National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Puʻuhonua o Hōnaunau National Historical Park

Natural Resource Report NPS/PUHO/NRR—2022/2456

ON THE COVER
Aerial photograph (2011) of Puʻuhonua o Hōnaunau National Historical Park with the Puʻuhonua, Royal Grounds, and Hōnaunau Bay in the foreground. NPS.

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Executive Summary

Ka‘ahumanu Stone (NPS photo).

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 set management targets for study indicators, and reference conditions are not necessarily ideal or target conditions. 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.

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. Pu‘uhonua o Hōnaunau National Historical Park (hereafter Pu‘uhonua o Hōnaunau NHP) encompasses 1.7 km^2 (0.7 mi^2) at the base of the Mauna Loa Volcano on the Kona coast of the island of Hawai‘i. The Kona coast of Hawai‘i Island is characterized by calm winds that increase in the late morning to evening hours, especially in the summer when there is also a high frequency of late afternoon or early evening showers. The climate is mild, with mean high temperature of 26.2° C (79.2° F) and a mean low temperature of 16.6° C (61.9° F) and receiving on average 66 cm (26 in) of rainfall per year. The Kona coast is the only region in Hawai‘i where more precipitation falls in the summer than in the winter. There is limited surface water runoff or stream development at Pu‘uhonua o Hōnaunau NHP due to the relatively recent lava flows (less than 1,500 years old) overlaying much of the park.

Ki‘ilae Stream is the only watercourse within the park. Ki‘ilae Stream is ephemeral, with occasional flows and a poorly characterized channel within the park. A stream gauge was located uphill from the park, but no measurements have been taken since 1982. Floods in Ki‘ilae Stream do occur, resulting in transport of fluvial sediment to the ocean, but there are no data documenting this phenomenon. There are a small number of naturally occurring anchialine pools occupying cracks and small depressions in the lava flows, including the Royal Fishponds; an anchialine pool modified for the purpose of holding fish. Although the park’s legal boundaries end at the high tide mark, the sense of place, story, and visitor experience would be completely different without the marine waters adjacent to the park.

Six resource elements were chosen for evaluation: air and night sky, water-related processes, terrestrial vegetation, vertebrates, anchialine pools, and marine resources. Resource conditions were determined through reviewing existing literature, meta-analysis, and where appropriate, analysis of unpublished short- and long-term datasets. However, in a number of 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 within the park to a quantitative reference condition. In those cases, data gaps are noted, and comparisons were made based on qualitative descriptions.

Overall, the condition of natural resources within Pu‘uhonua o Hōnaunau NHP reflects the surrounding landscape. The coastal lands immediately surrounding Pu‘uhonua o Hōnaunau NHP are zoned for conservation, while adjacent lands away from the coast are agricultural. The condition of most natural resources at Pu‘uhonua o Hōnaunau NHP reflect the overall condition of ecological communities on the west Hawai‘i coast. Although little of the park’s vegetation is native, native plant communities exist clustered around the brackish pools, near the cliffs, and in the coastal area dominated by coconut (*Cocos nucifera*), naupaka kahakai (*Scaevola taccada*), and mau‘u ‘aki‘aki (*Fimbristylis cymosa*). ‘Uhaloa (*Waltheria indica*) is commonly co-dominant with invasive grass species in the area near the park access road. Most bird species observed in the park are nonnative and invasive mammals are common within the park. However, a number of native birds and ‘Ōpe‘ape‘a (Hawaiian hoary bats, *Lasiurus cinereus semotus*) are also observed within the park, and there are several recent records of ‘īlio-holo-i-ka-uaua (Hawaiian monk seal, *Neomonachus schauinslandi*) basking on the park’s shores. Many of the native invertebrates known to inhabit anchialine pools and several species of native fish are found at Pu‘uhonua o Hōnaunau NHP, although introduced tilapia (*Oreochromis mossambicus)* and mosquitofish (*Gambusia affinis*) are also common. The marine waters off the shores of Pu‘uhonua o Hōnaunau NHP support a relatively rich coral community. It should be noted, however, that a series of coral bleaching events along the west Hawai‘i coast beginning in 2015 impacted the coral community adjacent to Pu‘uhonua o Hōnaunau NHP. These bleaching events occurred after analyses were conducted for this assessment, and updated data were not available in time to be incorporated here. Thus, the assessment of benthic invertebrates within this NRCA should be treated as a pre-bleaching baseline and conditions of the coral community may have significantly deteriorated following the bleaching events. Many of the resources within Pu‘uhonua o Hōnaunau NHP have been poorly characterized, with little data available from within the park or in adjacent areas.

Habitat restoration efforts within Pu‘uhonua o Hōnaunau NHP hold promise for improving the condition of the park’s natural resources. Managed coastal and wetland areas support native vegetation. Goat exclusion and habitat restoration in other conservation lands on the Kona coast demonstrate the potential to restore upland native vegetation communities. Techniques used to trap feral cats and mongooses in the park have proven successful, and ongoing trapping in nearby Kaloko-Honokōhau National Historical Park and elsewhere indicates that sustained efforts can be effective at reducing populations in trapping areas, leading to increased use by native species.

Acknowledgments

Many people beyond the listed authors and cited experts contributed to putting together this NRCA and deserve thanks. From the NPS, we thank Malia Hayes, MaryAnne Maigret, Adam Johnson, and Sallie Beavers, who served as points of contact, provided invaluable sources of information and context, and provided comments on the various drafts. 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. This project was funded by the NPS Natural Resource Condition Assessment Program, the NPS Pacific Islands Coral Reef Program, Kaloko-Honokōhau National Historical Park, and the Institute for Wildlife Studies.

Acronyms and Abbreviations

ALR:	All-sky Light Pollution Ratio
AMSL:	above mean sea level
B.P.:	before present
CCA:	crustose coralline algae
cfu:	colony-forming units
CI:	Confidence Interval
COOP:	Cooperative Observer Program
COTS:	Crown-of-Thorns seastar
CRAMP:	Hawai‘i Coral Reef Assessment and Monitoring Program
CWA:	Clean Water Act
DAR:	Division of Aquatic Resources (State of Hawai‘i, DLNR)
DLNR:	Department of Land and Natural Resources (State of Hawai‘i)
FHUS:	Fish Habitat Utilization Study
FRA:	Fish Replenishment Area
GA:	Porites growth anomalies
GIS:	Geographic Information System
GPS:	Global Positioning System
HDOH:	Hawai‘i Department of Health (State of Hawai‘i)
I&M:	Inventory & Monitoring (NPS)
IRMA:	Integrated Resource Management Applications portal
IUCN:	International Union for Conservation of Nature
KNHP:	Kalaupapa National Historical Park
KHNHP:	Kaloko-Honokōhau National Historical Park
MHI:	Main Hawaiian Islands

Acronyms and Abbreviations (continued)

MPA:	Marine Protected Area
NHP:	National Historical Park
NHS:	National Historic Site
NOAA:	National Oceanic and Atmospheric Administration
NOAA CRED:	NOAA Fisheries, Coral Reef Ecosystem Division
NP:	National Park
NPS:	National Park Service
NRCA:	Natural Resource Condition Assessment
NTU:	Nephelometric Turbidity Units
NWHI:	Northwest Hawaiian Islands
PACN:	Pacific Island Network, NPS Inventory and Monitoring Program
PHNHP:	Puʻuhonua o Hōnaunau National Historical Park (or PUHO)
RATS:	Rapid Assessment Transects
RAWS:	Remote Automatic Weather Station
SD:	Standard Deviation
SE:	Standard Error
SQI:	Sky Quality Index
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

Acronyms and Abbreviations (continued)

VIP:	Volunteers-In-Parks program
WHAP:	DAR West Hawai‘i Aquarium Project
WCHI:	West Coast of Hawai‘i Island
WHRR:	West Hawai‘i Reference Region

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
> - 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 Geographic Information System (GIS) products;[4]
- Summarize key findings by park areas;[5] and
- 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

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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.

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)
- 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)**

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.

[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.

[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.

2. Introduction and Resource Setting

By Brian Hudgens, Institute for Wildlife Studies

Fishpond in Royal Grounds (NPS photo).

2.1 Introduction

2.1.1 Enabling Legislation

Formation of the park was authorized by congress by PL 177 in the Act of July 26, 1955, (Chapter 385; 69 Stat. 376) for "*the benefit and inspiration of the people,"* while Hawai'i was a United States Territory. In 1961, approximately two years after Hawai'i became the 50th State, the City of Refuge National Historical Park was officially established after completion of land acquisition of 182 acres, *"to preserve and protect the pu'uhonua complex and surrounding archaeological features and landscape, and the historic fishing village of Ki'ilae"*. The name was changed as amended by section 305 of the National Parks and Recreation Act of 1978 (92 Stat. 3477) to "Puuhonua o Honaunau National Historical Park." The "Hawaiian National Park Language Correction Act of 2000" (106 S. 939), to "*correct spelling errors in the statutory designations of Hawaiian National Parks,"* further amended the name to the current designation with correct Hawaiian language diacritical markings. In 2006, Pu'uhonua o Hōnaunau National Historical Park acquired an additional 238-acre parcel, in the Ki'ilae ahupua'a, making the park a total of 420 acres (Figure 2.1-1).

A primary NPS management objective is "to restore and maintain the historic scene of the Pu'uhonua, [Royal] Grounds, and house complexes in the park to the year 1819, including restoring the vegetative community to native and Polynesian plants present in the early 1800's" (Else 2006).

2.1.2 Geographic Setting

The 1.7 km^2 (420 acres) site is located in the district of Kona on the western coastline of the Hawai'i Island (Figure 2.1-1). Situated at the base of the Mauna Loa Volcano, the park's western boundary follows the high tide mark from Hōnaunau Bay in the north to Ki'ilae Bay in the south. The eastern boundary extends inland approximately 0.7 km (0.4 mi) in the northern section to 1.7 km (1.1 mi) in the south. Elevation within the park boundary also varies with the inland range, extending further upslope on the Mauna Loa Volcano in the Ki'ilae ahupua'a section to approximately 195 m (640 ft) above mean sea level (amsl) and to an average elevation of 45.7 m (150 ft) amsl in the north. The park is located approximately 35 km (22 mi) south from the town of Kailua-Kona. A detached 1.47 ha (3.63 acre) parcel contains a native garden called Kihapai-uka or the "mauka (upland) garden" as well as a dormitory and curatorial storage facilities. This parcel was acquired at the time of park establishment along with a 6-ft wide easement for a proposed water pipeline.

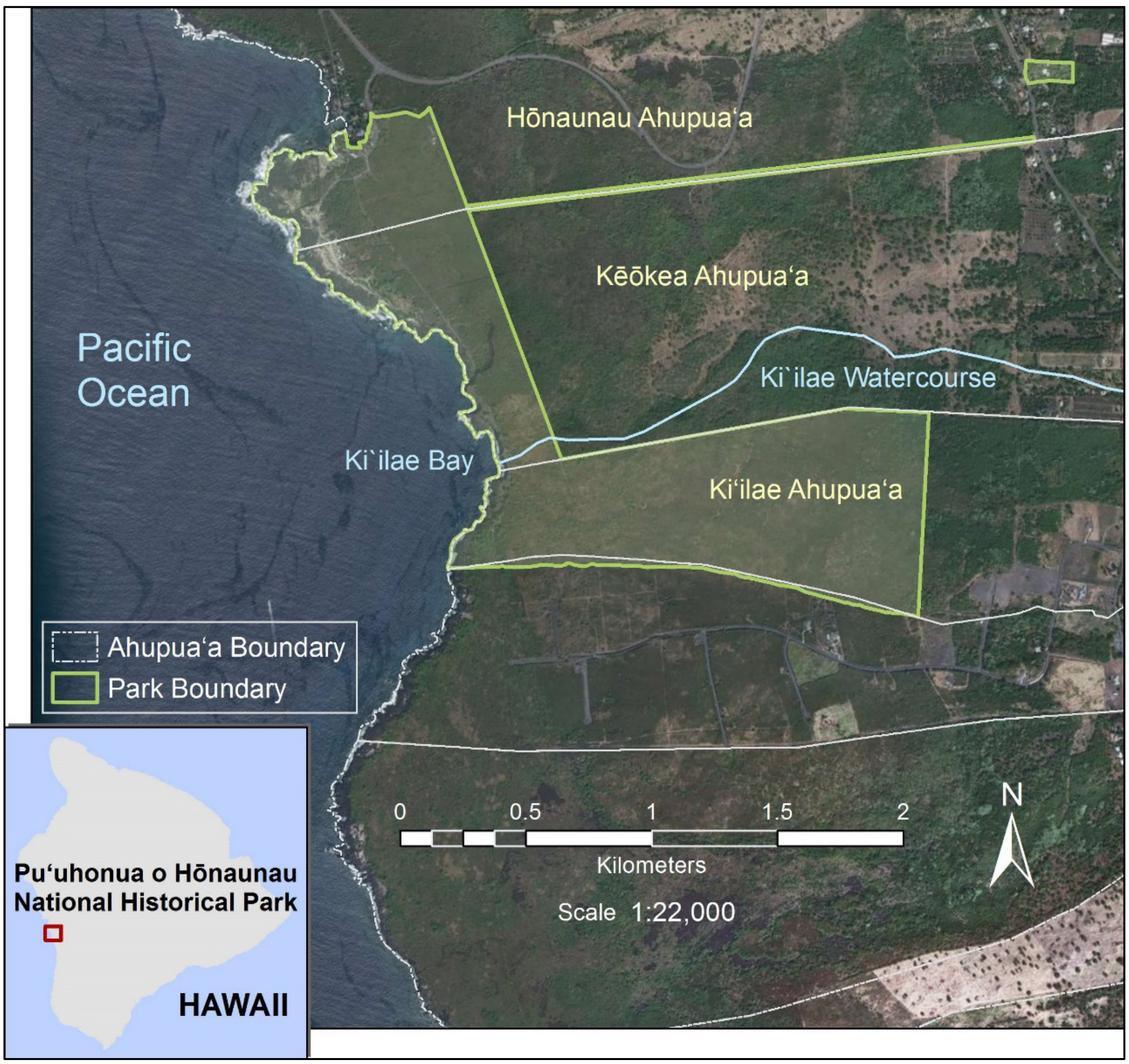


Figure 2.1-1. Map of Pu'uhonua o Hōnaunau NHP showing park boundaries and geographic locations. (Imagery source: ESRI, Digital Globe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USGS, AeroGRID, IGN, and the GIS User Community). The Ki'ilae watercourse is intermittent.

The coastal portions of three ahupuaʻa: Hōnaunau, Kēōkea, and Kiʻilae are managed by the park. Ahupuaʻa are Hawaiian land divisions that generally extend from the ocean to high elevation forests and above. They functioned as a unit throughout which Hawaiians could access the full range of resource opportunities, including the reef, the cultivated lands, the high elevation forests, and on the higher islands, the alpine resource environments. Where there are fully developed streams, they are coincident to watershed ridgeline boundaries; in the dry leeward environment of Kona, they are defined by landmarks such as hills, ridges, springs, groves of trees, and other "known" places.

