawaiʻi reference region is provided by Walsh et al. (2013). Walsh et al. (2013) reported that the average numerical density of food fishes in West Hawaiʻi have increased over the last 14 years (1999–2013) from 37.3 to 57.6 fish/100 m$^2$. It is important to note that while the West Hawaiʻi reference region average for all species of food fishes has increased over this time period, there are individual species that are in decline. Further, the increasing trends in some groupings seem to be driven by Marine Protected Areas (MPAs) that are protected from all types of fishing vs. Fish Replensiment Areas (FRAs) that only protect aquarium species.

### 4.4.3.5 Current Condition and Trend

Overall, the nearshore marine fish community in the Pu‘ukoholā Heiau NHS assessment polygon was depauperate compared to the rest of the West Hawai‘i reference region and Kalaupapa NHP. Data were transformed for normality (biomass$^{1/3}$, numerical density$^{1/3}$, species richnes$^{1/2}$). Three separate ANOVA showed that mean fish biomass ($F_{2,1285}$=191.2, p<0.001; Figure 29a), numerical density ($F_{2,1285}$ = 41.62, p <0.001; Figure 29b), and species richness ($F_{2,1265}$ = 54.52, p<0.001; Figure 29c) were all significantly lower in the Pu‘ukoholā Heiau NHS assessment polygon compared to Kalaupapa NHP, and the West Hawai‘i reference region. Mean fish biomass in the Pu‘ukoholā Heiau NHS assessment polygon was less than half the mean biomass within the West Hawai‘i reference region, and less than 15% of mean fish biomass at Kalaupapa NHP. Mean numerical density and species richness in the Pu‘ukoholā Heiau NHS assessment polygon were less than half that found within the rest of the West Hawai‘i reference region or Kalaupapa NHP. Species richness was significantly lower in the Pu‘ukoholā Heiau NHS assessment polygon than within the rest of the West Hawai‘i reference region or in Kalaupapa NHP.

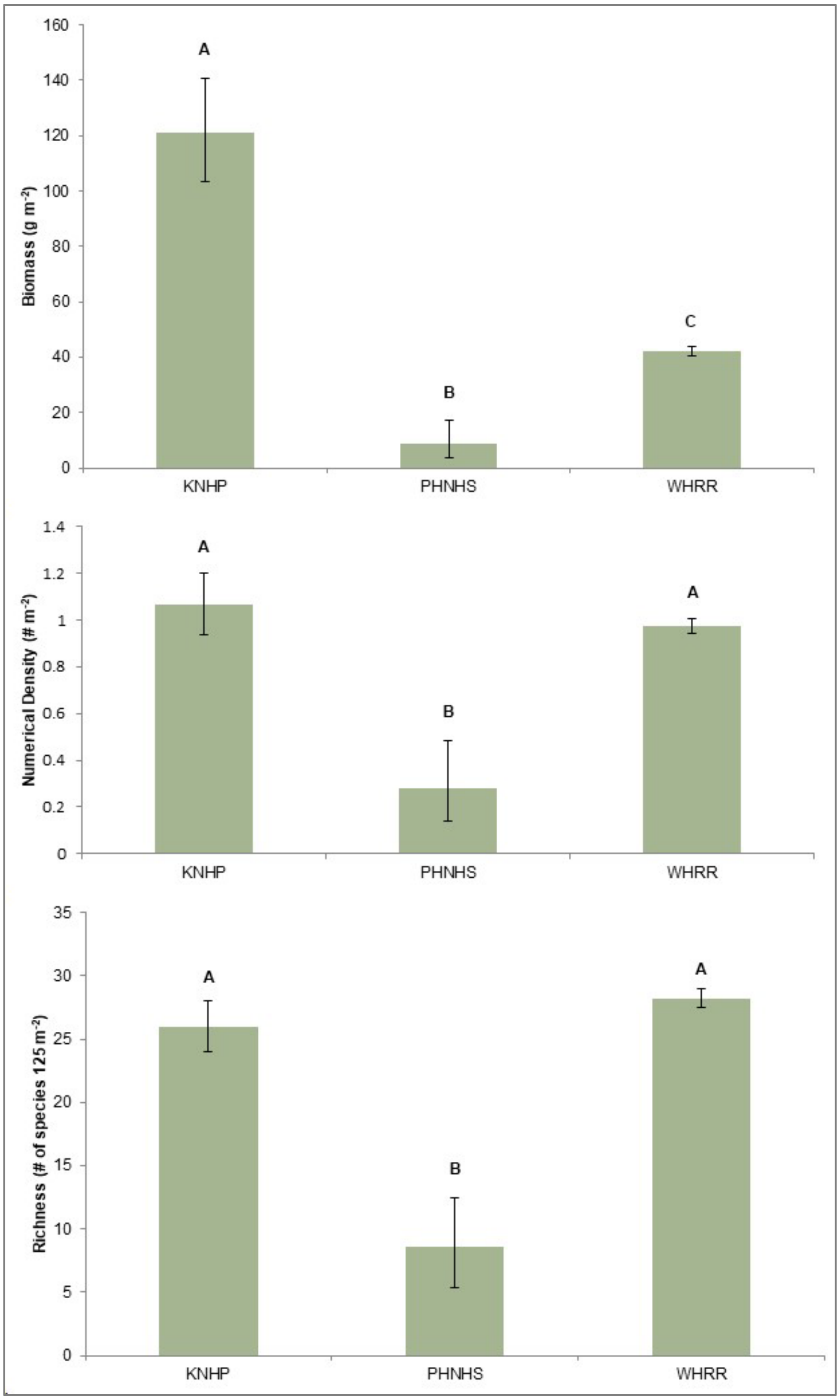

**Figure 29.** Richness of nearshore marine fish communities. Statistical analyses were conducted using data transformed for normality (biomass$^{(1/3)}$, Numerical Density$^{(1/3)}$, Richness$^{(1/2)}$). Bars represent backtransformed values. a) Mean biomass (g m$^{-2}$ ± 95% CI), b) mean numerical density (# m$^{-2}$), c) mean species richness (# of species 125 m$^{-2}$) in the Pu‘ukoholā Heiau NHS assessment polygon (PHNHS), the West Hawai‘i Reference Region (WHRR), and in Kalaupapa National Historical Park (KNHP) based on analysis of all available survey data collected within the West Hawai‘i reference region that became available since 2005 (Table 19). Different letters above bars denote statistically different means (α=0.05).

*Consumer group*

We found a weak but significant difference in the proportion of biomass in consumer groups between the Puʻukoholā Heiau NHS assessment polygon and the West Hawaiʻi reference region (PERMANOVA; $R^2$=0.0048, p = 0.011). There was no significant difference in the proportion of biomass in consumer groups and between the assessment polygon and Kalaupapa NHP (PERMANOVA; $R^2$=0.015, p = 0.053). Trophic composition (i.e., the average percentage of biomass within each consumer group) was comparable between the West Hawaiʻi reference region, and Kalaupapa NHP (Figure 30; PERMANOVA; $R^2$=0.0049, p = 0.012). The trophic composition within the Puʻukoholā Heiau NHS assessment polygon differed from the reference sites in that there was a lower percentage of top predators and a higher percentage of secondary consumers (Figure 30).

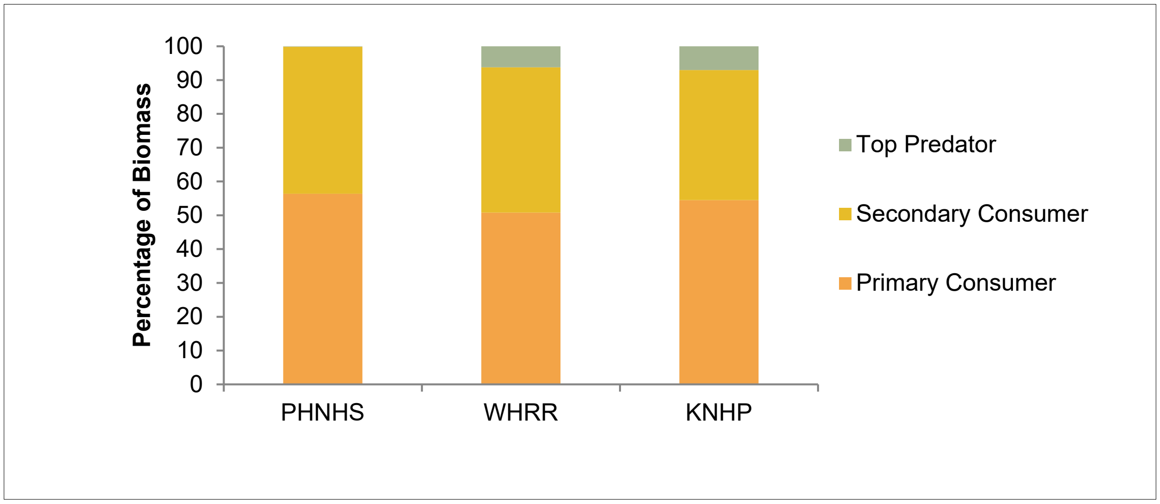

**Figure 30.** Mean percentage of biomass by consumer group in the Puʻukoholā Heiau NHS assessment polygon (PHNHS, n=30 transects), the West Hawaiʻi Reference Region (WHRR, n=1066 transects), and in Kalaupapa National Historical Park (KNHP, n=173 transects) based on analysis of all available survey data collected within the West Hawaiʻi reference region since 2005 (Table 19).

*Introduced Nearshore Marine Fish Species*

Taʻape (*Lutjanus kasmira*), toʻau (*Lutjanus fulvus*) and roi (*Cephalopholis argus*) were the only introduced fish species recorded from transect data collected within the Puʻukoholā Heiau NHS assessment polygon, the West Hawaiʻi reference region, or in Kalaupapa NHP. There were weak but significant differences in the percentages of species in the different groupings (i.e., endemic, indigenous, and introduced) between the Puʻukoholā Heiau NHS assessment polygon and the West Hawaiʻi reference region (PERMANOVA; $R^2$=0.011, p = 0.002) and Kalaupapa NHP (PERMANOVA; $R^2$=0.019, p = 0.037). The majority of species within the Puʻukoholā Heiau NHS assessment polygon, Kalaupapa NHP and within the West Hawaiʻi reference region excluding the Puʻukoholā Heiau NHS assessment polygon points consists of indigenous species. Even though the majority of species within all three study areas consists of indigenous species, Kalaupapa NHP and the Puʻukoholā Heiau NHS assessment polygon had a higher percentage of introduced species than the West Hawaiʻi reference region (Figure 31).

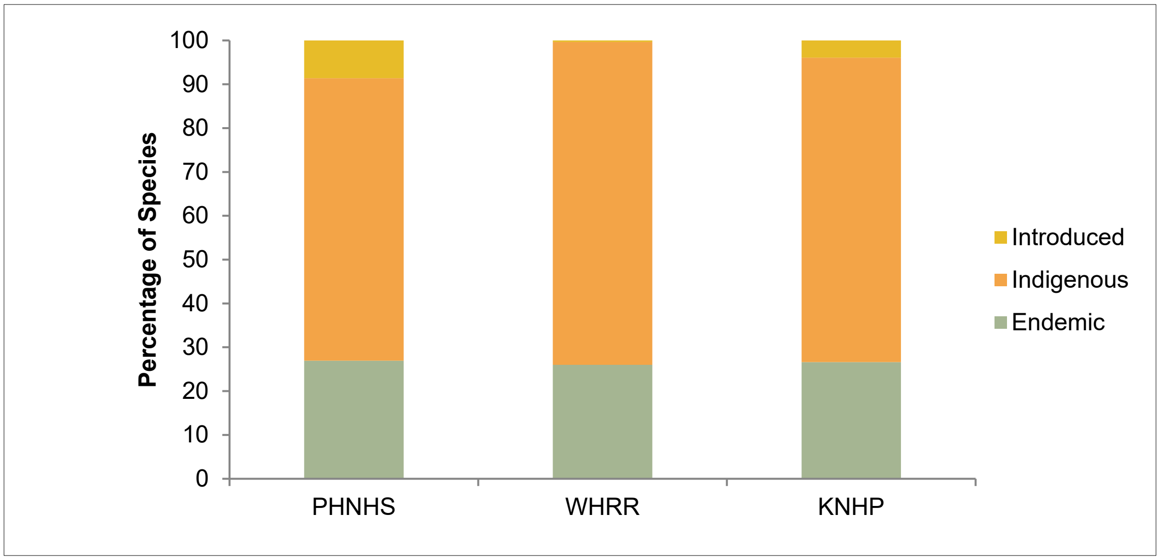

**Figure 31.** Percentage of species within the Puʻukoholā Heiau NHS assessment polygon (PHNHS; n=27 transects with non-zero values), along the West Hawaiʻi reference region (WHRR; n=1063 transects with non-zero values), and in Kalaupapa National Historical Park (KNHP, n=170 transects with non-zero values) that are endemic, indigenous and introduced based on analysis of all available survey data collected within the West Hawaiʻi reference region since 2005 (Table 19).

Beets et al. (2010) reported that toʻau was ranked as the sixth most dominant species by biomass within the Puʻukoholā Heiau NHS assessment polygon. Taʻape are a schooling species and often have a patchy distribution. Consequently, the biomass of taʻape within the study area may fluctuate widely over short periods of time as schools move in and out of the bay.