Coastal lands immediately north and south of the park are within the state's conservation district. In 2016, Ala Kahakai National Historic Trail acquired the 23.9 ha (59 acre) coastal parcel directly south of the park. Properties inland from the park and north of the park's main entrance are predominantly in the state's agricultural district (Figure 2.1-2). Human population densities in the vicinity of the park and upslope areas are low. Open land, mixed agriculture and scattered residences are found upslope of the park. Immediately north of the park's main entrance is a tiny shoreline community, a school, a boat ramp used by subsistence fishers, a canoe club, and a popular site for marine recreation including snorkeling and diving.

Figure 2.1-2. Land use classification near Puʻuhonua o Hōnaunau NHP.

<u>Climate</u>

The Kona coast of Hawaiʻi Island is characterized by calm winds and cool temperatures in the early morning hours, with onshore winds in the later morning to evening hours. The volcanic mountains Mauna Loa, Mauna Kea, and Hualālai to the east keep many of the trade wind-driven rain showers from reaching the western, leeward side of the island. As a result, areas of the Kona coast including Puʻuhonua o Hōnaunau National Historical Park experience relatively dry conditions (Leishmann 1986, Hoover and Gold 2006). There is a general trend of increasing precipitation with an increase in elevation up to 700–900 m (2600–29500 feet); just six kilometers east of the park is a band of maximum rainfall of about 200 cm (80 in; Giambelluca et al. 2013). Average annual precipitation within the park (based on 1978–2007 data) ranges from 68.7 cm (27.1 in) at Puʻuhonua Point (northwestern corner of the park) to 101.2 cm (39.8 in) at the southeastern corner of the park; the annual average at the Visitor Center is 70.8 ±4.4 cm (27.9 ±1.7 in) as interpolated from Giambelluca et al. (2013; Figure 2.1-3). Rainfall is greatest June through October, with a secondary peak in January (Figure 2.1-4). The Kona coast is the only region in Hawaiʻi where more precipitation falls in the summer than in the winter. The "Kona rainfall belt" is along the leeward side of Mauna Loa and Hualālai, where these large mountains block the prevailing easterly trade winds. Warm air in this leeward region moves upslope as the land warms during the day, then cools as it rises, thus clouds form and produce rain. Higher summer temperatures further magnifies this process and therefore causes increased rainfall (Giambelluca et al. 2013).

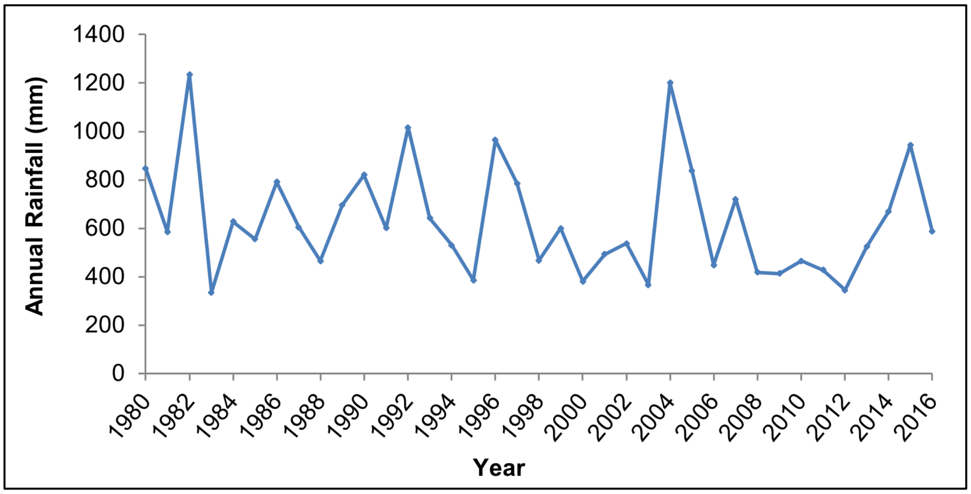


Figure 2.1-3. Annual rainfall, 1980–2016 for Pu'uhonua o Hōnaunau NHP. Data from NOAA National Climatic Data Center GHCND:USC00518552. Data from the park's RAWS station (located in the NE of the park, is 550 m (1800 feet) NW of the NOAA weather station, south-southwest of the visitor center) were used to fill in missing data prior to 2012 and all data from 2012–2016[1].

In 2012, a Remote Automatic Weather Station (RAWS) weather station was installed in the park at an elevation of 29.6 m (97 ft). During the first four years of operation (02/2012–01/2016), air temperature averaged 24.4º C (75.9º F), (ranging from 22.7º C [72.9º F] in January to 25.9º C [78.6º F] in August), relative humidity averaged 66%, and wind speed averaged 4.75 km/hr (2.95 mi/hr). The average daily low temperature was 21.1º C (70.0º F) and the average high was 28.1º C (82.6º F). Wind was dominantly from the east and secondarily from the west or east-northeast.

[1] NOAA 8 in COOP rain gauge data: https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USC00518552/detail; RAWS data: https://raws.dri.edu/cgi-bin/rawMAIN.pl?hiHPHO

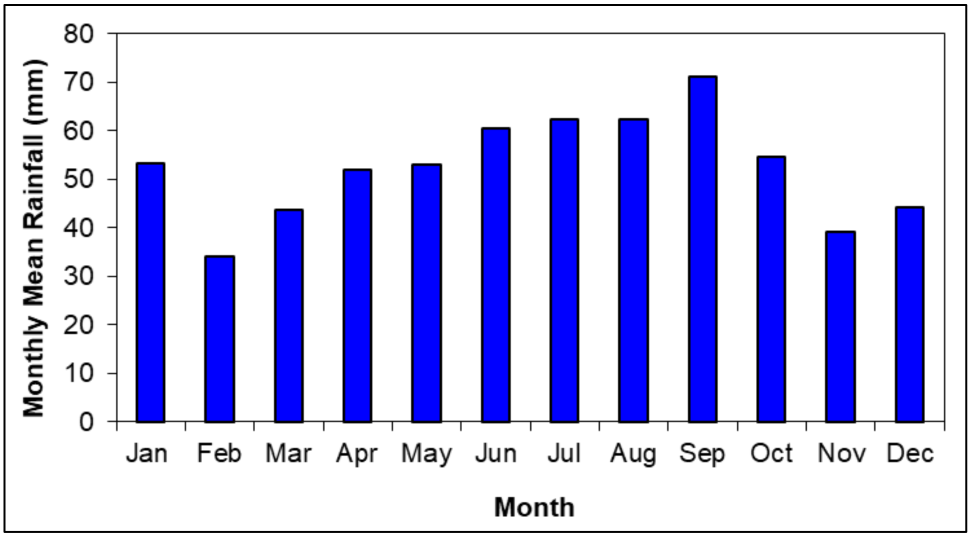


Figure 2.1-4. Mean monthly rainfall, 1980–2016 at Pu‘uhonua o Hōnaunau NHP. Data from NOAA's National Climatic Data Center (station GHCND:USC00518552) and the park's RAWS station, both located within the park boundaries.

Geologic processes

Pu‘uhonua o Hōnaunau National Historical Park is located on the western flank of Mauna Loa Volcano, which is one of the largest and most active volcanoes on Earth (Lipman 1980, Robinson and Eakins 2006). As with the rest of the Island of Hawai‘i, this site has been dominated by two processes: volcanic deposition and island subsidence. Volcanic deposition is dominated by lava flows rather than explosive activity. The youngest lava flows in the park were formed between 750 and 1,500 years ago and an eruption in 1950 resulted in an active lava flow reaching the shoreline approximately seven kilometers south of the park (Richmond et al. 2008). Island subsidence[2] has been documented from submerged coral reefs which show nearly 1.2 km (0.75 mi) subsidence over the past 450,000 years, corresponding to a rate of 2.6 mm/yr (0.1 in/yr; Zhong and Watts 2002). South of Pu‘uhonua o Hōnaunau NHP, massive prehistoric landslides have eroded the coastline and deposited debris on the ocean floor (Moore et al. 1987).

All lava flows in the park belong to the Ka‘ū Basalt series; these originate from Mauna Loa Volcano and take the form of pāhoehoe flows, which have smooth-surfaced flow with a ropy or wavy appearance (Richmond et al. 2008). Specific rock types include tholeiitic basalt, olivine tholeiitic basalt, and picritic tholeiitic basalt, which are all common on Hawaiian volcanoes during the shield-building stage (Langenheim and Clague 1987).

There are three dominant lava flows in the park categorized by age: 750 to 1,500, 1,500 to 3,000, and 3,000 to 5,000 years old (Figure 2.1-5; Trusdell et al. 2005, Richmond et al. 2008). All three flows sit atop Pāhala Ash, a tephra deposit (smaller fragmented materials distributed by wind) whose age is estimated to be 10,000 to 17,000 years old, and Kahuku Basalt (another tholeiitic basalt), estimated

[2] Section 4.1.3.4, especially the subsection "Sea Level Trends," provides more detail about sea level rise in addition to subsidence.

to be older than 30,000 years. The lava flows in the park are stratified, with newer flows concealing older flows. In some areas, however, the older flows are not covered; areas with older flows at the surface tend to have more developed soils and vegetation.

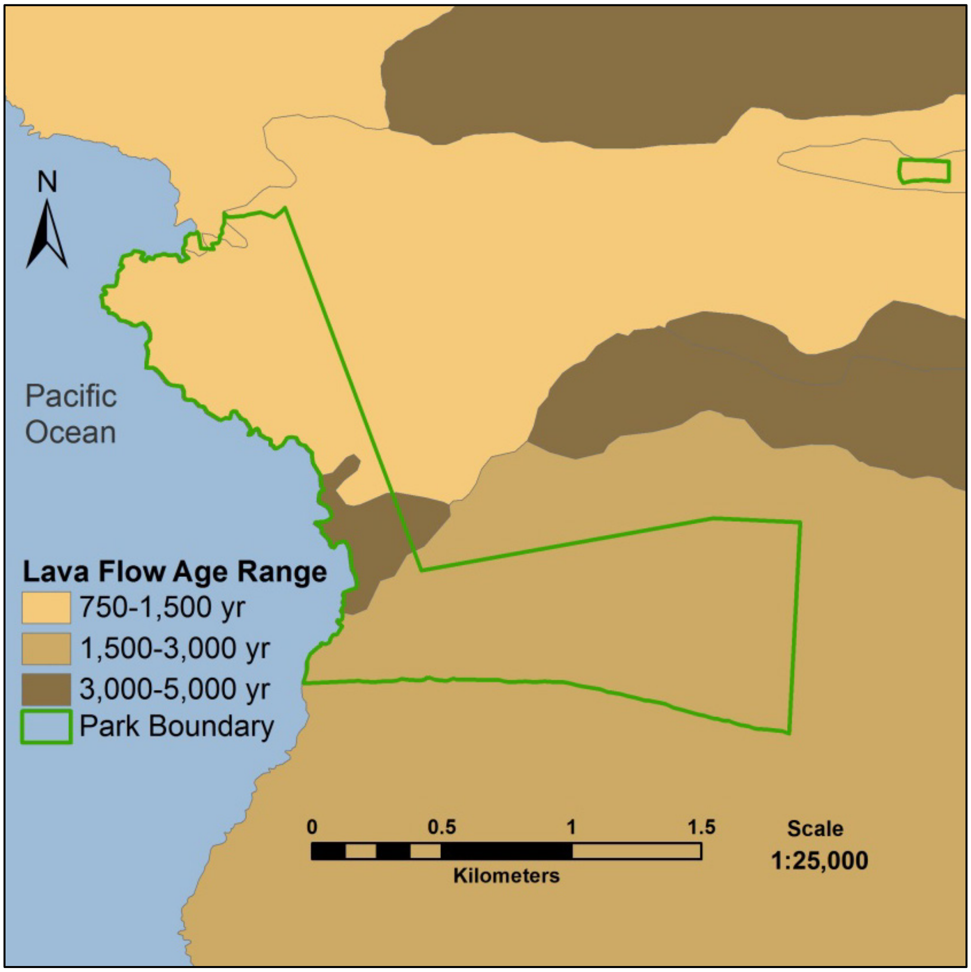


Figure 2.1-5. Geologic map showing the estimated age of lava flows (years before present) in Puʻuhonua o Hōnaunau NHP. (Age data from Trusdell et al. 2005).

A basalt platform makes up most of the shoreline at Puʻuhonua o Hōnaunau NHP (Richmond et al. 2008). The platform is the submerged western section of the lava flows exposed above sea level. The basalt platform contains the park's rocky intertidal zone, while the submerged portion of the platform serves as substrate for corals. Sand deposits of mostly marine origin are found along the intertidal beaches of the park, such as in Keoneʻele Cove. Perched beaches and boulder beaches are found along portions of the shoreline above normal tidal influence (Richmond et al. 2008).

Water Resources

The youth and permeability of the park's lava flows limit the generation of surface runoff and development of stream channels. Kiʻilae Stream is the only watercourse within the park. Kiʻilae Stream is ephemeral; within the park it has an indistinct channel and rarely flows. Groundwater underneath Mauna Loa's western flank flows to the sea, connecting upland areas with the coastal ecosystem. Within the park, groundwater is brackish and plays a key role in the water chemistry of anchialine pools. Anchialine pools are brackish groundwater-dependent ecosystems fed by freshwater and seawater, with no surface connection to the ocean (Holthuis 1973).

Several types of brackish water pools are found in the park (Hoover and Gold 2006, Richmond et al. 2008). There are a small number of naturally occurring anchialine pools occupying cracks and small depressions. In these locations, groundwater is exposed to the atmosphere and biological uptake is expected to affect the concentration of nutrients present in groundwater. The Royal Fishpond (Figure 2.1-6) is an anchialine pool that was modified for the purpose of holding fish. It is divided by a constructed wall that serves as a pathway between the separate northern and southern pools.

Figure 2.1-6. Royal Fishponds (anchialine pools) at Puʻuhonua o Hōnaunau NHP, as viewed from the south (NPS photo).

2.1.3 Visitation Statistics

Recreational visitation to Puʻuhonua o Hōnaunau NHP from 2005–2014 averaged 431,676 people per year (NPS 2016b). In 2014, monthly visitation was highest in February and March (Figure 2.1-7). Park closures from natural disasters and inclement weather such as the March 11th, 2011 tsunami and seasonal high surf have the potential to affect visitation numbers.

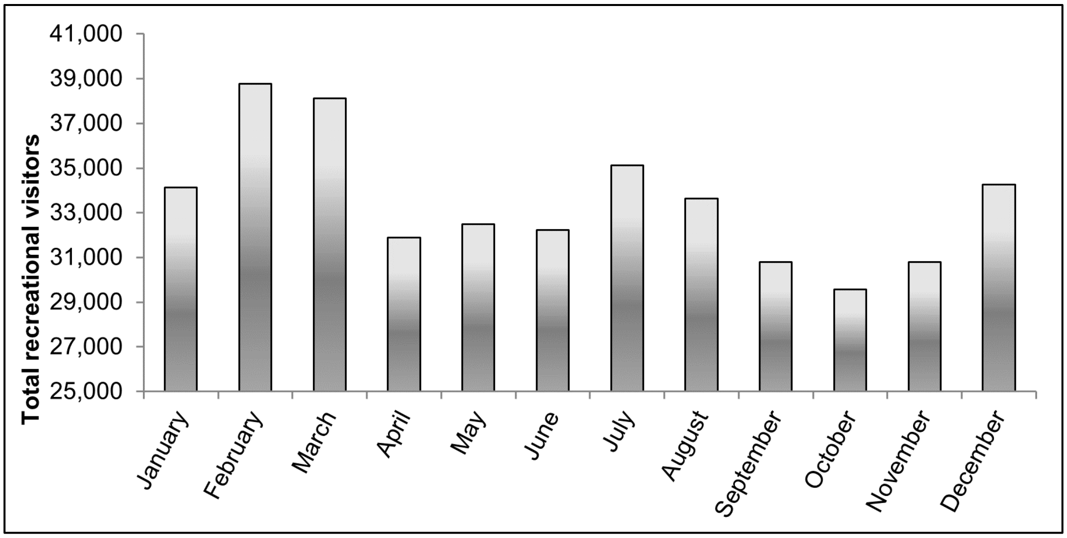


Figure 2.1-7. Puʻuhonua o Hōnaunau NHP, 2014 recreational visitors by month (NPS 2016b).

2.2 Natural and Cultural Resources

Basalt flows and coconut palms. Pu‘uhonua o Hōnaunau NHP (USGS photo, Phil Stoffer, 2004)

2.2.1 Ecological Setting and Watersheds

The first Polynesians directly altered the natural resources and landscapes they found through species introductions, and through use of native plants and animals. Introduced species included pigs (*Sus scrofa*), Polynesian rats (*Rattus exulans*), dogs (*Canis familiaris*) and chickens (*Gallus* sp.). In dryland environments such as at Pu‘uhonua o Hōnaunau, a range of adaptive strategies were used to take advantage of varying rainfall and create productive agriculture from the lowlands to the upland forests. Niu (coconut, *Cocos nucifera*) was planted at the shoreline, with ‘uala (sweet potato, *Ipomoea batatas*) in areas behind the shoreline.

The vegetation on Hawai‘i Island changed dramatically again after European contact, as additional plants, goats (*Capra hircus*), sheep (*Ovis aries*), and cattle (*Bos taurus*) were introduced. Browsing and grazing mammals in particular impacted native species, many of which are endemic to Hawai‘i. Nevertheless, many endemic, native, and Polynesian species still thrive within the park, often benefitting from management actions aimed at removing invasive species and cultivating the plants likely found at Pu‘uhonua o Hōnaunau NHP in the early 1800s. The park is predominantly shrubland with isolated areas of woodland and overall highly invaded by nonnative plants.

2.2.2 Cultural Resource Descriptions

The most prominent and interpreted cultural resources in the park are the “Chief’s House Site”, the “Royal Grounds” including the Royal Fishponds, Keone‘ele Cove, the Pu‘uhonua including the “Great Wall”, and Hale o Keawe. Many of the cultural sites today remain as stone ruins of structural foundations including the Chief’s and Keawe house sites which contain remnants of large multi-structure residences where ruling chiefs lived. Hundreds more archeological features are in the remainder of the park, including Ki‘ilae Village, last inhabited in the early 20th Century and linked by the 1871 trail.

Extensive preservation efforts on many of the park's cultural resources have been conducted. Perhaps the most striking cultural site is the Great Wall (Figure 2.2-1): a large L-shaped structure that defines the south and east sides of the Pu‘uhonua (place of refuge). The Great Wall stood as an ideological and physical barrier for combatants and non-combatants seeking refuge during times of warfare, and for individuals seeking refuge from reprisals, and forgiveness for violating kapu (sacred law).

Figure 2.2-1. The Great Wall, bounding the south and east sides of the Pu‘uhonua (place of refuge; NPS photo).

In addition to the stabilization and preservation of the Great Wall, the park conducted archeological investigations and restoration of the Hale o Keawe platform and reconstructed the Hale Poki and ki‘i images, investigated and stabilized ‘Āle‘ale‘a, and stabilized the seawalls and other wave- and tsunami-damaged sites. Additionally, restoration efforts to remove invasive fish species from the Royal Fishponds reflect the close association of cultural and natural resources in Pu‘uhonua o Hōnaunau NHP.

2.2.3 Natural Resource Descriptions

Air Quality

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 Puʻuhonua o Hōnaunau National Historical Park, 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.

Soils

The park's soils are generally very thin and poorly developed. Depending on rainfall and the age of the underlying lava flow (Figure 2.1-5), they vary in composition, fertility and vegetative cover (Richmond et al. 2008). The northern two-thirds of the park are mapped as pāhoehoe lava flows with little soil development. Moving upslope from the coastline, soils are less rocky and above the park they are capable of supporting intensive agriculture.

Cave Systems

There are over 50 known caves of various sizes located throughout the park. However, the current status of cave systems at Puʻuhonua o Hōnaunau National Historical Park is not well known; most were documented via reconnaissance level archeological surveys. The cave systems present within the park are lava tubes formed by flows between 750 and 5,000 years before present. These represent discrete features of the park's landscape and may include native flora and fauna, as well as native Hawaiian cultural material remains.

Hawaiian caves provide a unique habitat in which thousands of cave dwelling arthropods have evolved (Howarth 1990). Howarth and Mull (1992) remarked that Hawaiʻi Island "harbors the most surprising radiation" of cave species; in some cases, different cave species have evolved within a single lava tube. The NPS I&M Program initiated a survey of seven caves in the park to document geological, biological, archeological and paleontological materials (Burrell and Blakemore 2008). However, due to a multitude of factors, including safety/access issues and presence of sensitive resources, only two caves were qualitatively inventoried. Species-level identifications were limited to presence of nonnative vegetation at five of the seven cave entrances, as well as Tahitian prawns (*Macrobrachium lar*) in one of the caves.

In order to protect cave resources, the NPS seeks to inventory the natural resources of caves, and comply with cultural resource directives, policies, and laws (NPS 1991, Federal Cave Resources Protection Act 1988).

Vegetation

Vegetation in the park has changed substantially during the transition from pre-human inhabitation to post-European contact, and eventually post-park establishment. Based on relatively recent vegetative structure at the park, it is assumed that pre-inhabited vegetation would have likely been forest or shrubland (Kirch 1982, Pratt 1998). Paleoenvironmental studies by Athens et al. (2007, 2014) analyzed preserved pollen from pond core samples and found that the pre-human forest was dominated by *Pritchardia* (loulu, fan palms). Other native taxa present in the cores includes the genera *Dodonaea* (ʻaʻaliʻi), *Kanaloa* (kanaloa), *Chamaesyce* (ʻakoko), *Chenopodium* (ʻāweoweo), and *Cibotium* (hāpuʻu, tree fern). Polynesian settlers in west Hawaiʻi converted much of the lowlands to rain-fed dryland agriculture known as the "Kona field system" (Ladefoged et al. 2009, Lincoln et al. 2014). Many of Hawaiʻi's characteristic vegetation and agricultural cultigens were introduced by Polynesian settlers and travelers, such as niu or coconut (*Cocos nucifera*), ʻulu or breadfruit (*Artocarpus altilis*), kalo or taro (*Colocasia esculenta*), yams (*Dioscorea* spp.), and ʻuala or sweet potato (*Ipomoea batatas*) (Kirch 2007). The practice of slash and burn clearing likely allowed for establishment of pioneering weedy vegetation. Though areas in the park have reestablished as mixed-shrubland, species composition is dominated by exotics (Leishmann 1986). Most exotic plant species found in the park today were brought to the island following European contact, with the intentional introduction of plants for grazing livestock (e.g., *Prosopis pallida*, *Leucaena leucocephala*), as well as unintentional transport of weeds and escaped cultigens.

Following European contact, many lowland and coastal areas of Hawaiʻi Island, including those within what is now the park boundary, were used for grazing of cattle (*Bos taurus)* and goats (*Capra hircus*). The grazing of cattle and goats had deleterious effects on native flora diversity while facilitating transportation of nonnative seeds. As a result of anthropogenic alteration to the Hawaiian landscape, many of the plant species in the park were classified as alien (Leishmann 1986, Pratt 1998, Cogan et al. 2011). However, areas near anchialine pools, cliffs, and the coastline contain most of the park's remnant native vegetation, while restoration projects have successfully replaced exotics with native species along portions of the coastal trail.

Anchialine Pool Communities

Anchialine pools are brackish coastal waterbodies fed only by fresh upland and saline marine groundwater sources (Holthuis 1973). Although found throughout the world along karst and young volcanic coastlines, within the United States anchialine pools are only found in Hawaiʻi. National parks contain over 30% of Hawaiʻi's described anchialine pools. Fifteen anchialine pools have been documented in Puʻuhonua o Hōnaunau National Historical Park including those no longer present, such as a pool filled in with sand by Hurricane Iniki storm surge in 1992 (F. Galieto, NPS, personal communication, 2016).

Hawaiian anchialine pools support unique biological communities with many endemic species of crustaceans (Chai et al. 1989, Chai 1999, Tango et al. 2012). Species that commonly occur the anchialine pools of Puʻuhonua o Hōnaunau NHP are frequently absent from other pools along the Kona coast, including small red shrimp collectively called ʻōpae ʻula (chiefly *Halocaridina rubra* and *Metabetaeus lohena*), and the neritid snail pīpīwai (*Theodoxus cariosus*). Other important species include the Hawaiian dragonflies or pinao (including *Anax strenuus*) and the orangeblack Hawaiian damselfly or pinapinao maʻalaea (*Megalagrion xanthomelas*) (Polhemus and Asquith 1996, Englund 1999). Introduced species, particularly fish such as the Mozambique tilapia

(*Oreochromis mossambicus*) and mosquitofish (*Gambusia affinis*), impact anchialine pool ecosystems heavily.

Vertebrate Wildlife

Pu‘uhonua o Hōnaunau National Historical Park is used by several species of native Hawaiian vertebrates. Hawai‘i’s only native terrestrial mammal, the ‘ōpe‘ape‘a or Hawaiian hoary bat (*Lasiurus cinereus semotus*), feeds in the park and has been observed over a variety of vegetation types (Fraser et al. 2007). ‘Īlio-holo-i-ka-uaua or Hawaiian monk seals (*Neomonachus schauinslandi*) are occasionally seen basking on shore or near shore (Pacific Islands Fisheries Science Center 2016). The two Hawaiian endemic raptors, the ‘io or Hawaiian hawk (*Buteo solitarius*) and the pueo or Hawaiian short-eared owl (*Asio flammeus sandwichensis*), have both been observed within or adjacent to Pu‘uhonua o Hōnaunau NHP, and several native shorebirds inhabit the park (Table 2.2-1). However, as is generally true for low elevation lands on the west coast of Hawai‘i, most terrestrial vertebrates found in Pu‘uhonua o Hōnaunau NHP are nonnative (Morin 1996a, Table 2.2-2). A vertebrate species list for Pu‘uhonua o Hōnaunau NHP is presented in Appendix A.

Table 2.2-1. Some of the native terrestrial vertebrate species known to have occurred in Pu‘uhonua o Hōnaunau NHP (NPS 2015).

Group	Scientific name	Hawaiian name	Common name
Mammals	*Neomonachus schauinslandi*	‘Īlio-holo-i-ka-uaua	Hawaiian monk seal
Mammals	*Lasiurus cinereus semotus*	‘Ōpe‘ape‘a	Hawaiian hoary bat
Birds	*Buteo solitarius*	‘Io	Hawaiian hawk
Birds	*Pluvialis fulva*	Kolea	Pacific golden plover
Birds	*Himantopus mexicanus knudseni*	Ae‘o	Hawaiian stilt
Birds	*Heteroscelus incanus*	‘Ūlili	Wandering tattler
Birds	*Nycticorax nycticorax hoactli*	‘Auku‘u	Black-crowned night heron
Birds	*Asio flammeus sandwichensis*	Pueo	Hawaiian short-eared owl
Birds	*Fregata minor palmerstoni*	‘Iwa	Great frigatebird
Birds	*Sula leucogaster*	‘A	Brown booby
Reptiles	*Chelonia mydas*	Honu	Hawaiian green sea turtle

Table 2.2-2. Nonnative terrestrial mammal species known to have occurred in Pu‘uhonua o Hōnaunau NHP (NPS 2015).

Scientific name	Common name
Capra hircus	Feral goat
Sus scrofa	Feral pig
Canis familiaris	Domestic dog
Felis catus	Domestic cat
Herpestes javanicus	Small Indian mongoose

Table 2.2-2 (continued). Nonnative terrestrial mammal species known to have occurred in Puʻuhonua o Hōnaunau NHP (NPS 2015).

Scientific name	Common name
Mus musculus	House mouse
Rattus exulans	Polynesian rat
Rattus norvegicus	Norway rat, brown rat
Rattus rattus	Black rat, roof rat

Nonnative vertebrates, such as goats (*Capra hircus*), mongooses (*Herpestes javanicus* syn. *H. auropunctatus*), Norway rats (*Rattus norvegicus*), and Polynesian rats (*Rattus exulans*), are commonly encountered and threaten both natural and cultural resources within the park. Nonnative reptiles are abundant at Puʻuhonua o Hōnaunau NHP. Bazzano (2007) encountered five species of gecko (*Gehyra mutilate*, *Hemidactylus frenatus*, *H. typus*, *Lepidodactylus lugubris*, *Phelsuma laticauda*), green anole (*Anolis carolinensis*), metallic skink (*Lampropholis delicata*), and Brahminy blind snake (*Ramphotyphlops braminus*) in surveys conducted in 2004. All of the geckos except *H. typus* were considered common or abundant, as was the metallic skink. While not encountered during official surveys, cane toad (*Bufo marinus*) and Jackson's chameleon (*Chamaeleo jacksonii*) have been reported at Puʻuhonua o Hōnaunau NHP, and populations of green iguana (*Iguana iguana*) and coqui treefrog (*Eleutherodactylus coqui*) are established in the surrounding area (Bazzano 2007).