*Commercial Fisheries*

Zero inflation of biomass calculated at the taxa level prevented statistical analysis of individual taxa. A comparison of biomass summed across all 10 of the most commonly reported commercially caught inshore taxa showed no statistically significant difference between biomass in the Puʻukoholā Heiau NHS assessment polygon and the West Hawaiʻi reference region excluding the assessment polygon (Mann-Whitney U-test; u=13104; p=0.075; Figure 32)

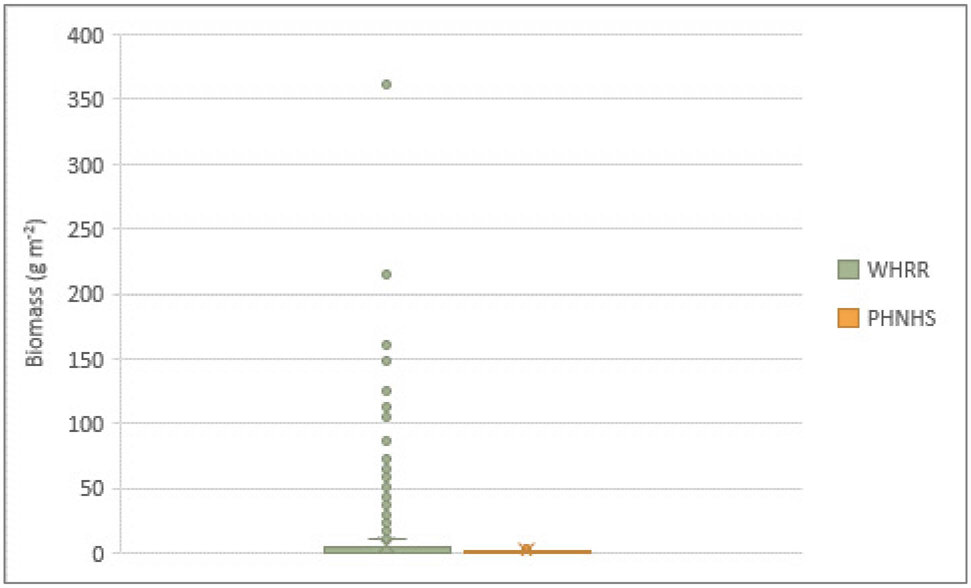

**Figure 32.** Biomass (g $m^{-2}$) of top summed 10 commercially harvested inshore taxa (Table 22) within the Pu‘ukoholā Heiau NHS assessment polygon (PHNHS, n=30 transects) and the West Hawai‘i Reference Region (WHRR, n=1066 transects) based on all available survey data collected within the West Hawai‘i reference region since the last assessment (Table 20). The upper and lower boundaries of the box represent the 25th and 75th percentiles, the horizontal line within the box represents the median, the X represents the mean, the whiskers represent the highest and lowest data values that fall within 1.5 IQR, and the points represent outliers.

*Aquarium Trade Fishery*

Zero inflation of numerical density calculated at the taxa level prevented statistical analysis of individual species. A comparison of biomass summed across all 10 of the most commonly reported aquarium species showed a statistically significant difference between numerical density of aquarium species in the Pu‘ukoholā Heiau NHS assessment polygon and the West Hawai‘i reference region excluding the assessment polygon (Mann-Whitney U-test; u=2129.5; p<0.0001; Figure 33).

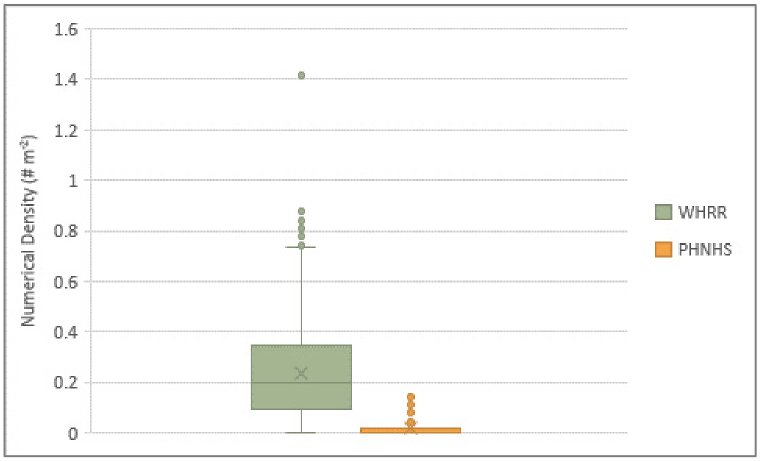

**Figure 33.** Numerical density (# $m^{-2}$) of summed top ten aquarium fish species (Table 23) within the Puʻukoholā Heiau NHS assessment polygon (PHNHS, n=30 transects) and the West Hawaiʻi Reference Region (WHRR, n=1066 transects) based on analysis of all available survey data collected within the West Hawaiʻi reference region since the last assessment (Table 20). The upper and lower boundaries of the box represent the 25th and 75th percentiles, the horizontal line within the box represents the median, the X represents the mean, the whiskers represent the highest and lowest data values that fall within 1.5 IQR, and the points represent outliers.

*Recreational and Subsistence Fisheries*

Zero inflation of biomass calculated at the taxa level prevented statistical analysis of individual taxa. A comparison of biomass summed across recreational and subsistence fisheries taxa showed no statistically significant difference between biomass in the Puʻukoholā Heiau NHS assessment polygon and the West Hawaiʻi reference region excluding the assessment polygon (Mann-Whitney U-test; u=12774; p=0.06; Figure 34)

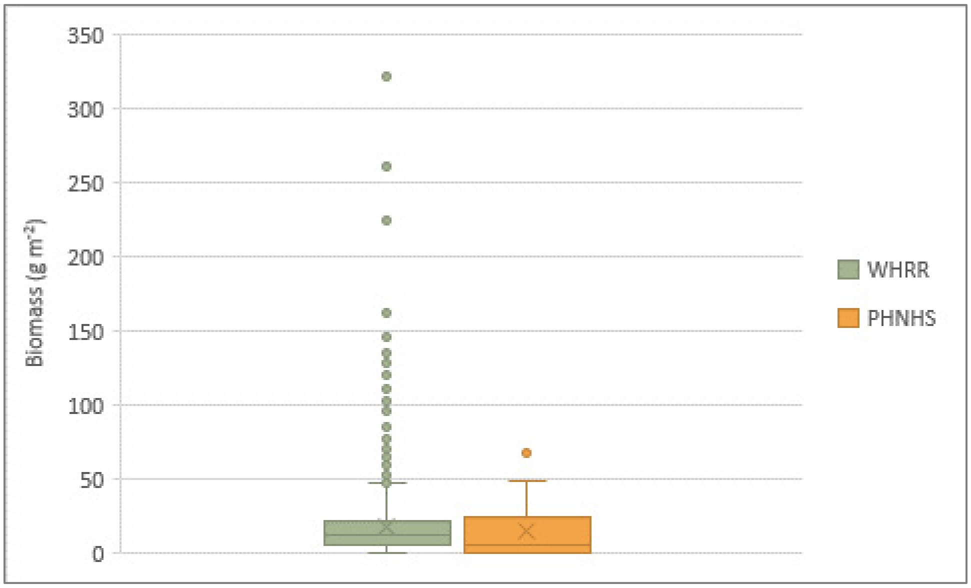

**Figure 34.** Biomass of summed fishes commonly targeted by subsistence and recreational fisheries within the Puʻukoholā Heiau NHS assessment polygon (PHNHS, n=30 transects) and the West Hawaiʻi Reference Region (WHRR, n=1066 transects). Species were selected based on Beets & Tom (unpublished data) and recommendations by NPS personnel. Analysis was based on all available survey data collected within the West Hawaiʻi reference region since the last assessment (Table 20). The upper and lower boundaries of the box represent the 25th and 75th percentiles, the horizontal line within the box represents the median, the X represents the mean, the whiskers represent the highest and lowest data values that fall within 1.5 IQR, and the points represent outliers.

#### 4.4.3.6 Data Gaps and Research Recommendations

While fisheries-independent data sets are comprehensive, data on fishing catch and effort are extremely limited. We summarized the commercial catch data for the reporting block containing the marine area of interest offshore of Puʻukoholā Heiau NHS. However, reporting blocks are large (block 102 is 24,846 ha in area), data are summed over 10 years owing to confidentially rules and recreational/subsistence fishing is not included, so this is likely not representative of fishing activity within the Puʻukoholā Heiau NHS assessment polygon. We recommend establishing a program to monitor fisheries-dependent data within Pelekane Bay.

# Chapter 5. Discussion

Overall, the natural resources at Puʻukoholā Heiau NHS are in poor condition. The state of the Pelekane watershed, vegetation community, benthic invertebrates and near shore marine fish all warrant significant concern. Levels of light pollution, water quality in the unnamed brackish waterbody, and water quality in marine waters in Pelekane Bay warrant moderate concern. None of the natural resources in the park evaluated in this assessment were considered to be in good condition. The state of natural resources at Puʻukoholā Heiau NHS reflects the influence of degraded habitats surrounding the park.

Makeāhua Stream serves as a useful focal point for examining how regional processes impact natural resources within Puʻukoholā Heiau NHS, and how the different processes and resources covered in this assessment are closely interrelated. Makeāhua Stream is a conduit from upslope lands into and through the park. Storm events bring eroded sediments—and seeds—down into the riparian zone of Puʻukoholā Heiau NHS, the brackish waterbody, and Pelekane Bay. In addition, the channel itself may act as a movement corridor promoting animal dispersal into Puʻukoholā Heiau NHS.

The integrity of the stream channel depends on, and influences, the biological community of the riparian corridor and beyond. Ungulate trampling tends to increase erosion, mostly by reducing vegetation cover, but also by tramping stream banks in the delicate riparian zone. Nonnative grasses, such as buffelgrass, promote wildfires (Mueller-Dombois 1981), which in turn, increase erosion during subsequent flooding events (see chapter 4.3). High erosion rates can reduce the capacity for riparian vegetation to establish, and favor disturbance-adapted plants, typically invasive species.

Managing Makeāhua Stream to minimize its role as a conduit for sediments and nonnative species into Puʻukoholā Heiau NHS requires a multifaceted approach. Stream channel restoration, ungulate removal, wildfire management, or native vegetation replanting alone are not sufficient, but must be done in concert to yield sustained success. The same holds true for restoration efforts in upland habitats. Within the park, the possibility of small-scale controlled burns, in combination with site- and species-specific habitat restoration activities (Hudgens et al. 2024*,* Ainsworth and Wasser 2016), could be explored as tools for restoring the vegetation landscape to the park's commemorative period when King Kamehameha I built the large luakini war temple. Controlled burns must be undertaken with extreme caution, however, because wildfires such as the one that swept through the park in 2015 can have detrimental effects on stream function and native vegetation, destroy ungulate exclusionary fencing, and threaten cultural resources (Witter and Rasmussen 2015). Unfortunately, even if the stream runoff and erosion were reduced, the disrupting influence of Kawaihae harbor may still result in sub-par water quality conditions impacting benthic invertebrates and nearshore fish communities. Thus, the park should prioritize different types of restoration efforts in view of costs and benefits.

The Kawaihae Harbor breakwater is another example of how regional processes acting outside of the park can degrade resources within Puʻukoholā Heiau NHS. Severe degradation of benthic ecosystems in Pelekane Bay is the result of erosion upstream of the park, re-routing of Makeāhua Stream during harbor construction, and the presence of the harbor breakwater, which prevents waves and currents from flushing sediment out of the bay (MKSWCD 2005, Li et al. 2009).

The flora and fauna within Puʻukoholā Heiau NHS generally reflect that of the surrounding landscape, though NPS vegetation restoration efforts have resulted in increased coverage by native species. The influence of these regional processes means that managing natural resources within Puʻukoholā Heiau NHS will necessitate cooperation with neighboring land managers and stakeholders.

Several engineering solutions to the sediment problem in Pelekane Bay have been considered but not acted on. The U.S. Army Corps of Engineers and State of Hawaiʻi Department of Transportation examined the possibility of creating a new circulation channel connecting Kawaihae Deep Draft Harbor to Pelekane Bay (Li et al. 2009). The purpose of the proposed channel was to increase water circulation, promote sediment removal, and improve water quality in Pelekane Bay. However, water flow models indicated that the channel could become blocked by sand and would have to be dredged at least once a year, and the Army Corps of Engineers recommended that a channel not be constructed (Li et al. 2009). A sediment detention basin is another measure that has been considered. Flow from Makeāhua Stream would be directed into the basin for long enough that coarse sediment would settle out. The finest sediment would likely remain in suspension. A rock quarry uphill from the highway was considered as a possible site for the detention basin. At this time there is no indication that a detention basin will be built.

Continued coordination with restoration in adjacent lands, such as the Kohala Watershed Partnership's Pelekane Watershed Restoration project, will be an important aspect of natural resource management within Puʻukoholā Heiau NHS. Coalition-building with neighboring landowners and stakeholders can lead to restoration efforts at larger scales, leading to more sustainable improvements within Puʻukoholā Heiau NHS. Reduction of nonnative plants and animals at the scale of the Pelekane Bay watershed will lead to lower immigration rates of invasive species into Puʻukoholā Heiau NHS, as well as improve the viewscape from the park (Figure 35).