Marine Resources

Puʻuhonua o Hōnaunau National Historical Park's legislative boundary ends at the shoreline and marine waters are managed by the State of Hawaiʻi. The biological, chemical, and physical quality of nearshore marine waters are, nevertheless, relevant to the condition of the park's cultural and natural resources. Coral reefs are diverse, productive systems that serve as foundation species to provide structurally complex habitat for many species of reef fishes, algae, and invertebrates (Connell et al. 1997). The west coast of Hawaiʻi Island has the largest area of intact, accreting reefs in the Main Hawaiian Islands (Jokiel et al. 2004). These reefs are an important asset to the park as coral reefs have significant cultural value in Hawaiʻi. According to the Kumulipo, a Hawaiian creation chant, coral was the first organism to emerge from the sea, and coral is used in ceremonies associated with caring for marine resources (Friedlander et al. 2008).

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 motivated the development of complex management systems within ahupuaʻa, district (moku), and island. Even today, subsistence fishing remains culturally and economically important in many communities throughout Hawaiʻi (Poepoe et al. 2007, Friedlander et al. 2013, 2014). Nearshore fisheries in Hawaiʻi comprise a mix of commercial, recreational, and subsistence fisheries, which use diverse gear types to catch a wide range of species (Pooley 1993, Schug 2001, Friedlander et al. 2014). Nearshore fisheries in Hawaiʻi have declined substantially over the past 100 years, with some highly valued species having declined by more than 90% during this time (Friedlander et al. 2015). Habitat degradation, pollution, coastal runoff, overfishing, lack of enforcement, and customary management practices, and climate change have all contributed to declines in fish catch and the overall health of Hawai‘i’s coral reefs (Smith 1993, Friedlander et al. 2003, 2015, Tissot et al. 2009).

2.2.4. Resource Issues Overview

Pu‘uhonua o Hōnaunau National Historical Park encompasses a variety of biocultural resources in a maintained cultural landscape setting. Biocultural resources are biologic, geologic, hydrologic, and atmospheric resources intrinsically intertwined with human cultural values and traditional practices. Some of the park’s biocultural resources are rare or unique and include federally protected species that are permanently or intermittently present in the park. Multiple anthropogenic pressures occurring on both local and global scales threaten and affect the park resources and their cultural values to varying intensities. Natural processes and events such as island subsidence and episodic drought, hurricane, tsunami, volcanic gas eruption, and large storm swell and wave events also affect park resources. In some cases the direct or indirect interaction of these anthropogenic and natural threats intensifies their negative effects on park resources. For a detailed discussion of threats, stressors, and resource issues associated with Pacific Islands park resources, see Chapter 2 in HaySmith et al. (2006).

Specific resource concerns and issues arising from global and local threats include degrading water and air quality; the multiple ecosystem effects on biocultural resources by invasive mammals (feral cats, feral goats, feral pigs, rats, mongooses), fish (tilapia, *Gambusia*), and other pests (insects and fungi); changes in rainfall patterns, and effects of sea-level rise coupled with island subsidence; challenges in preservation of soundscape and sense of place; increasing light pollution; increasing risk of anthropogenic wildfire; and effects of increasing shoreline subtidal collection and fishing pressure.

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 Pu‘uhonua o Hōnaunau National Historical Park Foundation Document (NPS 2017). 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 2017 Foundation Document, the City of Refuge Master Plan (1977) and the Statement for Management (1978) were the primary guiding documents. A General Management Plan was not written for this park. Other management guidance documents include: the Interpretive Concept Plan (1997), which replaced the Interpretive Prospectus (1965); and the Resource Management Plan (1994), which was re-issued in 1999. Several Statement of Management documents also exist ranging from the 1980s through the 1990s.

An important resource guidance document is Pratt’s 1998 report, “Vegetation Management Strategies for Three National Historical Parks on Hawai‘i Island.” This document serves as a general vegetation management plan for the park, covering the topics of invasive plant control and elimination, and restoration of the “historical scene” with pre-1819 as the target date for the majority of the park. The exception is Ki‘ilae Village, where the target interpretative time-period is pre-1926. 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 learning and management of park resources. At Pu‘uhonua o Hōnaunau NHP, park management and resource stewardship rely on existing scientific data, publications, oral histories and other documentation generated both before and since the park's 1955 authorization. These 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 (https://www.nps.gov/im/index.htm) and also through partnerships with universities, non-government organizations and institutions, and federal and state agencies. Among others, the U.S. Geological Survey, University of Hawai‘i, and NOAA Fisheries are key partners. Partner and interagency research and collecting permits are tracked through the online Research Permit Reporting System (https://irma.nps.gov/rprs/). At Pu‘uhonua o Hōnaunau NHP, the I&M program and external partnerships are not only crucial to accomplish natural resource inventory, monitoring, and research to guide park management, but also to understand the information in local, regional, and global contexts outside of park boundaries.

The NPS I&M Program collects long-term monitoring data on, and analyzes the long-term trends of "vital signs," or ecosystem elements and processes that represent the overall health or condition of park resources, known or hypothesized effects of stressors, and elements that have important human values (HaySmith et al. 2006). The 417-unit national park system, consisting of national parks and other federally-designated lands such as national monuments are grouped into 32 networks based on shared biogeography. Pu‘uhonua o Hōnaunau NHP is one of 10 national park units currently monitored by the I&M Pacific Island Network (PACN; https://www.nps.gov/im/pacn/index.htm). Monitoring data and trends are needed by park managers, science partners, and the public to evaluate the integrity of park ecosystems, better understand ecosystem processes and to make science-based management decisions. Vital signs monitored within Pu‘uhonua o Hōnaunau NHP are listed in Table 2.3-1.

Table 2.3-1. Vital Signs and their measures selected for monitoring in Puʻuhonua o Hōnaunau National Historical Park. Thematic Levels 1 and 2 are generally consistent across the 32 networks; however selected Vital Signs and their measures differ at the park level.

Level 1	Level 2	Selected vital sign	Measures
Air & climate	• Air Quality • Weather & Climate	Climate	Air temperature, precipitation, wind speed and direction, relative humidity
Geology and soils	• Subsurface Geologic Processes • Soil Quality	None	None
Water	• Hydrology • Water Quality	Water quality	Annual range, temporal and spatial variance of temperature, pH, salinity/conductivity, dissolved oxygen, turbidity, total nitrogen, total phosphorous, total nitrate, and chlorophyll in anchialine pools
Biological integrity	Invasive Species	None	None
	Focal species or Communities (including at-risk species)	Freshwater animal communities (Anchialine Pools)	Composition, distribution, abundance, and diversity of target species of native and introduced fish and invertebrates in selected anchialine pools; correlated with physical and chemical habitat measures
Landscapes	Landscape Dynamics	Landscape dynamics	Within wildland-urban interface: 10-yr cycle– remote-sensing based change-vector analysis of spatial and temporal characteristics of land use / land cover changes. 5-yr cycle– infrastructure distribution & density. 3–10-yr cycle– human habitation distribution & density

3. Study Scoping and Design

Puʻuhonua o Hōnaunau NHP landscape within the Puʻuhonua (NPS photo).

3.1 Preliminary Scoping

A joint scoping meeting for Puʻuhonua o Hōnaunau and Kaloko-Honokōhau National Historical Parks and Puʻukoholā Heiau National Historical Site was held in November 2014. The meeting included representatives from each of the three parks, the NPS-Hawaiʻi Pacific Islands Cooperative Ecosystems Studies Unit, the NPS Pacific Island Inventory and Monitoring Network, the Institute for Wildlife Studies, and the University of Hawaiʻi. During the scoping meeting, NPS staff from each of the three parks provided 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 legislation and natural resources that were to be focal points for their respective NRCAs. 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 parks as relatively small areas within a heavily impacted landscape, and 2) the cultural context that the parks were 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 portal (IRMA) database. The team was guided through the web portal to IRMA 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 as needed.

The scoping meeting provided NPS staff and the assessment team the first chance to discuss focal areas and potential reference conditions and indicators. The intensive anthropogenic influences on the parks' natural histories 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 and to provide information about how current and future management actions are interacting with out-of-park influences. Importantly, while NPS management goals were considered when deciding on appropriate reference conditions, reference conditions are not necessarily management targets or so-called "pristine" conditions. Rather, they serve to put the state of indicators into a context that facilitates the assignment of a condition for each natural resource evaluated.

3.2. Study Design

3.2.1. Indicator Framework, Focal Study Resources and Indicators

This assessment adapted the indicator framework by Heinz (2002) to accommodate the park's resources. The state of the park's natural resources was assessed by looking at the biological, chemical, and physical components of several resource elements. Six resource elements were chosen for evaluation: air and night sky, water-related processes, terrestrial vegetation, vertebrates, anchialine pools, and marine resources. Each resource element included one or more focal areas (Table 3.2-1).

Specific indicators for each focal area were determined by consensus between the assessment team and NPS staff from the three West Hawai'i parks. Indicators 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 similarity in ecological context (e.g., would similar species be expected to occur at a reference site and Pu'uhonua o Hōnaunau NHP in the absence of anthropogenic influences), NPS management goals for biocultural resources, and data availability. Indicators and measures were chosen based on data availability. Herein, we considered resources less impacted by human activities after European contact to be in better condition. Indicators and reference conditions for each focal area are described in Chapter 4.

Table 3.2-1. NRCA Framework, modified after Heinz (2002), used in assessing the condition of focal resources for Puʻuhonua o Hōnaunau NHP. 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	Air and Night Sky Resources	4.1.1 Air Quality	Exceedances of National Ambient Air Quality Standards (NAAQS) for Sulfur dioxide (SO_2) and particulate matter smaller than 2.5 microns ($PM_{2.5}$)
	Air and Night Sky Resources	4.1.2 Natural Night Sky	All-sky light pollution ratio (ALR)
	Water-Related Processes	4.1.3 Watershed Processes and Coastal Dynamics	Shoreline position, annual rainfall, maximum daily rainfall in a given year, frequency and duration of streamflow, flood stage and discharge, sediment loads (amount of sediment transported to the stream mouth per year), and the sediment concentration in flood waters, distribution of coral and sand deposits
4.2 Terrestrial ecosystem integrity	Vegetation Resources	4.2.1 Terrestrial Plant Communities	Species richness (number of species), density, species composition (presence/absence), and structure (percent cover and frequency)
	Vertebrate Faunal Resources	4.2.2 Birds	Proportion of native species encountered in National Audubon Society Christmas bird counts, species diversity of native shorebirds
	Vertebrate Faunal Resources	4.2.3 Native Mammals	Number of ʻīlio-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	Anchialine Pool Resources	4.3.1 Anchialine Pool Water Quality	Dissolved oxygen (DO), turbidity, nutrients, chlorophyll, and salinity
	Anchialine Pool Resources	4.3.2 Anchialine Pool Biota	Community composition, relative abundance of native and introduced species

Table 3.2-1 (continued). NRCA Framework, modified after Heinz (2002), used in assessing the condition of focal resources for Puʻuhonua o Hōnaunau NHP. 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**
4.4 Marine ecosystem integrity	Marine Resources	4.4.1 Marine Water Quality	*Enterococci* bacteria levels, turbidity
	Marine Resources	4.4.2 Benthic Invertebrates	Benthic percent cover, coral settlement, coral disease, invertebrate abundance
	Marine Resources	4.4.3 Nearshore Marine Fish	Mean fish biomass, numerical density, species richness

3.2.2. Reporting Areas

Because of the small area within Puʻuhonua o Hōnaunau NHP boundaries, assessments were done for the entire park. Although there are no marine habitats within Puʻuhonua o Hōnaunau NHP, natural resources in adjacent offshore marine habitats are integral to both the cultural context and visitor experience. We therefore included an assessment of marine waters within 0.8 km (0.5 miles) of the NHP. The assessment of benthic invertebrates was completed prior to the major bleaching event that occurred in 2015. 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 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. 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 buffer 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. Except as noted in each section in Chapter 4, data from 2005 to 2015 were used to determine the current condition of park resources.

Chapter 4 describes the data, analysis methods and findings for assessing the current condition and trend of park resources for each of the focal areas described above. Where sufficient data for assessment exist, a condition status of good, warrants moderate concern, or warrants significant concern is determined along with a trend determination of improving, unchanging, or deteriorating. Sometimes a resource lacks sufficient data, in which case its current condition and trend are indeterminate or unknown.

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 our determination of resource condition, trend in condition, and level of confidence in these determinations;

Description of the resource, including its relevance and context;

Indicators, Data and Methods describing indicator variables, data sources, comparisons made and any new analyses conducted as part of this assessment;

Reference Condition(s) of each indicator used as a basis for comparison;

Current Condition and Trend, describing the current state and recent trends in the resource condition and level of confidence in this determination;

When there are significant *Threats and Stressors* to a focal resource, those are presented following the *Condition and Trend* section, or woven into the discussion of condition and trend;

Data Gaps and Research Recommendations noting where a lack of information prevented a thorough assessment of the resource condition and recommended research to provide information to better determine resource condition in the future;

Sources of Expertise listing the subject expert(s) responsible for determining the condition and additional experts consulted.

4. Natural Resource Condition Assessments

Coastal environment along the southern shoreline of Puʻuhonua o Hōnaunau NHP, including: the Keanaʻe Pali (cliffs), the Alahaka Ramp, and the 1871 Trail (NPS photo).

4.1 Landscape-scale Physical Environment

The focal resources used to assess the physical environment at Puʻuhonua o Hōnaunau National Historical Park are air and night sky resources (air quality and natural night sky) as well as water-related processes (watershed processes and coastal dynamics). This section describes the status of air and light pollution, and hydrologic function.

Threats to air quality from natural and anthropogenic sources are described, along with specific pollutants that are monitored on the island, namely sulfur dioxide (SO_2) and fine particulate emissions ($PM_{2.5}$). Natural night sky data are presented along with threats to both wildlife and the human experience.

The condition of natural hydrologic function and water-related processes considered here include: movement and transportation of sediment and solutes, and erosion, runoff, coastal erosion, combined with sea level rise and subsidence, flood processes, sediment deposition loads, primary upstream impacts to hydrological processes, and the history of landscape level land use changes and the effects on park resources.

4.1.1 Air Quality

By Tonnie Cummings, NPS Pacific West Region Air Resources Specialist

Sunset silhouetting the Hale o Keawe Heiau and coconut palms (NPS photo).

Condition Summary

When the Kīlauea Volcano is not erupting, air quality at Pu‘uhonua o Hōnaunau National Historical Park warrants moderate concern. Confidence is high because the assessment is based on off-site, but representative, data. During volcanic eruptions, air quality at the park warrants significant concern.

4.1.1.1 Description

Most human activities, including industrial processes, agricultural practices, land disturbance, and fossil fuel combustion, produce air pollution. The air pollutants and effects of primary interest in all NPS-managed areas are particulates and gases that impair visibility and cause respiratory problems, atmospherically-deposited sulfur and nitrogen compounds that change soil and surface water chemistry, elevated concentrations of ground-level ozone that cause respiratory problems in humans and harm vegetation, and persistent bioaccumulative toxins that affect wildlife and human health. At Pu‘uhonua o Hōnaunau National Historical Park, there is also concern about particulates (dust) inhibiting plant transpiration or photosynthesis (Ulrichs et al. 2008, Rahul and Jain 2014).

Nitrogen compounds, such as nitrogen oxides and ammonia, result from fuel combustion and from agricultural activities. Ozone is formed when nitrogen oxides and volatile organic compounds emitted from vehicles, industry, and vegetation react in the atmosphere in the presence of sunlight.

Persistent bioaccumulative air toxics include heavy metals like mercury and organic compounds such as pesticides and industrial by-products. Burning of fuel oil at power plants is the primary source of anthropogenic sulfur emissions in the state of Hawaiʻi and on Hawaiʻi Island (EPA 2018). The Kīlauea Volcano is the largest natural source of sulfur dioxide (SO_2) and fine particulate emissions ($PM_{2.5}$) in the state.

Sulfur dioxide gas reacts in the atmosphere with oxygen, moisture, dust and sunlight to produce sulfuric acid (H_2SO_4) aerosols and other sulfate (SO_4^{2-}) aerosol compounds (Elias and Sutton 2017). It is these aerosol particulates that most strongly impact visibility and harm human health. The Hawaiʻi Interagency Vog Information Dashboard (https://vog.ivhhn.org/) provides useful information on actions people can take to protect their health and property. The dispersal and accumulation of vog from east to west Hawaiʻi Island is forecast and mapped via the Vog Measurement and Prediction Project (VMAP; http://weather.hawaii.edu/vmap), which uses estimates of volcanic emissions along with wind forecasts to predict concentrations of SO_2 and SO_4 across Hawaiʻi Island (Businger et al. 2015). West Hawaiʻi, in particular, can experience high levels of acidic fine particulates during prevailing trade wind conditions (Tam et al. 2016).

4.1.1.2 Indicators, Data and Methods

The NPS Air Resources Division's (ARD) general approach for evaluating air quality conditions and trends in NPS units is based on estimates of ozone, sulfur and nitrogen deposition, and visibility (Taylor 2017; NPS 2019). On a case-by-case basis, taking into consideration available data and park-specific issues, ARD uses other indicators such as mercury deposition, or SO_2 or $PM_{2.5}$ concentrations. The ARD estimates air quality conditions for all parks in the contiguous U.S. using the Inverse Distance Weighting interpolation method and data from national air quality monitoring networks. Monitoring data are too sparse for the geospatial estimation method in Alaska, Hawaiʻi, Puerto Rico, and the Virgin Islands, so in those locations, data from on-site or nearby representative monitors are used. In some cases, monitoring sites that do not fit the representative criteria (i.e., not within distance or elevation criteria) may still be used if the data have been found to be representative of the park.

No representative ozone or nitrogen, sulfur, or mercury deposition data are available for Puʻuhonua o Hōnaunau National Historical Park. The ARD determined the Hawaiʻi Department of Health (HDOH) Kona monitoring site (AQ Site ID: 15-001-1012) collects representative SO_2 and $PM_{2.5}$ data, as the station is located within 10 km (6 mi) of the park boundary (HDOH 2019b). There is only one visibility monitoring site on Hawaiʻi Island; it is located at Hawaiʻi Volcanoes National Park. The Interagency Monitoring of Protected Visual Environments (IMPROVE, site ID HAVO1) visibility monitor is within 150 km (93 mi), but it does not meet the elevation criteria. However, ARD determined data from this site can be used to represent visibility conditions at Puʻuhonua o Hōnaunau National Historical Park as an upper limit (i.e., how "good" it can be).

Due to health concerns about high, short-term exposures of vog, HDOH, Environmental Protection Agency (EPA), and others collaborated to develop a 15-minute average SO_2 advisory system (http://www.hiso2index.info). The purpose of the advisory is to provide the public with real-time information on SO_2 concentrations, along with associated recommendations about activity levels and possible health effects at different concentrations of SO_2. One of the reporting sites is the HDOH Kona station.

Air quality conditions were derived using 3-year averages (2015–2017) of SO_2 (99th percentile daily maximum 1-hour concentration) and annual $PM_{2.5}$ (98th percentile and weighted annual mean 24-hour concentration) data. Sulfur dioxide and $PM_{2.5}$ trends were computed from 10 years (2008–2017) of annual concentration data. These data were compiled from EPA (https://epa.maps.arcgis.com/apps/webappviewer/index.html) and analyzed by NPS Air Resources Division (K. Taylor, NPS, personal communication, November 1, 2018).

Visibility is expressed by the haze index in deciviews (dv), which is scored as a zero in pristine conditions and increases as visibility decreases. The haze index is a measure that corresponds to uniform incremental changes in visual perception across the entire range of conditions from pristine to highly impaired (Taylor 2017). The visibility condition assessment was based on the 5-year average (2011–2015) haze index on the mid-range days minus the estimated natural visibility (i.e., visibility estimated in the absence of pollution). Mid-range days are when visibility is between the 40th and 60th percentiles. Visibility trends were computed from 10 years (2006–2015) of annual haze index values on the 20% haziest days and the 20% clearest days, consistent with visibility goals in the Clean Air Act and Regional Haze Rule, which include improving visibility on the haziest days and allowing no deterioration on the clearest days. Although this legislation provides special protection for NPS lands designated as Class I viewsheds, such as Hawaiʻi Volcanoes National Park, the NPS applies these metrics to all units of the NPS. If the haze index trend on the 20% clearest days is deteriorating, the overall visibility trend is reported as deteriorating.

4.1.1.3 Reference Condition

The EPA has established National Ambient Air Quality Standards (NAAQS) for several air pollutants; these standards are intended to protect human health and welfare, including ecological resources. The Clean Air Act identifies two types of standards. Primary standards provide public health protection, including protecting the health of "sensitive" populations. Secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings. The EPA has developed an Air Quality Index for reporting daily air quality to the public. The Air Quality Index is based on pollutant concentration ranges for some NAAQS pollutants such as $PM_{2.5}$ and SO_2.

The ARD uses EPA's Air Quality Index breakpoints and natural visibility goals as benchmarks to assess SO_2, $PM_{2.5}$, and visibility conditions and trends in parks (Tables 4.1-1, 4.1-2, and 4.1-3). The visibility benchmarks were chosen to reflect the range of conditions across the IMPROVE monitoring network.

Table 4.1-1. Benchmarks for sulfur dioxide status. Sulfur dioxide concentrations are averaged over 3-years and are expressed in parts per billion (ppb) (https://aqs.epa.gov/aqsweb/documents/codetables/aqi_breakpoints.html).

Status category	**Ppb**
Warrants significant concern	≥ 76
Warrants moderate concern	36–75
Resource is in good condition	≤ 35

Table 4.1-2. Benchmarks for particulate matter status. Particulate matter concentrations are averaged over 3-years and are expressed in micrograms per cubic meter (µg/m3; Taylor 2017).

Status category	**98th percentile 24-hour PM2.5 concentration**	**Weighted annual mean 24-hour PM2.5 concentration**
Warrants significant concern	≥ 35.5	≥ 12.5
Warrants moderate concern	12.1–35.4	4.1–12.4
Resource is in good condition	≤ 12.0	≤ 4

Table 4.1-3. Benchmarks for visibility status. Status category is based on a 5-year average of estimated visibility on mid-range days minus natural condition of mid-range days (or measured, for locations outside the contiguous US; from Taylor 2017).

Status category	**Visibility (dv)**
Warrants significant concern	> 8
Warrants moderate concern	2–8
Resource is in good condition	< 2

4.1.1.4 Current Condition and Trend

Topographical features, such as Mauna Loa, Mauna Kea, and the Hualālai mountains, cause air masses to strongly influence the Kona coast, increasing the impact of emissions from the Kīlauea Volcano (Juvik and Juvik 1998). This is reflected in exceedances of the SO_2 and $PM_{2.5}$ NAAQS at the HDOH monitoring station in Kona from 2008–2017 (Table 4.1-4). Elevated concentrations of SO_2 and $PM_{2.5}$ have human health, and potential environmental, consequences. Nevertheless, states are allowed to exclude monitored NAAQS exceedances that are caused by exceptional or natural events. Because HDOH attributed all exceedances to either volcanic emissions or wild brushfires (i.e., natural sources), EPA has designated the state of Hawai‘i as "unclassifiable/attainment" for the NAAQS for all pollutants. Therefore, EPA has imposed no requirements on Hawai‘i to reduce anthropogenic emissions.

Table 4.1-4. National ambient air quality standard exceedances at the Kona monitoring station 2008–2017 (HDOH 2019a). Note: ppm = parts per million; µg/m3 = micrograms per cubic meter.

Date	Pollutant	Standard type	Standard	Actual	Cause
04/15/08	$PM_{2.5}$	24-hour avg.	35 µg/m^3	37 µg/m^3	Not listed
04/16/08	$PM_{2.5}$	24-hour avg.	35 µg/m^3	37 µg/m^3	Not listed
04/26/08	$PM_{2.5}$	24-hour avg.	35 µg/m^3	36 µg/m^3	Not listed
04/27/08	$PM_{2.5}$	24-hour avg.	35 µg/m^3	42 µg/m^3	Not listed
05/27/08	$PM_{2.5}$	24-hour avg.	35 µg/m^3	37 µg/m^3	Not listed
07/01/08	$PM_{2.5}$	24-hour avg.	35 µg/m^3	43 µg/m^3	Not listed
07/18/08	$PM_{2.5}$	24-hour avg.	35 µg/m^3	36 µg/m^3	Not listed
08/03/08	$PM_{2.5}$	24-hour avg.	35 µg/m^3	44 µg/m^3	Not listed
12/03/08	$PM_{2.5}$	24-hour avg.	35 µg/m^3	36 µg/m^3	Not listed
12/04/08	$PM_{2.5}$	24-hour avg.	35 µg/m^3	44 µg/m^3	Not listed
05/01/09	$PM_{2.5}$	24-hour avg.	35 µg/m^3	44 µg/m^3	Not listed
05/02/09	$PM_{2.5}$	24-hour avg.	35 µg/m^3	49 µg/m^3	Not listed
05/03/09	$PM_{2.5}$	24-hour avg.	35 µg/m^3	36 µg/m^3	Not listed
05/04/09	$PM_{2.5}$	24-hour avg.	35 µg/m^3	39 µg/m^3	Not listed
12/10/09	$PM_{2.5}$	24-hour avg.	35 µg/m^3	36 µg/m^3	Not listed
12/18/09	$PM_{2.5}$	24-hour avg.	35 µg/m^3	63 µg/m^3	brushfire
12/19/09	$PM_{2.5}$	24-hour avg.	35 µg/m^3	47 µg/m^3	brushfire
12/27/09	$PM_{2.5}$	24-hour avg.	35 µg/m^3	48 µg/m^3	possible brushfire
01/02/10	$PM_{2.5}$	24-hour avg.	35 µg/m^3	37 µg/m^3	volcanic emissions and wild brushfires
01/07/10	$PM_{2.5}$	24-hour avg.	35 µg/m^3	39 µg/m^3	volcanic emissions and wild brushfires
01/08/10	$PM_{2.5}$	24-hour avg.	35 µg/m^3	63 µg/m^3	volcanic emissions and wild brushfires
01/09/10	$PM_{2.5}$	24-hour avg.	35 µg/m^3	38 µg/m^3	volcanic emissions and wild brushfires
01/16/10	$PM_{2.5}$	24-hour avg.	35 µg/m^3	37 µg/m^3	volcanic emissions and wild brushfires
02/25/10	$PM_{2.5}$	24-hour avg.	35 µg/m3	36 µg/m3	volcanic emissions
10/29/11	SO_2	1-hour avg.	0.075 ppm	0.088 ppm	volcanic emissions
01/01/12	SO_2	1-hour avg.	0.075 ppm	0.106 ppm	volcanic emissions
02/03/12	SO_2	1-hour avg.	0.075 ppm	0.098 ppm	volcanic emissions

Table 4.1-4 (continued). National ambient air quality standard exceedances at the Kona monitoring station 2008–2017 (HDOH 2019a). Note: ppm = parts per million; µg/m3 = micrograms per cubic meter.

Date	Pollutant	Standard type	Standard	Actual	Cause
01/16/16	SO_2	1-hour avg.	0.075 ppm	0.101 ppm	volcanic emissions
01/04/17	SO_2	1-hour avg.	0.075 ppm	0.146 ppm	volcanic emissions

Particulate ($PM_{2.5}$) and SO_2 data from the Kona site, along with visibility data from the HAVO (IMPROVE) site, both described in 4.1.1.3, were compared to ARD benchmarks. Based on the results, air quality at Puʻuhonua o Hōnaunau National Historical Park warrant moderate concern. The 2015–2017 99th percentile daily maximum 1-hour SO_2 concentration was 41 ppb and the 2008–2017 trend improved. The 2015–2017 98th percentile 24-hour concentration of $PM_{2.5}$ was 25.0 µg/m^3 and the weighted annual mean concentration was 12.4 µg/m^3. For 2008–2017, the trend of both $PM_{2.5}$ metrics improved. At Hawaiʻi Volcanoes National Park, for 2011–2015, measured visibility on mid-range days was 3.4 dv above estimated natural conditions of 4.5 dv. For 2006–2015, the trend in visibility remained relatively unchanged (no statistically significant trend) on both the 20% clearest days and the 20% haziest days.

Tam et al. (2016) examined SO_2 and $PM_{2.5}$ concentrations from 2002 to 2005 and concluded that Hawaiʻi Island generally has four vog-exposure zones (Low, Intermittent, Frequent, and Acid) created by the amount of volcanic SO_2 emissions, meteorology (speed and direction of wind, humidity, precipitation, and height of the inversion layer), and the island's topography. Puʻuhonua o Hōnaunau National Historical Park is situated in the Acid zone (west Hawaiʻi). From 2002 to 2005, volcanic SO_2 emissions averaged 1600 metric tons per day, and the Acid Zone experienced mean SO_2, $PM_{2.5}$, and particulate acid concentrations (mean ± s.d.) as follows: (SO_2: 1.2±0.4 ppb, $PM_{2.5}$: 7.2±2.3 µg/m^3, particulate acid: 25.3±17.9 nmol H+/m^3). Mean $PM_{2.5}$ concentration was significantly greater in the Acid Zone than in all other zones. Mean particulate acidity in the Acid Zone was also significantly greater than in all other zones (Tam et al. 2016). Sullivan et al. (2011a and 2011b) calculated the relative threat from anthropogenic sulfur and nitrogen deposition at all 270 parks included in the NPS Inventory and Monitoring Program based on 2002 EPA National Emissions Inventory data. They concluded that, relative to the other 269 parks, at Puʻuhonua o Hōnaunau National Historical Park, there was a low risk of acidification from anthropogenic sulfur and nitrogen deposition (Sullivan et al. 2011a) and a very low risk of anthropogenic nutrient enrichment from nitrogen deposition (Sullivan et al. 2011b).