Nearshore fish management represents another opportunity for community stakeholder-driven action to improve conditions within Puʻukoholā Heiau NHS. The authors recommend a stakeholder-driven process to determine pono fishing practices in and around Puʻukoholā Heiau NHS. Pono fishing regulations would be those that respect and balance the economic and cultural importance of historic and current fishing practices employed at Puʻukoholā Heiau NHS with protection of fish populations for future generations. This will require a participatory process that includes all stakeholders including cultural practitioners, recreational, commercial, and subsistence fishers, non-extractive recreational and commercial users, scientists, and resource managers.

There are a variety of spatial marine management strategies in Hawaiʻi. These strategies work at a variety of scales throughout the state. State-managed, no-take Marine Protected Areas (MPA) cover <0.4% of nearshore waters (Friedlander et al. 2006). There is considerable resistance to the establishment of no-take MPAs by the fishing sector for a number of reasons including: loss of fishing areas, displacement or marginalization of subsistence fishers, perceived loss of income and cultural access, and the long lag time before benefits are realized (McClanahan et al. 2006, Cinner et al. 2009, Pauly 2009). MPAs which engage stakeholders early and often in the planning process tend to be more effective at achieving ecological and social goals (Mascia 2003, McClanahan et al. 2006, Cinner 2007, Agardy et al. 2011). The Fish Replenishment Areas along the west coast of Hawaiʻi Island are an example of a stakeholder-driven, adaptive management strategy that has been successful in achieving ecological objectives and economic benefits.

**Figure 35.** Landscape adjacent to John Young Homestead showing contrast in grass cover and erosion in (right of fence line) and out (left of fence line) of the goat exclusion area (IWS Photo, B. Hudgens).

Communities have increasingly explored the development of co-management partnerships between state resource management agencies and community groups to incorporate aspects of traditional ecological knowledge and customary marine tenure and shift some management authority to local scales where it was traditionally based (Friedlander et al. 2013). In 1994, the state of Hawaiʻi passed legislation for the designation of Community-Based Subsistence Fishing Areas (CBSFA) with the intent of revitalizing local fisheries through customary Hawaiian practices and tenure. Recently, the Department of Land and Natural Resources released standard operating procedures to establish CBSFA designation under Hawaiʻi Revised Statutes Chapter 188–22.6 (Zanre 2014).

Several communities throughout the Main Hawaiian Islands including Moʻomomi on Molokaʻi, Haʻena on Kauaʻi (Poepoe et al. 2007), and Kiholo on Hawaiʻi (Kittinger et al. 2015) have pursued the establishment of CBSFAs to manage harvest of nearshore fishes in their communities. The Kaʻūpūlehu community in north Kona on the Hawaiʻi Island has asked the state of Hawaiʻi to institute a 10-year moratorium/resting period on fish harvest in nearshore waters in response to declines in fish and coral abundance in that region (Minton et al. 2015). Kalaupapa National Historical Park located on the Kalaupapa peninsula on Molokaʻi has a semblance of local management due to its isolation as well as its political structure (Friedlander et al. 2013). The establishment of a CBSFA is one model for potential management of resources at Puʻukoholā Heiau NHS. The integration of traditional ecological knowledge and customary Hawaiian practices emphasized in the CBSFA process is in line with the mission of Puʻukoholā Heiau NHS.

There were numerous data gaps that made it either difficult to assess the condition of resources with high confidence or precluded assessments of recent trends. Data were completely lacking on stream sediment load, flood discharge, groundwater, and whether pollutants from Kawaihae Harbor are being transported to the marine waters of Puʻukoholā Heiau NHS. For many other resources within Puʻukoholā Heiau NHS, there were some data available but overall, their status was poorly characterized. These include watershed erosion rates, biota in the brackish waterbody, and the native mammal, bird and intertidal invertebrate communities within the park. Information on the latter two was restricted to one or two unreplicated studies over a decade old. Well-replicated studies are needed to characterize the dynamic nature of many of the biological communities found within Puʻukoholā Heiau NHS, and to determine how those communities respond to management efforts, disturbance events such as fire or storms, and long-term changes in climate. Many important events contributing to the health of biota in the park, such as recruitment of native marine fauna or use by transient species (e.g., migratory birds) are highly variable in both space and time, making them difficult to characterize in single studies. Evaluating the success of outplanting efforts at creating a sustained increase in native plant coverage requires knowledge about survival and reproduction of outplants. These studies would be particularly useful if combined with plant demography studies in other nearby restored areas, such as Kaloko-Honokōhau NHP.

In the case of the brackish waterbody, we faced the additional challenge of deciding upon a proper reference condition. Much like Royal Fishponds found at Puʻuhonua o Hōnaunau NHP and Kaloko-Honokōhau NHP, the brackish water body at Puʻukoholā Heiau NHS is influenced by the anthropogenic actions that resulted in its formation, and has no analogues, which are themselves poorly characterized. The reference conditions used for this assessment serve as a useful point of comparison but in no way are intended to represent an ideal condition. Studies describing population dynamics of fish and native invertebrates inhabiting the brackish water body could help determine appropriate comparisons to other Hawaiian brackish waterbodies for future assessment. A set of studies describing how these populations vary over time not only in the brackish water body at Puʻukoholā Heiau NHS but also at anchialine pools and Royal Fishponds along the coast would support a more complete understanding of brackish water communities on the Hawaiʻi Island.

## Conclusions

Two sets of regional forces exert a heavy influence on the natural resources in Puʻukoholā Heiau NHS: the pervasiveness of nonnative species inhabiting the west coast of Hawaiʻi, and large-scale modifications to the landscape surrounding the park. Both of these not only contribute to a degraded state of the biological community at Puʻukoholā Heiau NHS, but also threaten the cultural resources that are the focal point of the park's mission. Erosion, nonnative plants and mammals impact the viewscape of the park. Nonnative plants also increase wildfire risk, which may damage cultural resources. Erosion and the resulting sedimentation in Pelekane Bay have hidden the Hale o Kapuni.

Ongoing efforts to mitigate the effect of these processes have met with some success, and opportunities exist to improve the condition of natural resources at Puʻukoholā Heiau NHS. The regional nature of most threats and stressors acting on natural resources at Puʻukoholā Heiau NHS means that these opportunities will be maximized if the NPS is able to engage neighboring landowners/land managers, and local community stakeholders to coordinate efforts within and beyond the park borders. In particular, the park will likely gain most traction by working with partners on improving upstream erosion control along Makeāhua Stream and Pōhaukole Gulch and on increasing the abundance of native plants in both the park and adjacent lands.

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# Appendix A. Species list for Pu‘ukoholā Heiau National Historic Site

A species list for Pu‘ukoholā Heiau NHS can be found in Table 28.

**Table 28.** Species list reported by the NPS Pacific Island Network as of April 28, 2020. Bird data were further annotated with “island status” (* indicated as R=resident, M=migrant, V=vagrant) and the ‘io, nēnē, and pueo are further distinguished as “native-endemic” (Morin, personal communication, 21 January 2021).

| Category | Order | Family | Scientific Name | Common Name(s) | Nativeness |
|---|---|---|---|---|---|
| Bird | Accipitriformes | Accipitridae | *Buteo solitarius* | ‘Io, Hawaiian Hawk | Native-endemic*( R) |
| Bird | Anseriformes | Anatidae | *Anas clypeata* | Koloa Moha, Northern Shoveler | Native*(M) |
| Bird | Anseriformes | Anatidae | *Branta bernicla* | Brant | Native*(M) |
| Bird | Anseriformes | Anatidae | • *Branta hutchinsii minima*<br>• *Branta canadensis minima* | – | Native*(M) |
| Bird | Anseriformes | Anatidae | *Branta sandvicensis* | Nēnē, Hawaiian Goose | Native-endemic*( R) |
| Bird | Charadriiformes | Charadriidae | *Charadrius semipalmatus* | Semipalmated Plover | Native*(M) |
| Bird | Charadriiformes | Charadriidae | *Pluvialis fulva* | Kōlea, Pacific Golden Plover | Native*(M) |
| Bird | Charadriiformes | Laridae | • *Chroicocephalus philadelphia*<br>• *Larus philadelphia* | Bonaparte’s Gull | Native*(M) |
| Bird | Charadriiformes | Laridae | • *Hydroprogne caspia*<br>• *Sterna caspia* | Caspian Tern | Native*(M) |
| Bird | Charadriiformes | Laridae | *Larus delawarensis* | Ring-billed Gull | Native*(M) |
| Bird | Charadriiformes | Laridae | • *Leucophaeus pipixcan*<br>• *Larus pipixcan* | Franklin’s Gull | Native*(V) |
| Bird | Charadriiformes | Laridae | • *Sternula albifrons*<br>• *Sterna albifrons* | Little Tern | Native*(V) |
| Bird | Charadriiformes | Laridae | • *Sternula antillarum*<br>• *Sterna antillarum* | Least Tern[30] | Native*(M) |

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[30] Nesting has occurred on the island, but Least Terns are not officially considered established as residents (Morin, pers comm. 2021).

**Table 28 (continued).** Species list reported by the NPS Pacific Island Network as of April 28, 2020. Bird data were further annotated with "island status" (* indicated as R=resident, M=migrant, V=vagrant) and the ʻio, nēnē, and pueo are further distinguished as "native-endemic" (Morin, personal communication, 21 January 2021).

| Category | Order | Family | Scientific Name | Common Name(s) | Nativeness |
|---|---|---|---|---|---|
| Bird | Charadriiformes | Scolopacidae | *Arenaria interpres* | ʻAkekeke, Ruddy Turnstone | Native*(M) |
| Bird | Charadriiformes | Scolopacidae | *Calidris alba* | Hunakai, Sanderling | Native*(M) |
| Bird | Charadriiformes | Scolopacidae | *Limnodromus griseus* | Short-billed Dowitcher | Native*(M) |
| Bird | Charadriiformes | Scolopacidae | • *Tringa incana*<br>• *Heteroscelus incanus* | ʻŪlili, Wandering Tattler | Native*(M) |
| Bird | Columbiformes | Columbidae | *Columba livia* | Rock Dove | Non-native*(R) |
| Bird | Columbiformes | Columbidae | *Geopelia striata* | Zebra Dove | Non-native*(R) |
| Bird | Columbiformes | Columbidae | *Streptopelia chinensis* | Spotted Dove | Non-native*(R) |
| Bird | Columbiformes | Columbidae | *Zenaida macroura* | Mourning Dove | Non-native*(V) |
| Bird | Galliformes | Phasianidae | *Francolinus francolinus* | Black Francolin | Non-native*(R) |
| Bird | Galliformes | Phasianidae | *Francolinus pondicerianus* | Grey Francolin | Non-native*(R) |
| Bird | Gruiformes | Rallidae | *Fulica* | Coots[31] | See footnote [22] |
| Bird | Passeriformes | Alaudidae | *Alauda arvensis* | Eurasian Skylark, Skylark | Non-native*(R) |
| Bird | Passeriformes | Cardinalidae | *Cardinalis cardinalis* | Northern Cardinal | Non-native*(R) |
| Bird | Passeriformes | Estrildidae | • *Euodice cantans*<br>• *Lonchura malabarica* | African Silverbill, Warbling Silverbill | Non-native*(R) |
| Bird | Passeriformes | Estrildidae | *Lonchura punctulata* | Nutmeg Mannikin, Scaly-breasted Munia | Non-native*(R) |
| Bird | Passeriformes | Fringillidae | • *Crithagra mozambica*<br>• *Serinus mozambicus* | Yellow-fronted Canary | Non-native*(R) |
| Bird | Passeriformes | Fringillidae | • *Haemorhous mexicanus*<br>• *Carpodacus mexicanus* | House Finch | Non-native*(R) |

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[31] Observation does not indicate species, however, if this was a Hawaiian Coot, *Fulica alai*, it would be considered a rare, native-endemic, resident (Morin, pers comm. 2021).