No data are available to assess trends in sources of anthropogenic air pollution; however anthropogenic sources can be expected to increase as Hawaiʻi County, and West Hawaiʻi in particular, continues to urbanize.

Puʻuhonua o Hōnaunau National Historical Park is exposed to both volcanic pollution ("vog") from the Kīlauea Volcano and local anthropogenic sources of air pollutants. Under typical circumstances, based on representative data collected by nearby monitors, air quality at the park warrants moderate concern and the overall trend is improving. However, vog reduces park air quality and during times of substantial volcanic eruption, air quality warrants significant concern. The summer 2018 eruption is a telling example. On May 3, lava erupted in the Kīlauea Volcano East Rift Zone in the District of Puna. Kīlauea Volcano's summit caldera area also began experiencing large ash explosions and increased seismic activity. From mid-May to August, when activity largely ceased, more than 30,000 metric tons of volcanic gas per day was emitted (USGS-HVO 2018).

4.1.1.5 Threats and Stressors

The most significant threats to air quality at Puʻuhonua o Hōnaunau National Historical Park are emissions from the Kīlauea Volcano. Nevertheless, the NPS is concerned about and should encourage minimizing human-caused pollution along the Kona Coast. At the time of writing, there are agricultural, transportation, and fuel-oil burning sources in West Hawaiʻi that also likely affect air quality.

The interacting effects of climate change and air pollution are unknown. In arid areas such as West Hawaiʻi, acid aerosols in vog can negatively affect raindrop formation, similar to the effect of industrial pollution in the northeastern United States, and therefore reduce summer rainfall and negatively affect plants and groundwater recharge (Elias and Sutton 2017). Changes in precipitation patterns may affect the amount and timing of sulfur and nitrogen deposition. Nitrogen can negatively impact biodiversity in plant communities (Clark et al. 2013), with species that are better adapted to high nitrogen levels outcompeting species adapted to low nitrogen, and high nitrogen favoring invasive over native species. Climate change can exacerbate this effect with increases in temperatures and changes in precipitation regimes that favor some species over others.

4.1.1.6 Data Gaps and Research Recommendations

As a result of the 2018 volcano eruption, several additional monitors were added on the west side of Hawaiʻi Island, including a non-regulatory $PM_{2.5}$ monitor at Puʻuhonua o Hōnaunau National Historical Park. These monitors will improve understanding of $PM_{2.5}$ pollutant concentrations around the island. However, it may be helpful to collect information about additional air pollutants and potential resource effects at Puʻuhonua o Hōnaunau National Historical Park. For example, volcanic emissions contain mercury, but there are no park data regarding either atmospheric mercury deposition or concentrations in biota. Volatile organic compound markers could be used to identify air pollution sources impacting the park. The markers can distinguish between source types such as biomass burning, urban, agriculture, and transportation. Finally, while Sullivan et al.'s (2011a and 2011b) risk assessments ranked Puʻuhonua o Hōnaunau National Historical Park as relatively insensitive to acidification and nitrogen nutrient enrichment, studies would confirm the effects of deposition on park ecosystems.

4.1.1.8 Sources of Expertise

- Sulfur dioxide and $PM_{2.5}$ data were compiled from EPA (https://epa.maps.arcgis.com/apps/webappviewer/index.html) and analyzed on 11/1/2018 by Ksienya Taylor, NPS ARD Natural Resource Specialist.

4.1.2 Natural Night Sky

By Brian Hudgens, Institute for Wildlife Studies

Condition Summary

The current condition of the night sky at Pu‘uhonua o Hōnaunau NHP is good, with little light pollution generated within or adjacent to the park. This assessment is made with high confidence. Data are not available to determine a trend.

4.1.2.1 Description

Light pollution impacts one of the most visible resources in a park, the night sky. Impacts on the night sky can originate from light sources within the park, such as lighted parking lots or buildings, and from adjacent development. Since the park generally opens after sunrise and closes before dark there is little light development within Pu‘uhonua o Hōnaunau NHP — only three buildings (kiosk, administration, and Keōkea facilities) have outside lights that are regularly on at night by way of automatic light sensors. The largest light sources impacting the night sky may be expected to originate from development adjacent to the park. For that reason, light pollution provides a good metric for tracking changes in the surrounding landscape from predominantly agricultural to urban uses. Light pollution also has the potential to impact native fauna using park habitat; changing feeding behaviors of ‘ōpe‘ape‘a (Hawaiian hoary bat, *Lasiurus cinereus semotus*; Fullard 2001) and impacting feeding behaviors, migration, and even causing direct mortality in sea birds (Montevecchi 2006).

4.1.2.2 Indicators, Data and Methods

Measuring the condition of the night sky is challenging because there are numerous natural phenomena that affect the brightness of the night sky and numerous ways of measuring night-sky brightness. One of the most rigorous and easily interpreted metrics for measuring the condition of the night sky is called the sky quality index (SQI) and was developed by researchers from the National Park Service and U.S. Naval observatory (Duriscoe et al. 2007, Duriscoe 2013).

SQI is not available for Pu‘uhonua o Hōnaunau NHP, so we instead used the All-sky Light Pollution Ratio (ALR), estimated from upward radiant light observed by satellite. The ALR is the average anthropogenic sky luminance presented as a ratio over natural conditions. We used modeled ALR data provided by the NPS Natural Sounds and Night Skies Division. These data were based on 2015 Day/Night Band data collected by the Visible Infrared Imaging Radiometer Suite instrument (VIIRS) located on the Suomi National Polar Orbiting Partnership satellite, which is a collaborative effort between National Oceanic and Atmospheric Administration (NOAA) and National Aeronautics and Space Administration (NASA).

Horizontal trespass in this assessment was accounted for 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.

4.1.2.3 Reference Condition

A pristine night sky is one where natural cycles of light and dark prevail. In these instances, stargazing is uninhibited by stray light. For the ALR, lower values indicate a more pristine sky, with a value of 0 corresponding to a sky free from artificial glow. The National Park Service uses a three-step rankings 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 lowest 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.

4.1.2.4 Current Condition and Trend

Puʻuhonua o Hōnaunau NHP is not located near any potential sources of light pollution (Figure 4.1.2-1). The average ALR at Puʻuhonua o Hōnaunau NHP is less than 0.1 (Figure 4.1.2-1 inset) with little upward reflectance originating at or near the park. The nearest significant (locations with an ALR >0.1) light sources are communities several kilometers away and there is little reason to believe that much horizontal light trespass enters the park.

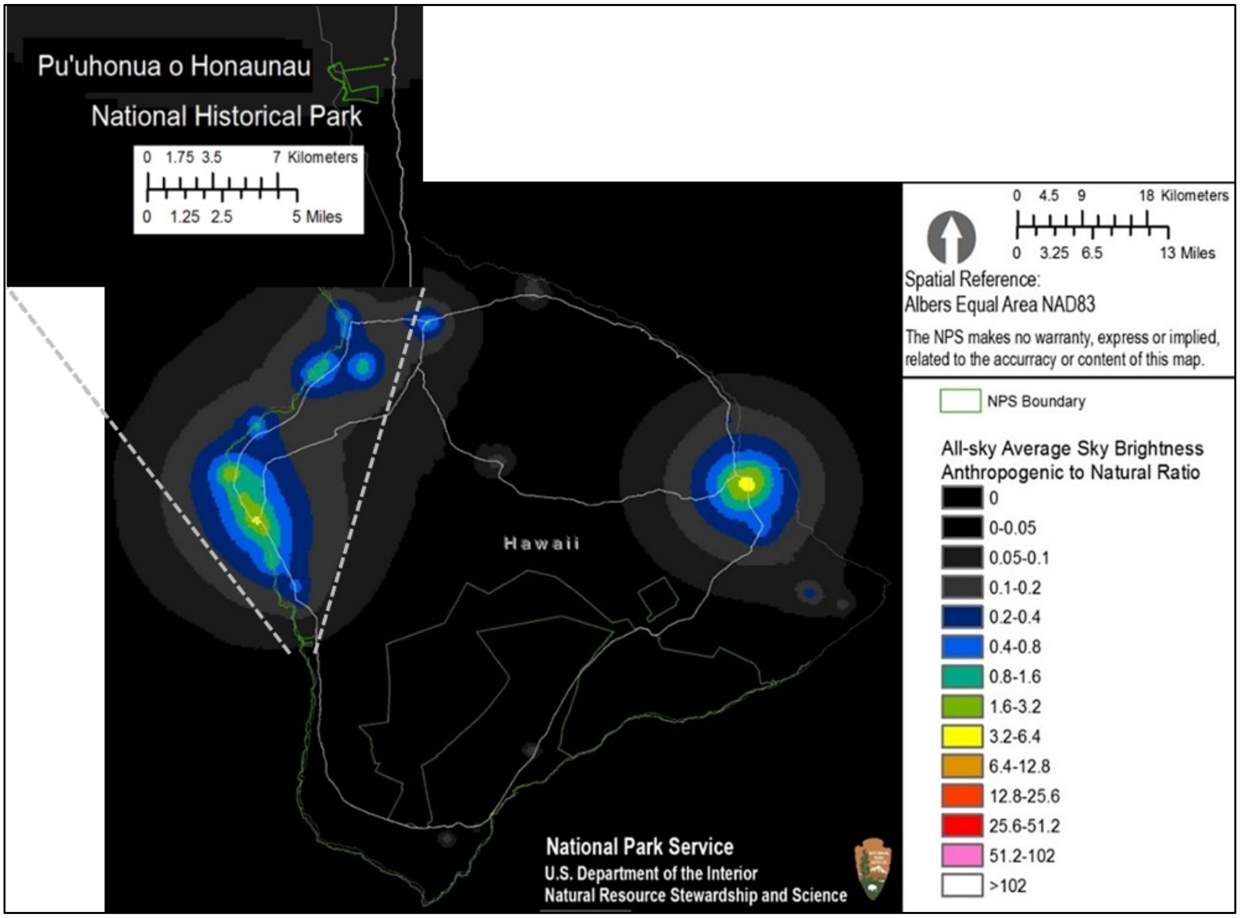


Figure 4.1.2-1. All-sky average anthropogenic to natural sky brightness ratio on Hawaiʻi Island, October 2015. Inset: All-sky average anthropogenic to natural sky brightness ratio at Puʻuhonua o Hōnaunau NHP and surrounding lands, October 2015.

4.1.2.5 Threats

The park is directly adjacent to an agricultural subdivision, Kiʻilae Estates, that has the potential to create light pollution at south end of the park when developed.

4.1.2.6 Data Gaps and Research Recommendations

All of the data on light pollution in Puʻuhonua o Hōnaunau NHP are extracted satellite imagery. However, the primary source of future light pollution at Puʻuhonua o Hōnaunau NHP is most likely to be horizontal trespass. 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 2016a). A more comprehensive method, and one less prone to observer bias, is 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.

4.1.2.7 Sources of Expertise

- Jeremy White, National Park Service Natural Sounds & Night Sky Division

4.1.3 Watershed Processes and Coastal Dynamics

By Jené Michaud, University of Hawaiʻi at Hilo

Picnic area and access road flooded due to a high surf event in 2002 (NPS photo).

Condition Summary

The current condition of the shoreline merits moderate concern because flooding and erosion have damaged the park's cultural resources and altered beaches (high confidence). In the last two decades there is no trend insofar as natural—albeit destructive—processes have continued at rates within the range of natural variability (low confidence). Over longer timescales, however, progressive sea level rise has resulted in the progressive loss of culturally- and ecologically-significant shoreline features (high confidence).

The current condition of the watershed merits moderate concern due to the occurrence of damaging flooding (medium confidence). There may be a deteriorating trend (low confidence). There are no data with which to establish a trend. Based on observations from a one-time survey there is no evidence that terrestrial sediments are accumulating in the ocean.

Water quality conditions in anchialine pools and nearshore marine waters are assessed in sections 4.3.1 and 4.4.1, respectively.

4.1.3.1 Description

Watersheds are a unifying element of the landscape. Water carries sediment, nutrients, and pollutants downslope to the shoreline, where they are discharged to the ocean. From the ocean side, tides and waves move marine waters and coastal sediment into and through Puʻuhonua o Hōnaunau National Historical Park. Hydrologic and shoreline processes operating in Puʻuhonua o Hōnaunau NHP are interlinked, affect all terrestrial, brackish, and marine resources, and connect the park to the surrounding landscape. The dynamic fluid nature of water resources has a continual bearing on the shaping of earth's surface materials and is essential in supplying life-sustaining nutrients to sustain biotic resources.

The physical environment is composed of semi-permanent features such as beaches, archeological features, and watercourses. These are disturbed, from time to time, by erosion and sedimentation associated with heavy rainfall, high surf, exceptional tides and tsunamis. Other disturbances are progressive in nature; these include climate change, sea-level rise, and changing land use patterns in upslope areas.

Throughout this section, processes affecting the condition of the watershed, shoreline, and coastal waters will be discussed from higher elevation to lower elevation. This is because what happens uphill affects what is downhill.

Watershed Features

Kiʻilae stream is the only watercourse in Puʻuhonua o Hōnaunau NHP; portions of the park drain uninfiltrated rainwater to Kiʻilae stream and other portions drain directly into the ocean. The section of Kiʻilae stream that is within the park is ephemeral, flowing only briefly after heavy or prolonged rainfall. Incised channels are not found within the park; debris left by floods shows a broad area of inundation (Rumsey 2010). Satellite imagery corroborates the absence of a defined channel and some satellite images do not even show riparian vegetation marking the position of the watercourse. Other satellite images taken at different times (e.g., undated imagery shown in Beets 2010) show a ribbon of greener vegetation along the watercourse. According to Federal Emergency Management Agency (FEMA), the stream has a contributing area of 34.2 km^2 (13.2 mi^2) at the point where it enters the ocean (FEMA, various dates). Rainfall in the watershed ranges from ~750 mm/yr (30 in/yr) near the coast to ~1900 mm/yr (75 in/yr) in the headwaters of the contributing area (Giambelluca et al. 2013). Further upslope is a noncontributing zone characterized by low rainfall (the summit of Mauna Loa receives only ~275 mm/yr [11 in/yr]) and young, very permeable lava flows without stream channels.

Agricultural activities in the watershed include grazing and growing coffee, macadamia nuts, and fruit (UHH SDAVL 2015). Orchards—and associated scattered residences—are found in a band that is 2.1–3.6 km (1.3–2.2 mi) from the shoreline. Maps place the beginning of Kiʻilae stream channel 6.3 km (3.9 mi) from shore and show a wetland on the north bank. The summit of Mauna Loa is 34 km (21.1 mi) from the shore.