**Table 28 (continued).** Species list reported by the NPS Pacific Island Network as of April 28, 2020. Bird data were further annotated with “island status” (* indicated as R=resident, M=migrant, V=vagrant) and the ʻio, nēnē, and pueo are further distinguished as “native-endemic” (Morin, personal communication, 21 January 2021).

| **Category** | **Order** | **Family** | **Scientific Name** | **Common Name(s)** | **Nativeness** |
|---|---|---|---|---|---|
| Bird | Passeriformes | Mimidae | *Mimus polyglottos* | Northern Mockingbird | Non-native*$^{(R)}$ |
| Bird | Passeriformes | Passeridae | *Passer domesticus* | House Sparrow | Non-native*$^{(R)}$ |
| Bird | Passeriformes | Sturnidae | *Acridotheres tristis* | Common Myna | Non-native*$^{(R)}$ |
| Bird | Passeriformes | Thraupidae | *Paroaria capitata* | Yellow-billed Cardinal | Non-native*$^{(R)}$ |
| Bird | Passeriformes | Thraupidae | *Sicalis flaveola* | Saffron Finch | Non-native*$^{(R)}$ |
| Bird | Passeriformes | Zosteropidae | *Zosterops japonicus* | Japanese White-eye | Non-native*$^{(R)}$ |
| Bird | Pelecaniformes | Ardeidae | *Bubulcus ibis* | Cattle Egret, Western Cattle Egret | Non-native*$^{(R)}$ |
| Bird | Pelecaniformes | Ardeidae | *Nycticorax nycticorax* | ʻAukuʻu, Black-crowned Night Heron | Native*$^{(R)}$ |
| Bird | Strigiformes | Strigidae | *Asio flammeus sandwichensis* | Pueo, Hawaiian Short-eared Owl | Native-endemic*$^{(R)}$ |
| Bird | Strigiformes | Tytonidae | *Tyto alba* | Barn Owl, Western Barn Owl | Non-native*$^{(R)}$ |
| Bird | Suliformes | Fregatidae | *Fregata minor* | Great Frigatebird, ʻIwa | Native*$^{(M)}$ |
| Fish | – | – | *Poecilia* sp. *hybrid complex* | Liberty/Mexican Molly | Non-native |
| Fish | Anguilliformes | Congridae | *Conger cinereus* | Mustache Conger | Native |
| Fish | Anguilliformes | Muraenidae | *Echidna nebulosa* | Snowflake, pūhi kāpā | Native |
| Fish | Anguilliformes | Muraenidae | *Gymnothorax flavimarginatus* | Yellowmargin, pūhi paka | Native |
| Fish | Carcharhiniformes | Carcharhinidae | *Carcharhinus melanopterus* | Blacktip Reef Shark | Native |
| Fish | Mugiliformes | Mugilidae | *Mugil cephalus* | Striped Mullet | Native |
| Fish | Perciformes | Acanthuridae | *Acanthurus achilles* | Achilles, pākuʻikuʻi | Native |
| Fish | Perciformes | Acanthuridae | • *Acanthurus blochii*<br>• *Acanthurus mata* | Ringtail, pualu | Native |
| Fish | Perciformes | Acanthuridae | *Acanthurus dussumieri* | Eye-stripe, palani | Native |

**Table 28 (continued).** Species list reported by the NPS Pacific Island Network as of April 28, 2020. Bird data were further annotated with “island status” (* indicated as R=resident, M=migrant, V=vagrant) and the ‘io, nēnē, and pueo are further distinguished as “native-endemic” (Morin, personal communication, 21 January 2021).

| Category | Order | Family | Scientific Name | Common Name(s) | Nativeness |
|---|---|---|---|---|---|
| Fish | Perciformes | Acanthuridae | *Acanthurus nigrofuscus* | Brown, ma‘i‘i‘i | Native |
| Fish | Perciformes | Acanthuridae | *Acanthurus nigroris* | Bluelined, maiko | Native |
| Fish | Perciformes | Acanthuridae | *Acanthurus olivaceus* | Orangeband, na‘ena‘e | Native |
| Fish | Perciformes | Acanthuridae | *Acanthurus triostegus* | Convict, manini | Native |
| Fish | Perciformes | Acanthuridae | *Acanthurus xanthopterus* | Yellowfin, pualu | Native |
| Fish | Perciformes | Acanthuridae | *Ctenochaetus strigosus* | Goldring, kole | Native |
| Fish | Perciformes | Acanthuridae | *Naso lituratus* | Orangespine, umaumalei | Native |
| Fish | Perciformes | Acanthuridae | *Zebrasoma flavescens* | Yellow Tang, lau‘ipala | Native |
| Fish | Perciformes | Chaetodontidae | *Chaetodon auriga* | Threadfin, kikakapu | Native |
| Fish | Perciformes | Chaetodontidae | *Chaetodon fremblii* | Bluestripe, ki¯ka¯kapu | Native |
| Fish | Perciformes | Chaetodontidae | *Chaetodon lunula* | Raccoon Butterflyfish, kikakapu | Native |
| Fish | Perciformes | Chaetodontidae | *Chaetodon lunulatus* | Oval, kapuhili | Native |
| Fish | Perciformes | Chaetodontidae | *Chaetodon multicinctus* | Multiband, ki¯ka¯kapu | Native |
| Fish | Perciformes | Chaetodontidae | *Chaetodon ornatissimus* | Ornate, kikakapu | Native |
| Fish | Perciformes | Chaetodontidae | *Chaetodon quadrimaculatus* | Fourspot, lau hau | Native |
| Fish | Perciformes | Chaetodontidae | *Chaetodon unimaculatus* | Teardrop, kikakapu | Native |
| Fish | Perciformes | Chaetodontidae | *Forcipiger longirostris* | Longnose, lau wiliwili nukunuku ‘oi‘oi | Native |
| Fish | Perciformes | Cichlidae | *Oreochromis mossambicus* | Mozambique mouth-breeder, Mozambique mouthbrooder, Mozambique tilapia | Non-native |
| Fish | Perciformes | Cirrhitidae | *Paracirrhites arcatus* | Arc-eye, pili ko‘a | Native |
| Fish | Perciformes | Gobiidae | *Asterropteryx semipunctatus* | Halfspotted | Native |
| Fish | Perciformes | Gobiidae | *Coryphopterus* sp. *1* | Hawaiian Sand | Native |

**Table 28 (continued).** Species list reported by the NPS Pacific Island Network as of April 28, 2020. Bird data were further annotated with “island status” (* indicated as R=resident, M=migrant, V=vagrant) and the ‘io, nēnē, and pueo are further distinguished as “native-endemic” (Morin, personal communication, 21 January 2021).

| Category | Order | Family | Scientific Name | Common Name(s) | Nativeness |
|---|---|---|---|---|---|
| Fish | Perciformes | Gobiidae | *Psilogobius mainlandi* | Hawaiian Shrimp Goby | Native |
| Fish | Perciformes | Labridae | *Coris gaimard* | Yellowtail Coris, hinalea ‘aki-lolo | Native |
| Fish | Perciformes | Labridae | *Coris venusta* | Elegant coris | Native |
| Fish | Perciformes | Labridae | *Gomphosus varius* | Bird, hinalea ‘i‘iwi | Native |
| Fish | Perciformes | Labridae | *Labroides phthirophagus* | Hawaiian Cleaner | Native |
| Fish | Perciformes | Labridae | • *Oxycheilinus unifasciatus*<br>• *Cheilinus rhodochrous*<br>• *Cheilinus unifasciatus* | Ringtail, po‘ou | Native |
| Fish | Perciformes | Labridae | *Stethojulis balteata* | Belted, ‘Omaka | Native |
| Fish | Perciformes | Labridae | *Thalassoma ballieui* | Blacktail | Native |
| Fish | Perciformes | Labridae | *Thalassoma duperrey* | Saddle, hi¯na¯lea lauwili | Native |
| Fish | Perciformes | Lutjanidae | *Lutjanus fulvus* | Blacktail, to‘au | Non-native |
| Fish | Perciformes | Mullidae | • *Mulloidichthys flavolineatus*<br>• *Mulloides flavolineatus*<br>• *Mulloides samoensis* | Yellowstripe, weke | Native |
| Fish | Perciformes | Mullidae | • *Parupeneus insularis*<br>• *Parupeneus bifasciatus* | Doublebar, munu, Island | Native |
| Fish | Perciformes | Mullidae | *Parupeneus multifasciatus* | Manybar, Moano | Native |
| Fish | Perciformes | Pomacanthidae | *Centropyge potteri* | Potter’s angelfish | Native |
| Fish | Perciformes | Pomacentridae | *Abudefduf abdominalis* | Sargent Major, mamo | Native |
| Fish | Perciformes | Pomacentridae | *Abudefduf sordidus* | Blackspot, ku¯pi¯pi¯ | Native |
| Fish | Perciformes | Pomacentridae | *Abudefduf vaigiensis* | Indo-Pacific Sargent | Native |
| Fish | Perciformes | Pomacentridae | *Chromis ovalis* | Oval | Native |
| Fish | Perciformes | Pomacentridae | *Chromis vanderbilti* | Blackfin | Native |

**Table 28 (continued).** Species list reported by the NPS Pacific Island Network as of April 28, 2020. Bird data were further annotated with “island status” (* indicated as R=resident, M=migrant, V=vagrant) and the ‘io, nēnē, and pueo are further distinguished as “native-endemic” (Morin, personal communication, 21 January 2021).

| Category | Order | Family | Scientific Name | Common Name(s) | Nativeness |
|---|---|---|---|---|---|
| Fish | Perciformes | Pomacentridae | *Dascyllus albisella* | Hawaiian dascyllus, 'a¯lo'ilo'i | Native |
| Fish | Perciformes | Pomacentridae | *Plectroglyphidodon imparipennis* | Brighteye | Native |
| Fish | Perciformes | Pomacentridae | • *Stegastes fasciolatus*<br>• *Pomacentrus jenkinsi* | Pacific Gregory | Native |
| Fish | Perciformes | Scaridae | • *Chlorurus perspicillatus*<br>• *Scarus perspicillatus* | Spectacled, uhu uliuli | Native |
| Fish | Perciformes | Scaridae | • *Chlorurus sordidus*<br>• *Scarus sordidus* | Bullethead, uhu | Native |
| Fish | Perciformes | Scaridae | *Scarus psittacus* | Palenose, Uhu | Native |
| Fish | Perciformes | Scaridae | *Scarus rubroviolaceus* | Redlip, pa¯lukaluka | Native |
| Fish | Perciformes | Scaridae | *Scarus* sp. *1* | Scarus sp. | Native |
| Fish | Perciformes | Serranidae | *Cephalopholis argus* | Blue-spotted | Non-native |
| Fish | Perciformes | Zanclidae | • *Zanclus cornutus*<br>• *Zanclus canescens* | Moorish Idol, Kihikihi | Native |
| Fish | Scorpaeniformes | Caracanthidae | • *Caracanthus typicus*<br>• *Caracanthus maculatus* | Orbicular Velvetfish | Native |
| Fish | Scorpaeniformes | Scorpaenidae | • *Sebastapistes coniorta*<br>• *Scorpaena coniorta* | Speckled scorpionfish | Native |
| Fish | Tetraodontiformes | Balistidae | *Melichthys niger* | Black Durgon, humuhumu'el'ele | Native |
| Fish | Tetraodontiformes | Balistidae | *Rhinecanthus rectangulus* | Reef, humuhumunukunukuapua'a | Native |
| Fish | Tetraodontiformes | Balistidae | *Sufflamen bursa* | Lei, Humuhumulei | Native |
| Fish | Tetraodontiformes | Diodontidae | *Diodon holocanthus* | Spiny puffer, 'o'opu okala | Native |
| Fish | Tetraodontiformes | Tetraodontidae | *Arothron meleagris* | Spotted | Native |

**Table 28 (continued).** Species list reported by the NPS Pacific Island Network as of April 28, 2020. Bird data were further annotated with "island status" (* indicated as R=resident, M=migrant, V=vagrant) and the ʻio, nēnē, and pueo are further distinguished as "native-endemic" (Morin, personal communication, 21 January 2021).

| Category | Order | Family | Scientific Name | Common Name(s) | Nativeness |
|---|---|---|---|---|---|
| Fish | Tetraodontiformes | Tetraodontidae | *Canthigaster amboinensis* | Ambon Toby | Native |
| Fish | Tetraodontiformes | Tetraodontidae | *Canthigaster jactator* | Hawaiian Whitespotted | Native |
| Mammal | Artiodactyla | Bovidae | *Capra hircus* | feral goat | Non-native |
| Mammal | Artiodactyla | Suidae | *Sus scrofa* | feral pig, pua'a | Non-native |
| Mammal | Carnivora | Felidae | • *Felis catus*<br>• *Felis silvestris* | Domestic Cat | Non-native |
| Mammal | Carnivora | Herpestidae | • *Herpestes javanicus*<br>• *Herpestes auropunctatus* | small Indian mongoose | Non-native |
| Mammal | Chiroptera | Vespertilionidae | *Lasiurus cinereus semotus* | Hawaiian Hoary Bat | Native |
| Mammal | Rodentia | Muridae | *Mus musculus* | House mouse | Non-native |
| Mammal | Rodentia | Muridae | *Rattus exulans* | Polynesian rat, ʻiole | Non-native |
| Mammal | Rodentia | Muridae | *Rattus norvegicus* | Norway rat | Non-native |
| Mammal | Rodentia | Muridae | *Rattus rattus* | black rat, roof rat | Non-native |
| Reptile | Squamata | Gekkonidae | *Hemidactylus frenatus* | Common house gecko | Non-native |
| Reptile | Squamata | Gekkonidae | *Phelsuma laticauda* | gold dust day gecko | Non-native |
| Reptile | Squamata | Typhlopidae | *Ramphotyphlops braminus* | Brahminy blind snake | Native |
| Reptile | Testudines | Cheloniidae | *Chelonia mydas* | green sea turtle, honu | Native |
| Vascular Plant | – | – | *Pleomele marginata* | money tree | Non-native |
| Vascular Plant | Apiales | Apiaceae | • *Centella asiatica*<br>• *Reynoldsia sandwicensis* | Asiatic pennywort, pohe kula | Non-native |
| Vascular Plant | Arecales | Arecaceae | *Cocos nucifera* | coconut palm, niu | Non-native |
| Vascular Plant | Arecales | Arecaceae | *Phoenix canariensis* | Canary Island date palm | Non-native |
| Vascular Plant | Arecales | Arecaceae | • *Pritchardia maideniana*<br>• *Pritchardia affinis* | loulu | Native |

**Table 28 (continued).** Species list reported by the NPS Pacific Island Network as of April 28, 2020. Bird data were further annotated with “island status” (* indicated as R=resident, M=migrant, V=vagrant) and the ‘io, nēnē, and pueo are further distinguished as “native-endemic” (Morin, personal communication, 21 January 2021).

| **Category** | **Order** | **Family** | **Scientific Name** | **Common Name(s)** | **Nativeness** |
|---|---|---|---|---|---|
| Vascular Plant | Asparagales | Asparagaceae | • *Cordyline fruticosa*<br>• *Cordyline terminalis*<br>• *Dracaena aurea* | ti, kī | Non-native |
| Vascular Plant | Asparagales | Xanthorrhoeaceae | *Aloe vera* | aloe vera | Non-native |
| Vascular Plant | Asterales | Asteraceae | *Bidens cynapiifolia* | West Indian beggarticks | Non-native |
| Vascular Plant | Asterales | Asteraceae | • *Conyza bonariensis*<br>• *Erigeron bonariensis* | hairy fleabane | Non-native |
| Vascular Plant | Asterales | Asteraceae | *Emilia fosbergii* | pualele | Non-native |
| Vascular Plant | Asterales | Asteraceae | *Emilia sonchifolia* | Flora’s paintbrush | Non-native |
| Vascular Plant | Asterales | Asteraceae | • *Gamochaeta purpurea*<br>• *Gnaphalium purpureum*<br>• *Gnaphalium peregrinum* | purple cudweed | Non-native |
| Vascular Plant | Asterales | Asteraceae | • *Pluchea carolinensis*<br>• *Pluchea symphytifolia* | Sourbush | Non-native |
| Vascular Plant | Asterales | Asteraceae | *Senecio madagascariensis* | fireweed | Non-native |
| Vascular Plant | Asterales | Asteraceae | *Sonchus oleraceus* | pualele, sow thistle | Non-native |
| Vascular Plant | Asterales | Asteraceae | *Tridax procumbens* | cadillo chisaca, coat buttons, coatbuttons, tridax | Non-native |
| Vascular Plant | Asterales | Asteraceae | • *Xanthium strumarium* var. *canadense*<br>• *Xanthium saccharatum* | cocklebur, kikania | Non-native |
| Vascular Plant | Asterales | Goodeniaceae | • *Scaevola taccada*<br>• *Scaevola sericea* | naupaka kahakai, beach naupaka | Native |
| Vascular Plant | Boraginales | Cordiaceae | *Cordia subcordata* | kou | Native |
| Vascular Plant | Boraginales | Heliotropiaceae | *Heliotropium curassavicum* | kipukai, lau po`opo`ohina, nena, seaside heliotrope | Native |

**Table 28 (continued).** Species list reported by the NPS Pacific Island Network as of April 28, 2020. Bird data were further annotated with "island status" (* indicated as R=resident, M=migrant, V=vagrant) and the ʻio, nēnē, and pueo are further distinguished as "native-endemic" (Morin, personal communication, 21 January 2021).

| Category | Order | Family | Scientific Name | Common Name(s) | Nativeness |
|---|---|---|---|---|---|
| Vascular Plant | Boraginales | Heliotropiaceae | • *Tournefortia argentea*<br>• *Messerschmidia argentea* | tree heliotrope | Non-native |
| Vascular Plant | Brassicales | Brassicaceae | *Lepidium hyssopifolium* | hyssopleaf pepperweed | Non-native |
| Vascular Plant | Brassicales | Caricaceae | *Carica papaya* | papaya | Non-native |
| Vascular Plant | Brassicales | Cleomaceae | • *Cleome gynandra*<br>• *Gynandropsis gynandra* | wild spider flower | Non-native |
| Vascular Plant | Brassicales | Moringaceae | *Moringa oleifera* | horseradishtree | Non-native |
| Vascular Plant | Caryophyllales | Aizoaceae | *Sesuvium portulacastrum* | ʻākulikuli, sea purslane | Native |
| Vascular Plant | Caryophyllales | Amaranthaceae | *Alternanthera pungens* | khaki weed | Non-native |
| Vascular Plant | Caryophyllales | Amaranthaceae | *Amaranthus dubius* | spleen amaranth | Non-native |
| Vascular Plant | Caryophyllales | Amaranthaceae | *Amaranthus lividus* ssp. *polygonoides* | amaranth | Non-native |
| Vascular Plant | Caryophyllales | Amaranthaceae | *Amaranthus spinosus* | spiny amaranth | Non-native |
| Vascular Plant | Caryophyllales | Amaranthaceae | *Atriplex semibaccata* | Australian saltbush | Non-native |
| Vascular Plant | Caryophyllales | Amaranthaceae | • *Atriplex suberecta*<br>• *Atriplex muelleri* | peregrine saltbush | Non-native |
| Vascular Plant | Caryophyllales | Amaranthaceae | *Chenopodium murale* | \`aheahea, nettle-leaved goosefoot | Non-native |
| Vascular Plant | Caryophyllales | Amaranthaceae | • *Dysphania carinata*<br>• *Chenopodium carinatum* | – | Non-native |
| Vascular Plant | Caryophyllales | Molluginaceae | *Mollugo cerviana* | threadstem carpetweed | Non-native |
| Vascular Plant | Caryophyllales | Nyctaginaceae | *Boerhavia coccinea* | no common name | Non-native |
| Vascular Plant | Caryophyllales | Nyctaginaceae | • *Boerhavia repens*<br>• *Boerhavia diffusa* | alena | Native |
| Vascular Plant | Caryophyllales | Portulacaceae | *Portulaca oleracea* | common purslane, pigweed | Non-native |

**Table 28 (continued).** Species list reported by the NPS Pacific Island Network as of April 28, 2020. Bird data were further annotated with “island status” (* indicated as R=resident, M=migrant, V=vagrant) and the ‘io, nēnē, and pueo are further distinguished as “native-endemic” (Morin, personal communication, 21 January 2021).

| **Category** | **Order** | **Family** | **Scientific Name** | **Common Name(s)** | **Nativeness** |
|---|---|---|---|---|---|
| Vascular Plant | Caryophyllales | Portulacaceae | • *Portulaca pilosa*<br>• *Portulaca cyanosperma* | ‘ākulikuli, chisme, kiss me quick | Non-native |
| Vascular Plant | Cucurbitales | Cucurbitaceae | *Cucumis dipsaceus* | teasel gourd | Non-native |
| Vascular Plant | Cucurbitales | Cucurbitaceae | *Lagenaria siceraria* | ipu, bottle gourd | Non-native |
| Vascular Plant | Dioscoreales | Taccaceae | *Tacca leontopetaloides* | pia, Polynesian arrowroot | Non-native |
| Vascular Plant | Fabales | Fabaceae | *Acacia koa* | koa | Native |
| Vascular Plant | Fabales | Fabaceae | • *Desmanthus pernambucanus*<br>• *Desmanthus virgatus* | Slender mimosa | Non-native |
| Vascular Plant | Fabales | Fabaceae | • *Desmodium sandwicense*<br>• *Desmodium uncinatum* | chili clover, kikania pipili, pilipili, pilipili `ula, pua pilipili, Spanish clover | Non-native |
| Vascular Plant | Fabales | Fabaceae | • *Erythrina sandwicensis*<br>• *Erythrina monosperma* | wiliwili | Native |
| Vascular Plant | Fabales | Fabaceae | *Leucaena leucocephala* | koa haole | Non-native |
| Vascular Plant | Fabales | Fabaceae | *Medicago lupulina* | black medick | Non-native |
| Vascular Plant | Fabales | Fabaceae | • *Melilotus indica*<br>• *Caesalpinia kavaiensis* | sourclover | Non-native |
| Vascular Plant | Fabales | Fabaceae | *Prosopis pallida* | kiawe, algaroba, mesquite | Non-native |
| Vascular Plant | Fabales | Fabaceae | *Samanea saman* | `ohai, monkeypod, raintree | Non-native |
| Vascular Plant | Fabales | Fabaceae | *Sesbania tomentosa* | Ohai | Native |
| Vascular Plant | Fabales | Fabaceae | *Tamarindus indica* | tamarind | Non-native |
| Vascular Plant | Gentianales | Rubiaceae | *Morinda citrifolia* | Indian mulberry, noni | Non-native |
| Vascular Plant | Gentianales | Rubiaceae | • *Oldenlandia corymbosa*<br>• *Hedyotis corymbosa* | flattop mille graines, flat-top mille graines | Non-native |
| Vascular Plant | Gentianales | Rubiaceae | *Spermacoce* sp. *1* | buttonweed | Non-native |

**Table 28 (continued).** Species list reported by the NPS Pacific Island Network as of April 28, 2020. Bird data were further annotated with “island status” (* indicated as R=resident, M=migrant, V=vagrant) and the ʻio, nēnē, and pueo are further distinguished as “native-endemic” (Morin, personal communication, 21 January 2021).

| Category | Order | Family | Scientific Name | Common Name(s) | Nativeness |
|---|---|---|---|---|---|
| Vascular Plant | Lamiales | Bignoniaceae | *Spathodea campanulata* | African tuliptree | Non-native |
| Vascular Plant | Lamiales | Oleaceae | *Noronhia emarginata* | Madagascar olive | Non-native |
| Vascular Plant | Lamiales | Plantaginaceae | *Plantago australis* ssp. *hirtella* | dwarf plantain | Non-native |
| Vascular Plant | Lamiales | Plantaginaceae | *Plantago lanceolata* | English plantain | Non-native |
| Vascular Plant | Lamiales | Plantaginaceae | *Plantago major* | common plantain | Non-native |
| Vascular Plant | Lamiales | Verbenaceae | *Lantana camara* | lākana, largeleaf lantana | Non-native |
| Vascular Plant | Malpighiales | Calophyllaceae | *Calophyllum inophyllum* | kamani | Non-native |
| Vascular Plant | Malpighiales | Clusiaceae | *Clusia rosea* | autograph tree | Non-native |
| Vascular Plant | Malpighiales | Euphorbiaceae | *Aleurites moluccana* | kukui | Non-native |
| Vascular Plant | Malpighiales | Euphorbiaceae | • *Euphorbia heterophylla*<br>• *Euphorbia geniculata* | kaliko | Non-native |
| Vascular Plant | Malpighiales | Euphorbiaceae | • *Euphorbia hirta*<br>• *Chamaesyce hirta* | hairy spurge | Non-native |
| Vascular Plant | Malpighiales | Euphorbiaceae | • *Euphorbia hypericifolia*<br>• *Chamaesyce hypericifolia*<br>• *Euphorbia glomerifera* | graceful spurge | Non-native |
| Vascular Plant | Malpighiales | Euphorbiaceae | • *Euphorbia hyssopifolia*<br>• *Chamaesyce hyssopifolia* | hyssopleaf sandmat | Non-native |
| Vascular Plant | Malpighiales | Euphorbiaceae | • *Euphorbia prostrata*<br>• *Chamaesyce prostrata* | prostrate spurge | Non-native |
| Vascular Plant | Malpighiales | Euphorbiaceae | *Ricinus communis* | castor bean | Non-native |
| Vascular Plant | Malpighiales | Passifloraceae | *Passiflora edulis* | lilikoʻi, passion fruit | Non-native |
| Vascular Plant | Malpighiales | Passifloraceae | *Passiflora foetida* | love-in-a-mist, scarlet-fruited passion flower | Non-native |
| Vascular Plant | Malvales | Malvaceae | *Abutilon grandifolium* | hairy Indian mallow | Non-native |

**Table 28 (continued).** Species list reported by the NPS Pacific Island Network as of April 28, 2020. Bird data were further annotated with “island status” (* indicated as R=resident, M=migrant, V=vagrant) and the ‘io, nēnē, and pueo are further distinguished as “native-endemic” (Morin, personal communication, 21 January 2021).

| Category | Order | Family | Scientific Name | Common Name(s) | Nativeness |
|---|---|---|---|---|---|
| Vascular Plant | Malvales | Malvaceae | *Gossypium tomentosum* | huluhulu, ma‘o | Non-native |
| Vascular Plant | Malvales | Malvaceae | *Hibiscus brackenridgei* ssp. *brackenridgei* | ma`o hau hele | Native |
| Vascular Plant | Malvales | Malvaceae | *Pachira aquatica* | malabar chestnut | Non-native |
| Vascular Plant | Malvales | Malvaceae | *Sida fallax* | ‘ilima | Native |
| Vascular Plant | Malvales | Malvaceae | *Thespesia populnea* | milo | Native |
| Vascular Plant | Malvales | Malvaceae | *Triumfetta semitriloba* | Sacramento burr | Non-native |
| Vascular Plant | Malvales | Malvaceae | • *Waltheria indica*<br>• *Waltheria americana* | ‘ala‘ala pūloa, ‘uhaloa | Native |
| Vascular Plant | Malvales | Thymelaeaceae | • *Wikstroemia pulcherrima*<br>• *Wikstroemia* sp. *1*<br>• *Jambosa malaccensis* | `akia | Native |
| Vascular Plant | Myrtales | Onagraceae | *Oenothera stricta* ssp. *stricta* | evening primrose | Non-native |
| Vascular Plant | Ophioglossales | Ophioglossaceae | • *Ophioglossum polyphyllum*<br>• *Ophioglossum concinnum* | pololei | Native |
| Vascular Plant | Oxalidales | Oxalidaceae | *Oxalis corniculata* | yellow wood sorrel, ‘ihi ‘ai | Non-native |
| Vascular Plant | Pandanales | Pandanaceae | • *Pandanus tectorius*<br>• *Pandanus odoratissimus* | hala, pū hala, Tahitian screwpine | Native |
| Vascular Plant | Pandanales | Pandanaceae | • *Pandanus veitchii*<br>• *Pandanus* sp. *1* | hala, variegated pandanus | Non-native |
| Vascular Plant | Poales | Bromeliaceae | *Ananas comosus* | pineapple | Non-native |
| Vascular Plant | Poales | Cyperaceae | *Bolboschoenus maritimus* ssp. *paludosus* | Kaluha | Native |
| Vascular Plant | Poales | Cyperaceae | *Cyperus polystachyos* | manyspike flatsedge | Native |