The only hydrological characterization of Kiʻilae stream comes from a discontinued U.S. Geological Survey (USGS) streamgage (station 16759800) sited at an elevation 883 m (2898 ft). The contributing area above the gage is 2.75 km^2 (1.06 mi^2; USGS various dates). It was once common to install gages upstream of agricultural diversions; it is therefore possible that diversions occurred downstream of the gage. The average flow at the streamgage was 0.06 m^3/s (0.20 ft3/s) during the 25-year period of record (1958–1983) and the maximum peak flow was 3.0 m^3/s (9.84 ft3/s), not including overbank flow (NPS 1999a, USGS, various dates). Streamflow at the gage may not be representative of what flows through the park, however. Water flowing past the streamgage could infiltrate into the ground, especially in the semi-arid lower reaches. On the other hand, water flowing into the ocean could be generated anywhere in the watershed and not necessarily above the stream gage.

Near-surface groundwater[3] along the western shoreline of Hawaiʻi Island occurs as a seaward-flowing freshwater lens floating on more saline water (Lau and Mink 2006). In coastal aquifers, the transition from fresh to saline water is gradual and the brackish transition zone is found at progressively shallower depths as recharge decreases and as one approaches the shoreline (Fetter 2001). Groundwater recharge patterns affect water levels and salinities within the anchialine pools. More recharge leads to lower salinity in the anchialine pools. Recharge is primarily from rainfall that infiltrates without being evaporated or used by plants; there is also a contribution from fog drip (Engott 2011). Based on water budget calculations, groundwater recharge near the shoreline is on the order of 100–500 cm/yr (40–200 in/yr; depending on land use) and maximum recharge of about 800–1000 cm/yr (300–400 in/yr) occurs 6 km (4 mi) inland (Engott 2011). Several research groups have identified areas of coastal springs discharging relatively fresh water (Doty 1969 as cited in Hoover and Gold 2006, Fischer et al. 1966, Johnson et al. 2008). The sites at Puʻuhonua o Hōnaunau NHP with springs include Alahaka Bay and the beach area in Keoneʻele Cove. Springs also occur along the north shore of Hōnaunau Bay; the most vigorous spring is near the boat ramp.

Coastal and Oceanographic Features

The prominent features of the park's coastline are Keoneʻele Cove, Puʻuhonua Point, Alahaka Bay, and Kiʻilae Bay (Figures 4.1.3-1 and 4.1.3-2). Kiʻilae stream discharges into Kiʻilae Bay. The shoreline includes exposed basalt platforms, coastal cliffs, and sandy beaches (Hoover and Gold 2006). Notable beaches are discussed below. Offshore, the pāhoehoe basalt platform slopes seaward and is covered, to varying degrees, by coral and boulders (Cochran et al. 2007), with only minor pockets of sand. The upper portions of the platform slope at 10–15 degrees before dropping off more steeply. In Hōnaunau, Alahaka, and Kiʻilae Bays, the drop-off terminates in a sand-covered area. The fringing reefs and their underlying basalt platform are not topographically prominent and, unlike barrier reefs (which are not present here), do not absorb significant amounts of wave energy. Corals in this area do not form spur and groove structures (seaward-stretching ridges and channels that affect sediment transport).

Puʻuhonua Point is more exposed to wave action than other sections of the park (Figure 4.1.3-2), which reduces the amount of coral cover. Here, the upper portion of the platform is mostly bare bedrock (Cochran et al. 2007). Keoneʻele Cove is the most sheltered section of the park's shoreline

[3] Deep aquifers underneath the surface aquifer have been discovered in Hilo and north of Kailua Kona. It is not known if deep aquifers underlie the shallow aquifers at Puʻuhonau o Hōnaunau NHP.

owing to its position within Hōnaunau Bay. The water is quite shallow near the shore, with depths of only 5 m (16 ft) found more than 100 m (300 ft) from shore. The volcanic platform is largely bare in the broad intertidal zone; coral cover increases with increasing water depth (Cochran et al. 2007).

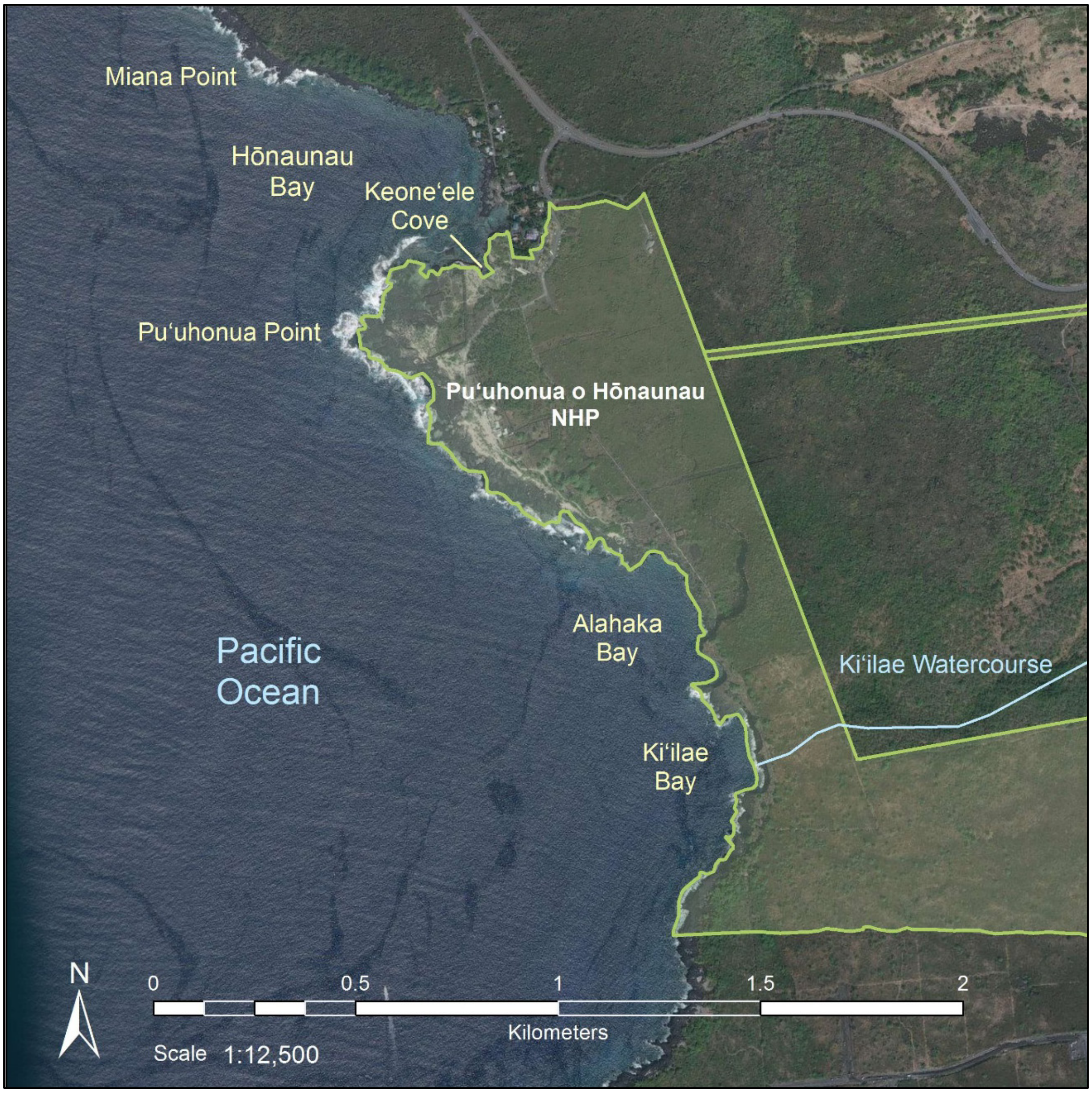


Figure 4.1.3-1. Pu‘uhonua o Hōnaunau NHP coastline and coastal features. The perched beaches can be seen as lighter-colored areas set back from the shoreline (Imagery source: ESRI, Digital Globe, GeoEye, Eathstar Geographics, CNES/Airbus DS, USGS, AeroGRID, IGN, and the GIS User Community). Ki‘ilae Watercourse is intermittent.

The intertidal zone is rocky except for the small sandy pocket beach at Keone‘ele Cove. Sand in the cove is a mixture of carbonate material and basaltic material derived from lava flows. Sandy carbonate beaches are also found above the reach of normal tides and waves. These are called perched beaches and are attributed to storm waves that reach well-above high tide. Perched beaches are found near Keoneʻele Cove, at the southern end of the Puʻuhonua enclosure, and along a 400 m (1300 ft) segment of shoreline south of the Puʻuhonua enclosure (Hoover and Gold 2006).

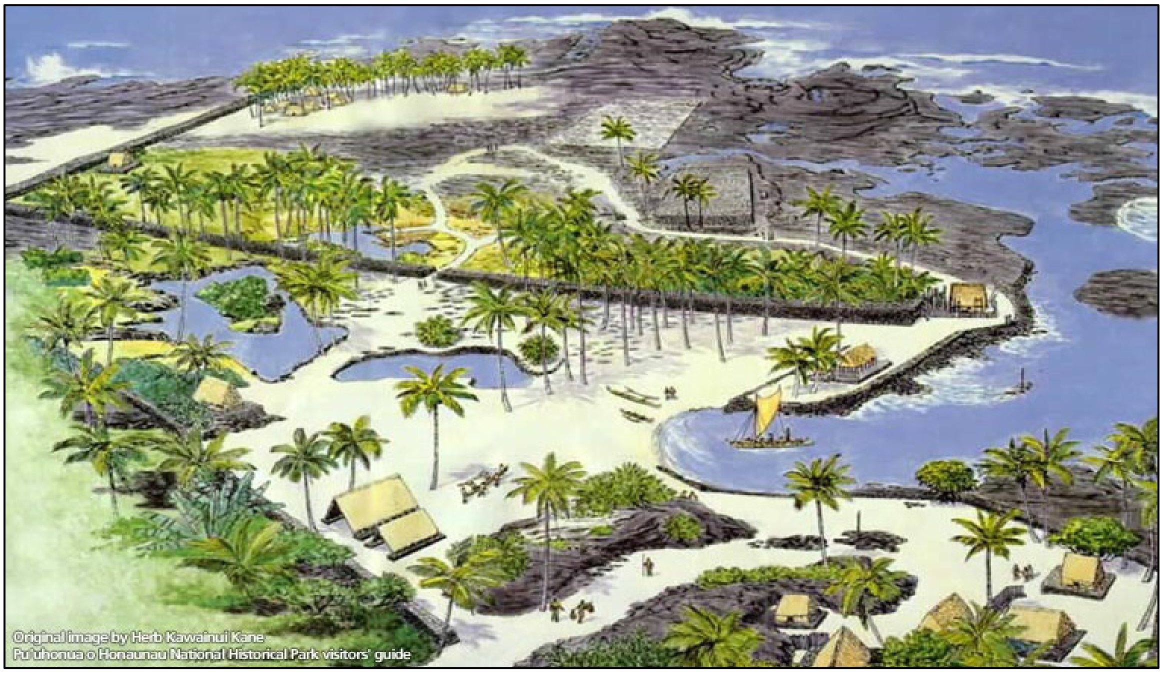


Figure 4.1.3-2. Puʻuhonua Point. View is to the west-southwest. Features that can be seen in this illustration are the exposed basalt platform, perched beaches (top of image with a line of palm trees), the intertidal beach Keoneʻele Cove, a seawall that extends into Keoneʻele Cove, and the Royal Fishponds. Imported crushed coral fill has contributed to the extensive areas of white sand around Keoneʻele Cove. Original illustration by Herb Kawainui.

The shorelines of Alahaka and Kiʻilae Bays are characterized as low cliffs (~5–10 m high) alternating with steeply dipping basalt platforms (Richmond et al. 2008). Part of the Alahaka Bay sea cliff lines up with a similar feature further inland. The sea cliffs are fronted by narrow boulder beaches. The oldest lava flows within the park (3,000–5,000 years old) occur along this segment of coast. The submerged volcanic platform is sparsely covered, in places, with boulders and coral. A shore-parallel band of aggregate reef is found offshore of both bays before the platform drops off into a sandy bottom (Cochran et al. 2007). The SHOALS bathymetry data (Figure 4.1.3-3) show a submerged ridge separating the basin in Alahaka Bay and the basin in Kiʻilae Bay.

A seawall was built in 1926 to protect the Hale o Keawe from wave damage, although most of the seawall was destroyed (presumably by the ocean) by the 1960s (Dolan and Dougherty 2009). A modern dry stack seawall was built to replace the missing sections; it surrounds Hale o Keawe and extends into Keoneʻele Cove (Figure 4.1.3-2). Dolan and Dougherty (2009) indicate that the sea wall has suffered frequent wave damage, especially on the eastern end, and has been repaired almost every year.

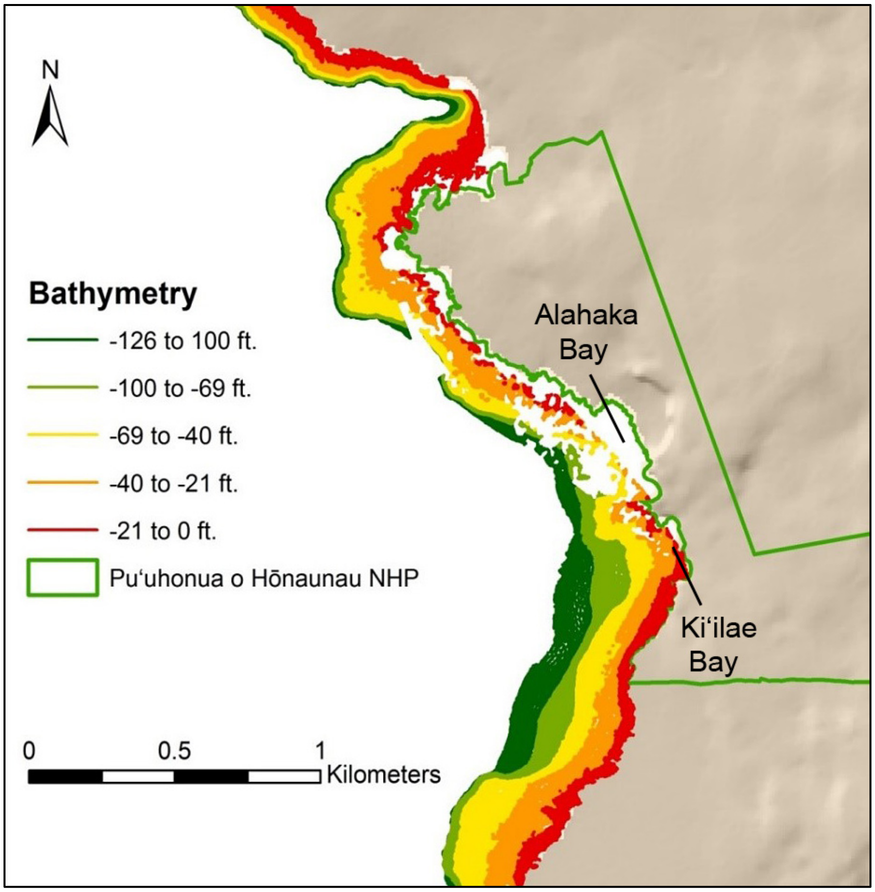


Figure 4.1.3-3. SHOALS bathymetry data. Adapted from Cochran et al. (2007).