**Table 28 (continued).** Species list reported by the NPS Pacific Island Network as of April 28, 2020. Bird data were further annotated with “island status” (* indicated as R=resident, M=migrant, V=vagrant) and the ‘io, nēnē, and pueo are further distinguished as “native-endemic” (Morin, personal communication, 21 January 2021).

| Category | Order | Family | Scientific Name | Common Name(s) | Nativeness |
|---|---|---|---|---|---|
| Vascular Plant | Poales | Cyperaceae | • *Kyllinga brevifolia*<br>• *Cyperus brevifolius* | kili‘o‘opu, shortleaf spikesedge | Non-native |
| Vascular Plant | Poales | Cyperaceae | • *Kyllinga nemoralis*<br>• *Cyperus kyllingia* | kili`o`opu | Non-native |
| Vascular Plant | Poales | Poaceae | *Aristida adscensionis* | sixweeks threeawn | Non-native |
| Vascular Plant | Poales | Poaceae | *Axonopus* sp. *1* | carpetgrass | Non-native |
| Vascular Plant | Poales | Poaceae | • *Cenchrus ciliaris*<br>• *Pennisetum ciliare* | buffelgrass | Non-native |
| Vascular Plant | Poales | Poaceae | • *Cenchrus clandestinus*<br>• *Pennisetum clandestinum* | kikuyu grass | Non-native |
| Vascular Plant | Poales | Poaceae | *Cenchrus echinatus* | common sandbur | Non-native |
| Vascular Plant | Poales | Poaceae | • *Cenchrus setaceus*<br>• *Pennisetum setaceum* | fountain grass | Non-native |
| Vascular Plant | Poales | Poaceae | • *Chloris barbata*<br>• *Chloris inflata* | swollen fingergrass | Non-native |
| Vascular Plant | Poales | Poaceae | *Chloris virgata* | feather fingergrass, feather windmill grass, showy chloris | Non-native |
| Vascular Plant | Poales | Poaceae | *Cynodon dactylon* | Bermudagrass, manienie haole | Non-native |
| Vascular Plant | Poales | Poaceae | *Dactyloctenium aegyptium* | beach wiregrass | Non-native |
| Vascular Plant | Poales | Poaceae | *Digitaria ciliaris* | Henry’s crabgrass | Non-native |
| Vascular Plant | Poales | Poaceae | *Digitaria eriantha* | pangolagrass | Non-native |
| Vascular Plant | Poales | Poaceae | *Digitaria fuscescens* | creeping kukaepua`a | Non-native |
| Vascular Plant | Poales | Poaceae | *Digitaria violascens* | violet crabgrass | Non-native |
| Vascular Plant | Poales | Poaceae | *Digitaria* sp. *1* | – | Non-native |

**Table 28 (continued).** Species list reported by the NPS Pacific Island Network as of April 28, 2020. Bird data were further annotated with “island status” (* indicated as R=resident, M=migrant, V=vagrant) and the ‘io, nēnē, and pueo are further distinguished as “native-endemic” (Morin, personal communication, 21 January 2021).

| Category | Order | Family | Scientific Name | Common Name(s) | Nativeness |
|---|---|---|---|---|---|
| Vascular Plant | Poales | Poaceae | *Eleusine indica* | wiregrass | Non-native |
| Vascular Plant | Poales | Poaceae | • *Eragrostis amabilis*<br>• *Eragrostis tenella* | lovegrass | Non-native |
| Vascular Plant | Poales | Poaceae | *Eragrostis cilianensis* | stinkgrass | Non-native |
| Vascular Plant | Poales | Poaceae | • *Festuca bromoides*<br>• *Vulpia bromoides*<br>• *Vulpia sp. 1* | brome fescue | Non-native |
| Vascular Plant | Poales | Poaceae | *Heteropogon contortus* | pili, tanglehead | Native |
| Vascular Plant | Poales | Poaceae | • *Melinis repens*<br>• *Rhynchelytrum repens*<br>• *Tricholaena rosea* | rose Natal grass | Non-native |
| Vascular Plant | Poales | Poaceae | *Paspalum conjugatum* | Hilo grass | Non-native |
| Vascular Plant | Poales | Poaceae | *Saccharum officinarum* | ko, sugarcane | Non-native |
| Vascular Plant | Poales | Poaceae | *Setaria verticillata* | bristly foxtail, mau`u pilipili | Non-native |
| Vascular Plant | Poales | Poaceae | • *Sporobolus indicus*<br>• *Sporobolus africanus* | West Indian dropseed | Non-native |
| Vascular Plant | Poales | Poaceae | *Sporobolus virginicus* | `aki`aki, akiaki, beach dropseed | Native |
| Vascular Plant | Poales | Poaceae | • *Urochloa maxima*<br>• *Panicum maximum* | guineagrass | Non-native |
| Vascular Plant | Polypodiales | Lomariopsidaceae | • *Nephrolepis brownii*<br>• *Nephrolepis multiflora*<br>• *Nephrolepis hirsutula* | swordfern | Non-native |
| Vascular Plant | Polypodiales | Pteridaceae | *Doryopteris decora* | `iwa`iwa | Native |
| Vascular Plant | Psilotales | Psilotaceae | *Psilotum nudum* | moa, pipi | Native |
| Vascular Plant | Rosales | Moraceae | *Broussonetia papyrifera* | paper mulberry, wauke | Non-native |

**Table 28 (continued).** Species list reported by the NPS Pacific Island Network as of April 28, 2020. Bird data were further annotated with “island status” (* indicated as R=resident, M=migrant, V=vagrant) and the ‘io, nēnē, and pueo are further distinguished as “native-endemic” (Morin, personal communication, 21 January 2021).

| Category | Order | Family | Scientific Name | Common Name(s) | Nativeness |
|---|---|---|---|---|---|
| Vascular Plant | Rosales | Moraceae | *Ficus microcarpa* | Chinese banyan | Non-native |
| Vascular Plant | Rosales | Rosaceae | *Osteomeles anthyllidifolia* | u`ulei | Native |
| Vascular Plant | Sapindales | Rutaceae | *Citrus* sp. *1* | – | Non-native |
| Vascular Plant | Sapindales | Sapindaceae | • *Dodonaea viscosa*<br>• *Dodonaea eriocarpa* | ‘a‘ali‘i, ‘a‘ali‘i kū ma kua | Native |
| Vascular Plant | Solanales | Convolvulaceae | *Ipomoea batatas* | `uala, sweet potato, uala | Non-native |
| Vascular Plant | Solanales | Convolvulaceae | • *Ipomoea indica*<br>• *Ipomoea congesta* | koali `awa, koali `awahia | Native |
| Vascular Plant | Solanales | Convolvulaceae | • *Ipomoea pes-caprae* ssp. *brasiliensis*<br>• *Ipomoea brasiliensis* | pōhuehue, beach morning glory | Native |
| Vascular Plant | Solanales | Convolvulaceae | • *Jacquemontia sandwicensis*<br>• *Jacquemontia ovalifolia* ssp. *sandwicensis* | pa‘uohi‘iaka | Native |
| Vascular Plant | Solanales | Convolvulaceae | *Merremia aegyptia* | hairy merremia | Non-native |
| Vascular Plant | Solanales | Solanaceae | • *Capsicum annuum*<br>• *Capsicum frutescens* | cayenne pepper | Non-native |
| Vascular Plant | Solanales | Solanaceae | *Solanum americanum* | popolo | Native |
| Vascular Plant | Zingiberales | Musaceae | *Musa X paradisiaca* | banana, Mai'a | Non-native |
| Vascular Plant | Zingiberales | Zingiberaceae | • *Curcuma longa*<br>• *Curcuma domestica* | ‘ōlena, tumeric | Non-native |
| Vascular Plant | Zygophyllales | Zygophyllaceae | *Tribulus terrestris* | puncture vine | Non-native |

# Appendix B. Fishing Regulations in the West Hawai‘i Regional Fisheries Replenishment Area

Fishing regulations for the West Hawai‘iHawai‘i Regional Fishery Management Area are promulgated through Chapter 13–60.4 of the Hawai‘iHawai‘i Administrative Rules (DLNR). Sections relevant to fishing regulations in Pu‘ukohola Heiau National Historical Site are excerpted below:

§13–60.4–2 Geographical jurisdiction of chapter provisions.

(a) The provisions of this chapter shall apply to the West Hawai‘iHawai‘i regional fishery management area, bounded by the west coast of Hawai‘iHawai‘i Island, from Ka Lae, Ka‘ū (South Point) to ‘Upolu Point, North Kohala, and extending from the upper reaches of the wash of the waves on shore, seaward to the limit of the State’s police power and management authority.

(4) Kaloko-Honokōhau fish replenishment area, identified on shore to the north by the southern boundary of Wāwāloli Zone (a Kona Coast fisheries management area defined in section 13–58–2) at Wawahiwa‘a Point and to the south by Noio Point;

Unless otherwise described, any area described in this chapter shall be described by four reference points identified by their latitude and longitude coordinates, as provided in the tables located at the end of this chapter entitled “Table of Reference Coordinates to Fish Replenishment Area Boundaries”, dated 9/21/11, and “Table of Reference Coordinates to Netting Restricted Area Boundaries”, dated 9/21/11, and as may be further indicated by signage on or about the shoreline. The four points shall be identified as the landward northern point, the landward southern point, the seaward northern point, and the seaward southern point. The landward boundary for each of these areas shall be an imaginary line drawn along the highest wash of the waves between the landward northern point and the landward southern point. Should there be a stream or river flowing into the ocean, the landward boundary shall be an imaginary straight line drawn between the shoreline on either side of the stream or river, as if the stream or river was not there. Imaginary straight lines drawn through the landward and seaward northern points, and through the landward and seaward southern points, shall constitute the northern and southern boundary lines of each area. The seaward boundary of each area shall be determined by an imaginary line drawn along the one hundred fathom (six hundred feet) depth contour, between the intersection of the one hundred fathom depth contour and the northern and southern boundary lines. Seaward GPS reference points are for guidelines and the one hundred fathom depth contour otherwise controls the seaward boundary. Any area designated in this chapter shall include the submerged lands and overlying waters within these four boundaries.

§13–60.4–3 Definitions. As used in this chapter unless otherwise provided:

“Aquarium collecting gear” means any equipment or gear adapted, designed, or commonly used to collect, capture or maintain aquatic life alive in a state of captivity, including but not limited to hand nets, fence or barrier nets, fiberglass, plastic, wood or metal ‘tickle sticks‘ (including spears or similar implements used to manipulate the movement of aquarium fish or animals), catch buckets, keeps, baskets or venting needles.

“Aquarium collecting vessel” means any motorized or non-motorized vessel used by any person to collect, ferry, or scout for aquarium fish or animals.

“Aquarium purposes” means to hold aquatic life alive in a state of captivity, whether as pets, for scientific study, for public exhibition, for public display, or for sale for these purposes. Aquatic life collected under a valid aquarium permit may not be used for human consumption, for bait, or for other consumptive purposes.

“Aquatic life” means any type or species of mammal, fish, amphibian, reptile, mollusk, crustacean, arthropod, invertebrate, coral, or other animal that inhabits the freshwater or marine environment and includes any part, product, egg, or offspring thereof; or freshwater or marine plants, including seeds, roots, products, and other parts thereof.

“Commercial purpose” means the taking of aquatic life for profit, gain, sale, purchase, barter, exchange, to offer for sale, or upon any offer to purchase.

“Department” means the department of land and natural resources.

“Fish feeding” means deliberately introducing into the water any food material, substance, or device used as an attractant, for any purpose except catching and removing marine life.

“Lay net” means a panel of net mesh that is suspended vertically in the water with the aid of a float line that supports the top edge of the net upward towards the water surface and a lead line that keeps the bottom edge of the net downward towards the ocean bottom.

“Lay net fishing” or to “lay net fish” means deploying or attempting to deploy a lay net in a set location and in an open configuration, and retrieving the lay net from the same location after a certain time period has passed. This fishing method is also known as set netting, cross netting, pa‘ipa‘i, and moemoe netting. This term does not apply to the use of a lay net to completely encircle a pre-identified school of fish, where the net is constantly attended at all times while in the water, such as in the practice of surround netting.

“Natural fibers” means fibers derived wholly from plant materials including, olonā, linen, cotton, hemp, and sisal.

“SCUBA gear” means any equipment adapted, designed, or commonly used to enable a diver to breathe while underwater, including but not limited to SCUBA regulators, high pressure cylinders, rebreathers, SNUBA, and hookah rigs.

“SCUBA spearfishing” means to take or to attempt to take aquatic life through the combined use of a spear and SCUBA gear.

“Set” when used as a noun with respect to the use of lay nets, means a sequential act beginning from when the lay net is fully deployed in the water and ending on the next complete removal of the lay net from the water.

“Spear” means any device or implement which is designed or used for impaling marine life. Spears may include but are not limited to spear gun shafts, arbaletes, arrows, bolts, Hawaiian slings, tridents, or three-prong spears. A dive knife is not considered to be a spear.

“Speared” means pierced, impaled, penetrated, stuck, or run through by a sharp, pointed implement.

“Take” means to fish for, catch, or harvest, or to attempt to fish for, catch, or harvest, aquatic life. The use of any gear, equipment, tool, or any means to fish for, catch, capture, or harvest, or to attempt to fish for, catch, capture, or harvest, aquatic life by any person who is in the water, or in a vessel on the water, or in the shoreline area where aquatic life can be fished for, caught, or harvested, shall be construed as taking.

“Total length” means the length of a fish measured from the tip of the snout to the tip of the longer lobe of the caudal (tail) fin. The length measurement shall be a straight-line measure, not measured over the curvature of the body of the fish.

“White list” means a list of species of marine life that may be taken for aquarium purposes. [Eff 12/26/13] (Auth: HRS §§187A-5, 188–53, 188F-6) (Imp: HRS §§187A-5, 188–53, 188F-6)

§13–60.4–4 Activities prohibited within the West Hawai‘iHawai‘i regional fishery management area. While within the West Hawai‘iHawai‘i regional fishery management area, no person shall:

(1) Take, kill, possess, sell, or offer for sale, any specimen of the following species: *Aetobatus narinari* (spotted eagle ray*),* *Carcharhinus amblyrhynchos* (gray reef shark), *Carcharhinus melanopterus* (blacktip reef shark), *Cassis cornuta* (horned helmet), *Charonia tritonis* (Triton’s trumpet), *Dasyatis Hawaiiensis* (Hawaiian stingray), *Dasyatis lata* (broad stingray), *Pteroplatytrygon violacea* (pelagic stingray), *Galeocerdo cuvier* (tiger shark), *Rhincodon typus* (whale shark), or *Triaenodon obesus* (whitetip reef shark);

(2) Possess more than five *Zebrasoma flavescens* (yellow tang) larger than 4.5 inches in total length, or possess more than five *Zebrasoma flavescens* smaller than two inches in total length;

(3) Possess aquarium collecting gear, or take or possess any specimen of aquatic life for aquarium purposes:

(A) Between sunset and sunrise, provided that collecting gear or collected aquatic life may be possessed after sunset or before sunrise if notification by phone is made to the Division of Aquatic Resources West Hawai‘iHawai‘i (DAR-Kona) office prior to sunset. The notification shall include the names of individuals who plan to possess the gear or aquatic life and the location where the possession will take place;

(B) Without holding a valid West Hawai‘iHawai‘i aquarium permit issued pursuant to section 13–60.4–7(a);

(C) In violation of the terms and conditions of a West Hawai‘iHawai‘i aquarium permit issued to that person; or

(D) While occupying any vessel that does not conform to the registration and marking requirements of section 13- 60.4–7(d);

(4) Possess or use any net or container employed underwater to capture or hold aquatic life alive for aquarium purposes, that is not labeled with the commercial marine license number or numbers of the person or persons owning, possessing or using the equipment;

(5) Possess a lay net or engage in lay net fishing in violation of the requirements of section 13–60.4–6; or

(6) Engage in or attempt to engage in SCUBA spearfishing, possess both SCUBA gear and a spear at the same time, or possess SCUBA gear and any specimen of speared aquatic life at the same time. [Eff 12/26/13] (Auth: HRS §§187A-5, 188–53, 188F-6) (Imp: HRS §§187A-5, 188–53, 188F-3)

§13–60.4–5 <u>Activities prohibited within selected areas</u>. (a) No person may engage in fish feeding while within any of the fish replenishment areas or netting restricted areas described in section 13–60.4–2(b) or any of the other areas listed in section 13–60.4–2(c).

(b) While within the fish replenishment areas described in section 13–60.4–2(b)(1) to (10), or while within any of the areas listed in section 13–60.4–2(c) other than the Kīholo Bay fisheries management area, no person may:

(1) Collect aquatic life for aquarium purposes;

or

(2) Possess any aquarium collecting gear, or take or possess any specimen of aquatic life for aquarium purposes, except that aquarium collecting gear or aquatic life collected for aquarium purposes may be possessed while onboard a vessel in active transit through the areas, provided that no collecting gear is in the water during the transit. Boats that are adrift, anchored, or moored are not considered to be in active transit.

(c) No person may lay net fish while within the following areas, as described in section 13–60.4–2(b) and in the tables located at the end of this chapter entitled “Table of Reference Coordinates to Fish Replenishment Area Boundaries”, dated 9/21/11, and “Table of Reference Coordinates to Netting Restricted Area Boundaries”, dated 9/21/11: (1) Puakō-‘Anaeho‘omalu fish replenishment area;

(2) Ka‘ūpūlehu fish replenishment area;

(3) Kikaua Point-Mākole‘ā netting restricted area (Kekaha Kai State Park);

(4) Nenue Point (Red Hill fish replenishment area)-Kealakekua Bay netting restricted area;

(5) Hanamalo Point-Kanewa‘a Point netting restricted area;

(6) Kanonohe–Kalīpoa netting restricted area;

and

(7) Kaloko-Honokōhau fish replenishment area, except that a person may lay net fish in the Kaloko-Honokōhau fish replenishment area using only a locally-constructed, handmade lay net of natural fibers, that is registered and used in compliance with section 13–60.4–6. [Eff 12/26/13] (Auth: HRS §§187A-5, 188–53, 188F-6) (Imp: HRS §§187A-5, 188–53, 188F-6)

§13–60.4–6 Lay net registration and use requirements. (a) It is unlawful for any person within the West Hawai‘iHawai‘i regional fishery management area to:

(1) Possess or use a lay net that has not been registered with the department;

(2) Possess or use more than one lay net;

(3) Possess or use a lay net:

(A) Longer than one hundred twenty-five feet in length or more than seven feet in stretched height;

(B) With less than two and three-fourths inches stretched mesh; and in Kailua Bay fisheries management area, with less than three inches stretched mesh; or

(C) With two or more joined lay nets with a combined total length of more than two hundred fifty feet;

(4) Possess or use a multi-panel lay net; or

(5) Possess or use a lay net that does not have at least four identification tags as specified or provided by the department. One identification tag must be attached at each end of both the net float line and the net lead line for a total of four attachment points on each lay net.

(b) It is unlawful for any person lay net fishing to:

(1) Use a lay net that is not marked by buoys as specified or provided by the department. The buoys shall display the lay net registration number, be marked with reflective tape, and be visible above the surface of the water. The buoys shall be attached to each end of the float line for a total of two buoys for each lay net;

(2) Use a lay net within one thousand two hundred feet of any other lay net; provided that two or more individuals working together and using the lay net fishing method may use a joined net;

(3) Use a lay net in water that is more than eighty feet in depth;

(4) Use a lay net for more than four hours during any one set; provided that after one set, the same lay net may not be set again within twenty-four hours after the ending of the set; and provided further that the same person shall not set any other lay net within that twenty-four hour period after the ending of the set;

(5) Leave a lay net unattended for more than one-half hour;

(6) Retrieve a lay net in such a manner as to cause coral to break from its attachment to the bottom or to break into smaller pieces. Any coral brought to the surface in the net shall be considered prima facie evidence of a violation of this section;

(7) Fail to complete inspection of an entire lay net within two hours after the beginning of the set. The person lay net fishing shall inspect the lay net and release any threatened, endangered, prohibited, or unwanted species; or

(8) Discard, abandon, or leave any lay net, or portion thereof, in the water for longer than four hours.

(c) It is unlawful for any person to falsely identify, with identification tags, any lay net that is not registered with the department as required in subsection (a)(1) and (a)(5).

(d) Persons using a vessel or float may use a total maximum of two hundred fifty feet of lay net, provided that at least two persons are present and associated with the same vessel or float.

(e) Should any registered lay net be lost, destroyed, sold, traded, stolen, given away, or otherwise no longer the property of, or no longer in the possession of the registered owner, then the registered owner shall be responsible for the lay net until a report is filed and confirmed by the department.

(f) Any lay net within the West Hawai‘iHawai‘i regional fishery management area that is not registered or does not have proper identification tags, as required in subsection (a)(1) and (a)(5), shall be subject to immediate seizure according to section 199–7, HRS, and subject to forfeiture by the department under procedures similar to chapter 712A, Hawai‘iHawai‘i Revised Statutes.

(g) This section shall not apply to panel mesh nets with a stretched mesh size of less than two and three-fourths inches that are marked with commercial marine license numbers as required under section 13–60.4–4(4) and permitted for use and possession under an aquarium permit and a West Hawai‘iHawai‘i aquarium permit issued under section 13–60.4–7(a). [Eff 12/26/13] (Auth: HRS §§187A-5, 188–53, 188F-6) (Imp: HRS §§187A-5, 188–53, 188F-6, 199–7, 712A-6)

§13–60.4–7 <u>Aquarium collecting permit and vessel registration requirements.</u> (a) West Hawai‘iHawai‘i aquarium permit. The department may issue West Hawai‘iHawai‘i aquarium permits authorizing persons to engage in aquarium collecting activities for species listed in subsection (b) and to use fine meshed traps and nets (other than throw nets) to collect those species in the West Hawai‘iHawai‘i regional fishery management area, notwithstanding section 13–75–14, subject to terms and conditions the department deems necessary for themanagement of the area and its resources. No person, unless exempted from provisions of this chapter by the issuance and possession of a valid special activity permit under section 187A-6, Hawai‘iHawai‘i Revised Statutes, shall engage in aquarium collecting activities within the West Hawai‘iHawai‘i regional fishery management area without first having been issued and possessing a West Hawai‘iHawai‘i aquarium permit in addition to a valid State of Hawai‘iHawai‘i aquarium fish permit. Permits shall be valid for one year from the date of issuance unless revoked sooner and are non-transferable. In addition to applying any other penalties provided by law, the department may revoke any West Hawai‘iHawai‘i aquarium permit for any infraction of these rules or the terms and conditions of the permit, and any person whose permit has been revoked shall not be eligible to apply for another West Hawai‘iHawai‘i aquarium permit until the expiration of one year from the date of revocation.

(b) Aquarium species white list. In addition to other regulations deemed necessary for the management of the West Hawai‘iHawai‘i regional fishery management area, an aquarium permit holder may only take or possess specimens of the following species of fish for aquarium purposes while within the West Hawai‘iHawai‘i regional fishery management area: *Acanthurus achilles* (Achilles tang), *Acanthurus dussumieri* (eyestripe surgeonfish), *Acanthurus nigricans* (goldrim surgeonfish), *Acanthurus nigrofuscus* (brown surgeonfish), *Acanthurus olivaceus* (orangeband surgeonfish), *Acanthurus thompsoni* (Thompson’s surgeonfish), *Anampses chrysocephalus* (psychedelic wrasse), *Canthigaster jactator* (whitespotted Toby), *Centropyge fisheri* (Fisher’s angelfish), *Centropyge potteri* (Potter’s angelfish), *Cephalopholis argus* (peacock grouper), *Chaetodon kleinii* (blacklip butterflyfish), *Chaetodon miliaris* (milletseed butterflyfish), *Chaetodon multicinctus* (multiband butterflyfish), *Chaetodon quadrimaculatus* (fourspot butterflyfish), *Chaetodon tinkeri* (Tinker’s butterflyfish), *Cirrhilabrus jordani* (flame wrasse), *Cirrhitops fasciatus* (redbarred hawkfish), *Coris gaimard* (yellowtail Coris), *Ctenochaetus Hawaiiensis* (chevron tang), *Ctenochaetus strigosus* (goldring surgeonfish, kole), *Dascyllus albisella* (Hawaiian Dascyllus), *Forcipiger flavissimus* (forcepsfish), *Gomphosus varius* (bird wrasse), *Halichoeres ornatissimus* (ornate wrasse), *Hemitaurichthys polylepis* (pyramid butterflyfish), *Lutjanus kasmira* (bluestripe snapper), *Macropharyngodon geoffroy* (shortnose wrasse), *Melichthys niger* (black Durgon), *Naso lituratus* (orangespine unicornfish), *Ostracion meleagris* (spotted boxfish), *Paracirrhites forsteri* (blackside hawkfish), *Pseudanthias Hawaiiensis* (Hawaiian longfin Anthias), *Pseudocheilinus octotaenia* (eightline wrasse), *Pseudocheilinus tetrataenia* (fourline wrasse), *Pseudojuloides cerasinus* (smalltail wrasse), *Sufflamen bursa* (lei triggerfish), *Thalassoma duperrey* (saddle wrasse), *Xanthichthys auromarginatus* (gilded triggerfish), and *Zebrasoma flavescens* (yellow tang); provided further that:

(1) No *Zebrasoma flavescens* (yellow tang) may be taken or possessed in violation of section 13–60.4–4(2);

(2) No more than five *Ctenochaetus strigosus* (goldring surgeonfish or kole) larger than four inches in total length may be taken per day or possessed at any time; and

(3) No more than ten *Acanthurus achilles* (Achilles tang) may be taken per day or possessed at any time.

(c) Aquarium collecting vessel registration and marking requirements. All aquarium collecting vessels shall:

(1) Be registered every year with the Division of Aquatic Resources West Hawai‘iHawai‘i (DAR-Kona) office to take aquatic life for aquarium purposes within the West Hawai‘iHawai‘i regional fishery management area. Each registration shall be valid for one year from the date of registration. The current vessel identification number issued by either the department or the United States Coast Guard shall serve as the registration number for each vessel;

(2) Clearly display the capital letters "AQ" permanently affixed to both sides of the vessel, either near the top of the gunwales or on the superstructure. Unless otherwise

specified, the "AQ" letters shall be no less than six inches high and three inches wide in either black or a color that contrasts with the background;

(3) Fly a "stiffened" flag or pennant from the vessel with the letter "A" as specified by the department. The flag or pennant shall be provided at cost to aquarium permittees as specified by the department. The flag or pennant shall be displayed and clearly visible from both sides of the vessel at all times while aquarium collecting gear or collected aquarium marine life or both are onboard;

(4) Display a dive flag at all times when divers are in the water; and

(5) In the event an aquarium collecting vessel becomes inoperable, the operator of the vessel shall immediately notify the department's division of conservation and resources enforcement or United States Coast Guard or both by VHF radio or by cellular phone or both.

(d) Control date. A control date was established in August 1, 2005 to possibly limit participation in the West Hawai‘iHawai‘i regional fishery management area commercial aquarium fishery. Persons who begin fishing in the West Hawai‘iHawai‘i regional fishery management area commercial aquarium fishery on or after the control date will not be assured continued participation if the department establishes an aquarium limited entry program in the future.

(e) Nothing in this chapter shall prevent the department from establishing another control date. [Eff 12/26/13] (Auth: HRS §§187A-5, 188–53, 188F-6) (Imp: HRS §§187A-5, 188–53, 188F-3)

§13–60.4–8 Penalty. Any person violating any provision of this chapter, or any term or condition of any permit issued pursuant to this chapter, shall be subject to the provisions of sections 187A-12.5 and 188–70, Hawai‘iHawai‘i Revised Statutes, or as may be otherwise provided by law. [Eff 12/26/13] (Auth: HRS §§187A-5, 188–53, 188F-6) (Imp: HRS §§187A-12.5, 188–53, 188–70)

§13–60.4–9 Severability. If any provision of this chapter, or the application thereof, to any person or circumstance is held invalid, the invalidity shall not affect other provisions or applications of the chapter which can be given effect without the invalid provision or application, and to this end the provisions of this chapter are severable. [Eff 12/26/13] (Auth: HRS §§187A-5, 188–53, 188F-6) (Imp: HRS §§1–23, 187A-5, 188–53, 188F-6)

# Appendix C. Map of Fish Replenishment Area and Netting Restricted Area Boundaries

A map of fish replenishment areas and netting restricted areas can be found in Figure 36.

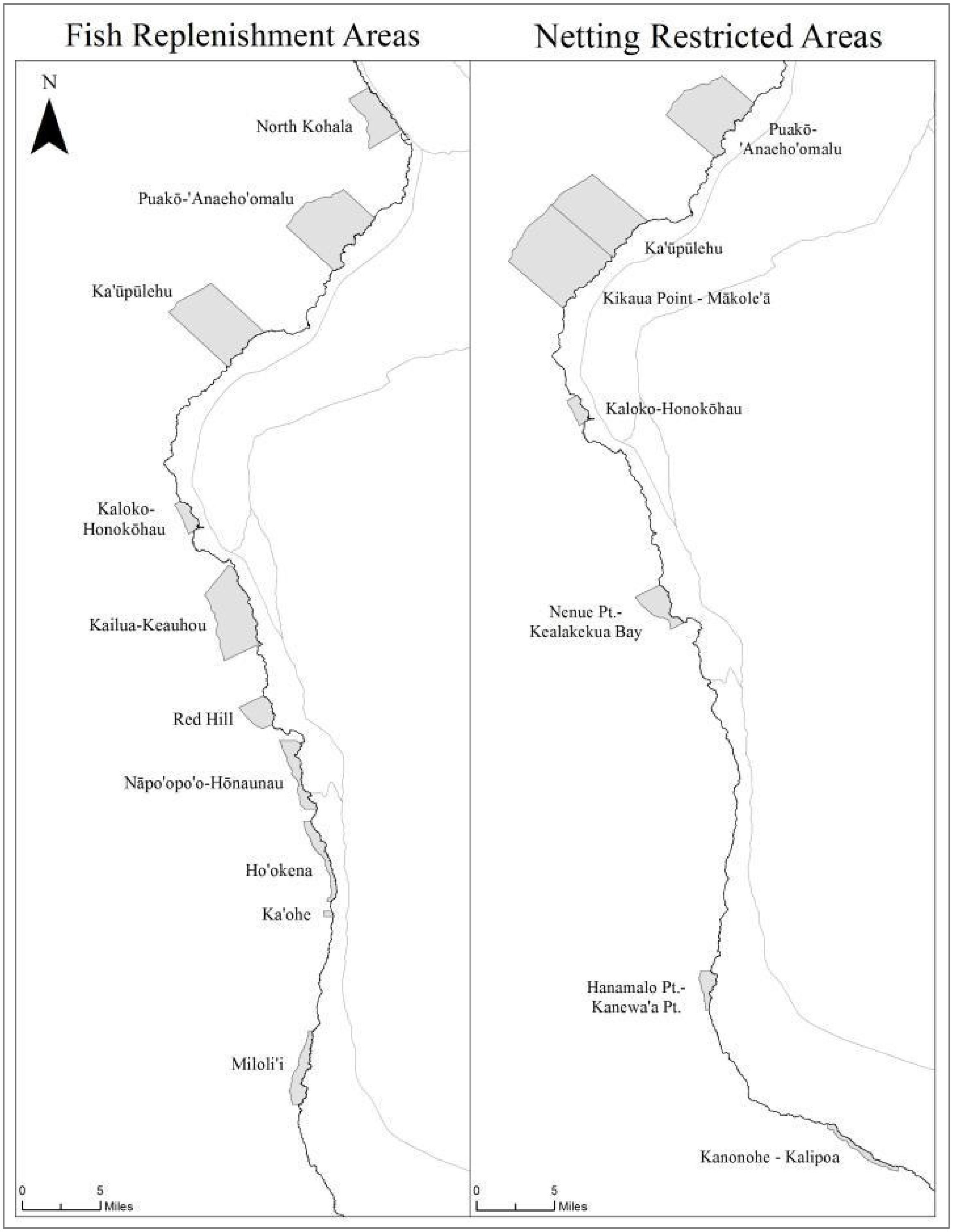

**Figure 36.** Map of Fish Replenishment Area and Netting Restricted Area Boundaries. Maps and tables do not reflect regulated areas and their specific prohibitions (including gear restrictions) that are defined in other chapters, as described in section 13–60.4–5(c).

# Appendix D. Tables of Reference Coordinates

Reference coordinates for fish replenishment area boundaries and netting restricted area boundaries can be found in tbe appendix subchapters below.

## Fish Replenishment Area Boundaries (2011)

The fish replenishment area boundariy coordinates for 2011 can be seen in Tables 29 and 30.

**Table 29.** Landward dGPS coordinates for fish replenishment area boundaries.

| | Northern Point | | Southern Point | |
|---|---|---|---|---|
| **Fish Replenishment Area** | **North** | **West** | **North** | **West** |
| North Kohala | 20°04.826' | 155°51.934' | 20°02.471' | 155°49.988' |
| Puako –‘Anaeho’omalu | 19°57.529' | 155°55.553' | 19°54.641’ | 155°53.893' |
| Ka’upulehu | 19°51.011’ | 155°58.111’ | 19°49.209' | 156°00.132' |
| Kaloko–Honokohau | 19°41.422' | 156°02.350' | 19°40.059' | 156°01.741’ |
| Kailua–Keauhou | 19°37.903' | 155°59.472 | 19°33.716' | 155°57.829' |
| Red Hill | 19°30.823' | 155°57.630' | 19°29.252' | 155°57.068' |
| Napo’opo’o–Honaunau | 19°28.230' | 155°55.370 | 19°24.559' | 155°54.343' |
| Ho’okena | 19°23.796' | 155°54.685' | 19°19.458' | 155°53.426' |
| Ka’ohe | 19°18.954' | 155°53.362' | 19°18.714' | 155°53.296' |
| Miloli’i | 19°12.179' | 155°54.369' | 19°08.098' | 155°55.132' |

**Table 30.** Seward dGPS coordinates (600ft.) for fish replenishment area boundaries.

| Fish Replenishment Area | Northern Point [A] | | | Southern Point [A] | | | @ [C] |
|---|---|---|---|---|---|---|---|
| | North | West | D (nm) [B] | North | West | D (nm) [B] | |
| North Kohala | 20°04.378' | 155°53.344' | 1.40 | 20°01.654' | 155°51.875' | 1.94 | 225° |
| Puako –‘Anaeho’omalu | 19°59.206' | 155°53.383' | 2.40 | 19°57.034' | 155°56.658' | 3.54 | 300° |
| Ka’upulehu | 19°53.817' | 156°00.994' | 3.91 | 19°51.724' | 156°03.947' | 4.39 | 300° |
| Kaloko–Honokohau | 19°41.368’ | 156°03.031’ | 0.35 | 19°39.844' | 156°02.169' | 0.46 | 240° |
| Kailua–Keauhou | 19°37.089' | 156°01.449 | 2.02 | 19°32.801’ | 156°00.004' | 2.21 | 245° |
| Red Hill | 19°30.166' | 155°58.953' | 1.41 | 19°28.991’ | 155°57.536' | 0.51 | 235° |
| Napo’opo’o–Honaunau | 19°28.350' | 155°56.898 | 1.13 | 19°24.725' | 155°55.162' | 0.79 | 270° |
| Ho’okena | 19°23.690' | 155°55.095' | 0.40 | 19°19.403' | 155°53.688’ | 0.25 | 240° |
| Ka’ohe | 19°18.947' | 155°53.824' | 0.44 | 19°18.706' | 155°53.806' | 0.48 | 270° |
| Miloli’i | 19°12.179' | 155°54.599' | 0.15 | 19°08.160' | 155°55.510' | 0.36 | 270° |

[A] Northern Boundary runs 0.25 nm along existing Kealakekua Bay MLCD southern boundary to 19° 28.443‘ N/155° 55.708‘ W and then 270° to seaward northern point.

[B] D (nm) = distance in nautical miles from the landward points to the seaward points.

[C] @ = compass heading from landward coordinates to seaward coordinates.

## Netting Restricted Area Boundaries (2011)

The netting restricted boundary coordinates for 2011 can be seen in Tables 31 and 32.

**Table 31.** Landward dGPS coordinates for netting restricted area.

| | Northern Point | | Southern Point | |
|---|---|---|---|---|
| **Netting Restricted Area** | **North** | **West** | **North** | **West** |
| Puako –‘Anaeho’omalu | 19°57.529' | 155°51.553' | 19°54.641' | 155°53.893' |
| Ka’upulehu | 19°51.011' | 155°58.111' | 19°49.209' | 156°00.132' |
| Kikaua Point–Makole’a | 19°49.130' | 156°00.063' | 19°46.356' | 156°03.024' |
| Kaloko–Honokohau | 19°41.442' | 156°02.350' | 19°40.059' | 156°01.741' |
| Nenue Point–Kealakekua Bay | 19°30.823' | 155°57.630' | 19°28.699' | 155°56.114' |
| Hanamalo Point–Kanewa’a Point | 19°09.273' | 155°54.973' | 19°07.091' | 155°55.115' |
| Kanonone–Kalipoa | 19°00.662' | 155°48.302' | 18°58.180' | 155°44.182' |

**Table 32.** Seward dGPS coordinates (600ft.) for netting restricted area.

| | **Northern Point** | | | **Southern Point** | | | |
|---|---|---|---|---|---|---|---|
| **Netting Restricted Area** [A] | **North** | **West** | **D (nm)** [B] | **North** | **West** | **D (nm)** [B] | **@** [C] |
| Puako –‘Anaeho’omalu | 19°59.206' | 155°53.383' | 2.40 | 19°57.034' | 155°56.658' | 3.54 | 300° |
| Ka’upulehu | 19°53.817' | 156°00.994' | 3.91 | 19°51.724' | 156°03.947' | 4.39 | 300° |
| Kikaua Point–Makole’a | 19°52.100' | 156°03.566' | 4.41 | 19°49.000' | 156°06.164' | 3.98 | 300° |
| Kaloko–Honokohau | 19°41.368' | 156°03.031' | 0.35 | 19°39.844' | 156°02.169' | 0.46 | 240° |
| Nenue Point–Kealakekua Bay | 19°30.166' | 155°58.953' | 1.41 | 19°28.316' | 155°56.983' | 0.90 | 235° |
| Hanamalo Point–Kanewa’a Point | 19°09.275' | 155°55.564' | 0.55 | 19°07.093' | 155°55.313' | 0.18 | 260° |
| Kanonone–Kalipoa | 19°00.409' | 155°48.302' | 0.25 | 18°57.941' | 155°44.183' | 0.24 | 200° |

[A] Netting restrictions may also apply in fisheries replenishment areas (see map entitled “Map of Fish Replenishment Area and Netting Restricted Area Boundaries”, dated 9/21/11) and in areas designated under separate chapters, as described in section 13–60.4–2(c).

[B] D (nm) = distance in nautical miles from the landward points to the seaward points.

[C] @ = compass heading from landward coordinates to seaward coordinates.

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