Tides on Hawaiʻi Island are mixed semi-diurnal and tidal currents are weak owing to the small tidal range (~0.65 m [0.71 yd]; Richmond et al. 2008). Water levels also vary with seasonal wind patterns; Kawaihae sea level in August–September averages 88 mm (3.5 in) higher than in February–April. According to local fisherman, offshore currents (up to 1.6 km [1 mi] from land) tend to flow northwestward from April to October, while a stronger southerly current occurs in the winter months (Hoover and Gold 2006). The largest waves on the Kona coast come from the northwest (Vitousek et al. 2009) but waves from the west cause the most damage to cultural and natural resources and facilities.

Watershed Disturbances

Watershed disturbances affecting Puʻuhonua o Hōnaunau NHP include unusually high or low rainfall. Prolonged or intense rainfall results in flooding with associated erosion and sediment deposition. The frequency and magnitude of these disturbances, along with their impact on watershed features and other natural resources are influenced by interacting factors such as topography, soil permeability and erodibility, vegetation and land use.

Rainfall is a key variable affecting hydrologic processes. The impact of rainfall on runoff, erosion, and groundwater recharge is complicated, however, by feedbacks associated with vegetation. Consistent rainfall promotes more lush vegetation which in turn promotes more transpiration (decreasing recharge and runoff), greater infiltration (decreasing runoff), and soil stability (roots stabilize soil). Vegetation slows raindrops that otherwise would dislodge particles on the soil surface and slows overland flow. Vegetation also slows the wind, promoting deposition rather than erosion. Extended periods of lower rainfall reduce vegetation cover so that subsequent rainstorms generate an unusual amount of surface runoff and erosion. Extended periods of lower rainfall also increase fire risk. Fires reduce vegetation and litter cover; especially intense fires can make soil water repellant. These changes promote higher rates of runoff, erosion, and sedimentation. The NPS and the community recognize that fire is a hazard (Fee and Nakahara 2010).

Floods capable of transporting sediment are most likely to occur when intense or prolonged rainfall exceeds the infiltration capacity of the soil, creating overland flow. Young lava flows with limited soil development cover most of the park; these are very permeable (limiting runoff) and not very erodible. The infiltration capacity of the more developed soils upland from the coast and above the park is strongly influenced by land use. Anthropogenic disturbances such as clearing vegetation, compacting soil, and installing impervious surfaces promote enhanced runoff. Forms of agriculture that reduce vegetation cover or till the soil tend to promote overland flow and increase erosion rates.

Surface flow, whether concentrated into rills or present as sheetflow, can erode soil particles if the water velocities are swift enough (Bierman and Montgomery 2014). The impact of falling raindrops may dislodge soil particles so that they are easier to move. Once flow is concentrated into channels or watercourses, the bed and banks may be eroded by flowing water. Alternatively, sediment in motion can be deposited anywhere where the current slows, for example when the discharge lowers at the end of a storm, the channel becomes less steep or widens, or water spills overbank and flows across the floodplain (Bierman and Montgomery 2014). The stream channel within the park is poorly defined; here flood waters flow over a broad swath instead of being concentrated in a channel (Rumsey 2010).

Coastal Disturbances

The primary coastal disturbances affecting Puʻuhonua o Hōnaunau NHP are exceptionally high tides, strong surf, and tsunami. These result in saltwater flooding, erosion, and sedimentation. Factors that affect the frequency and extent of coastal flooding include wave runup, sea level, and topography. Coastal floods impact anchialine pools through changes to salinity from inundation (and salt spray in the case of surf), transport of small biota into or out of the pools, and transport of sediment into or out of the pools. Erosion of beaches and the rocky coastline occurs through weathering and wave action, production of biogenic sediment (carbonate sand), and transport of sand by wave action, currents, or tsunami. Various transport processes govern movement and eventual deposition of sediment grains. Sediment can be suspended by shoaling or breaking waves during high surf events or by tsunami of any size and then transported by currents generated by tides or wind/wave set up[4]. Tidal currents on Hawaiʻi Island are weak due to the low tidal range; storm waves are energetic and are the most likely mechanism for transporting suspended sediment. Deposition of suspended sediment depends on wave- and/or current-driven shear stress, grain size, and grain density. Fine

[4] Waves and wind can push water against the shore; built-up water escapes by flowing seaward.

sediment remains in suspension longer than coarse sediment and is more likely to be flushed away from the shoreline. Lower energy conditions favor deposition.

Wave runup[5] is a key variable in terms of overwash into anchialine pools, damage to archeological features, inland transport of sand, and loss of sand to unrecoverable areas offshore. The astronomical tide, overall sea level, storm surge[6], and beach steepness all affect the overall reach of incoming storm waves. Hurricanes represent the worst-case scenario for storm-related damage. During Hurricane Iniki the water surface at Nāwiliwili harbor (Kaua‘i) reached six meters above mean sea level; wave runup, storm surge, and astronomical tides contributed approximately 67%, 27%, and 6% of this total, respectively (Hall et al. 2016).

There is abundant evidence that sediment and nutrients in terrestrial runoff—and associated turbidity—degrade coral reefs (Fabricius 2005, Perez et al. 2014, Koop et al. 2001). 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, increase metabolic costs, and inhibit coral recruitment. Further, stream sediment generally contains particulate nutrients that can later be recycled to bioavailable forms. Nutrient levels of marine waters are discussed in section 4.4.1.

Sediment in nearshore marine waters can be derived from marine or terrestrial sources. Biogenic carbonate sediment, which is derived from coral, coralline algae, and shells of other carbonate-secreting organisms, is important on the Kona coastline. Stream sediment on Hawai‘i Island contains material derived from weathering and erosion of basalt, plus variable amounts of organic material. Other sediment sources include dust, volcanic ash, wave erosion of the shoreline, and runoff from land surfaces that drain directly to the ocean rather than to Ki‘ilae stream. The predominance of carbonate sediment in the perched beaches (Richmond et al. 2008) and in the sands at the center of Hōnaunau Bay (J. Michaud, University of Hawai‘i, personal observation) suggest that carbonate sediment is more abundant than terrestrial sediment. An anthropogenic source of sediment is the crushed coral that has been imported to the park and placed on trails, around trees, and the ground near the Royal Fishponds and portions of the royal enclosure. At times this crushed coral has been eroded and washed into the ocean (Else 2006).

4.1.3.2 Indicators, Data and Methods

Watershed indicators include annual rainfall, maximum daily rainfall in a given year, frequency and duration of streamflow, flood stage and discharge, sediment loads (amount of sediment transported to the stream mouth per year), and the sediment concentration in flood waters. Additional indicators are the human population in the watershed, land use and vegetation, wildfire occurrence, and the location of incised stream channels. The width or extent of the floodplain is an indicator that can be monitored by identifying scours, high water marks, disturbed vegetation, and deposits of sediment or debris.

[5] Wave runup is the maximum elevation reached by a wave as it comes ashore. It is a function of wave energy and is relative to the still water level (sum of astronomic tides and storm surge).

[6] Storm surge is the temporary rise in coastal water levels due the effects of wind and atmospheric pressure. Storm surge does not include the effects of astronomic tides or wave runup.

Shoreline indicators include the shoreline position (highest wash of the waves at the end of summer under calm conditions), location of perched beaches, and the areal extent of the beach at Keone‘ele cove. Another important indicator is monthly mean sea level, measured relative to a fixed datum on land.

The overall distribution of coral and sand deposits are indicators of sedimentation processes. The presence, grain-size composition, and thickness of sediment on the aggregate reef (or inshore of the reef) are indicators relevant to sediment dynamics. Seawater turbidity near the shoreline is an additional indicator that is relevant to sediment dynamics. The occurrence of high surf is difficult to document quantitatively; significant wave height is measured at offshore NOAA buoys, but the size of breaking waves is also dependent on the orientation of the shoreline with respect to wave direction.

Apart from sea level and rainfall, none of the indicators discussed above have been monitored regularly. A variety of methods were employed in the condition assessment. These range from formal statistical analysis (sea level and rainfall), review of one-time scientific studies, and qualitative assessment and discussion of key processes based on the literature and expert opinion. Studies conducted since 2005 were emphasized because an extensive review was published in 2006 (Hoover and Gold 2006). Data collected from approximately 2015 onward were not yet available for this NRCA.

NOAA tide gage data for Hilo and Kawaihae harbors were evaluated for trends and placed in the context of studies that examine local, regional, and global factors affecting relative sea level rise. NOAA tide gage data for Hilo and Kawaihae harbors were obtained from NOAA data portals (http://tidesandcurrents.noaa.gov/). 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 were evaluated by fitting a quadratic curve to annual data. Fitting a quadratic equation to sea level data is a common method of evaluating acceleration or deceleration, but results may be unduly sensitive to the time period examined and length of record (Rahmstorf and Vermeer 2011), therefore linear analysis was used to corroborate conclusions from quadratic regression, fitting separate linear regressions to data from 1927–1991 and 1992–2015. Monthly rain gauge data were obtained from NOAA's National Climate Data Center https://www.ncdc.noaa.gov/cdo-web/) and from the Western Regional Climate Center, which houses the RAWS Climate Archive (http://www.raws.dri.edu/index.html). Precipitation trends were evaluated using linear regression and differences in mean value between sub-periods were evaluated using the Student’s t test. Spatial variations in mean rainfall were evaluated using the Rainfall Atlas of Hawai‘i (Giambelluca et al. 2013).

Literature related to watershed conditions, flooding, oceanographic conditions, sea level rise, and coastal hazards were reviewed and summarized. The studies examined were:

- A NPS study on coastal water resources and watershed conditions (Hoover and Gold 2006), a compilation of historical oral accounts (Greene 1993), a natural resource overview (Else 2006), and a study on groundwater recharge (Engott 2011);
- Studies and documents that describe past and projected upslope land use (Hoover and Gold, 2006, South Kona Community Development Plan – County of Hawaiʻi 2008);
- Descriptions of oceanographic and benthic characteristics (Hoover and Gold 2006, Vitousek et al. 2009, Cochran et al. 2007, Rodgers et al. 2004a);
- Studies addressing coastal landforms (Thornberry-Ehrlich et al. 2011, Hoover and Gold 2006, Cochran et al. 2007, Richmond et al. 2008).
- Studies addressing coastal hazards (Dolan and Dougherty 2009, Fletcher et al. 2002, Richmond et al. 2008, Thornberry-Ehrlich 2011, Vitousek et al. 2009);
- Studies that mapped flooding from high surf, tsunami, exceptionally high tides, and sea level rise scenarios (Marrack and OʻGrady 2014, Sweet et al. 2014, Vitousek et al. 2009, Trusdell et al. 2012);
- Studies relevant to recent sea level change in Hawaiʻi (Apple and MacDonald 1966, Caccamise et al. 2005, Firing et al. 2004, Ludwig et al. 1991, Nerem et al. 2010 - updated data at https://sealevel.colorado.edu/, Merrifield 2011, Merrifield and Maltrud 2011, Zhong and Watts 2002), along with selected studies on methods of sea level analysis or sea level projections (Hall et al. 2016, IPCC 2013, Parris et al. 2012, Rahmstorf and Vermeer 2011, Stammer et al. 2013, Sweet et al. 2017, Watson 2016).
- Park staff were interviewed regarding present watershed conditions, notable events and maintenance activities. USGS Water Resources publications and data (available at https://wdr.water.usgs.gov/) were consulted for historic information on the Kiʻilae stream gage. A search for information on Kiʻilae stream found no information apart from the USGS records. It is possible, however, that hard copy reports from the 1950s and 1960s were not discovered by the search. General descriptions and discussions of hydrologic and coastal processes are based on the expert opinion of the authors.

Flood maps disseminated by the Federal Emergency Management Agency (FEMA) were consulted. FEMA Flood Insurance Studies (FIS), Flood Insurance Rate Maps (FIRM), and Letter of Map Revisions (LOMR) for Hawaiʻi County are available at: http://gis.Hawaiinfip.org/fhat. Maps refer to Kiʻilae Stream as "South Kona watercourse no. 20" and the watercourse that enters Hōnaunau Bay just north of the park is referred to as "South Kona watercourse no. 17". The methods used to delineate these floods zones are described in the Hawaiʻi County FIS, Volume 1.

4.1.3.3 Reference Condition

The reference conditions at Puʻuhonua o Hōnaunau NHP for watershed and coastal processes are those that occur in the absence of substantial anthropogenic influences. For upland watersheds, the reference condition corresponds to streams flowing through undisturbed forest and native grasslands. Such streams would be expected to carry low sediment loads into and through the park because plants promote infiltration and roots stabilize soil. In addition, lush upstream vegetation would: slow raindrops that otherwise would dislodge particles on the soil surface, slow overland flow, and slow overbank flow on floodplains. Native forest and grasslands would have only rarely experienced erosion-promoting disturbances such as fire (Cuddihy and Stone 1990) or altered stream courses. Flood frequency and extent would be determined by upland rainfall and soil/vegetation characteristics. Coastal flood frequency and erosion would be governed by 1) natural processes generating large wave events, including unusual atmospheric conditions, storms, and tsunamis, and 2) rising sea level associated with island subsidence[7].

Ki'ilae stream flowing over the coastal cliff during the December 2007 flood event (NPS photo).

4.1.3.4 Current Condition and Trend

Watershed Processes

Rainfall has been measured in the park since April 1979. A NOAA Cooperative Observer Program (COOP) station (ID 518552) has data from 1979–2015 and the PACN RAWS station has data from 2012 to the present. Data from these stations (Figures 2.1-2 and 4.1.3-4) show that the period 2008–2012 was particularly dry, averaging only 413 mm/yr (16.3 in/yr) in contrast to 664 mm/yr (26.1 in/yr) for the years 1980–2005 and 2013–2016 (Student's t test p=0.02). The period 1998–2003 was also dry, with an average of 474 mm/yr (18.7 in/yr). The years 2004, 2005, and 2015 were wet, with 1200, 837 and 905 mm (47.2, 33.0, 35.6 in) of annual precipitation, respectively. The wettest year on

[7] Global sea level rose very slowly—due to natural causes—in the two millennia before the late 19th century (IPCCC 2013). This background is included in the sea level reference condition.

record is 1982 with 1236 mm (48.7 in) of precipitation. The two wettest months were April 2004 (483 mm [19.0 in]) and September 2015 (344 mm [13.5 in]). In September 2015 the PACN RAWS rain gauge recorded 14 cm (5.5 in) in five days. This extreme event was associated with a strong El Niño.

The recent rainfall patterns can be put in a longer-term perspective by examining data from Hōnaunau 27 rain gauge (ID 511665), which is upslope at an elevation of 281 m (922 ft) and has data going back to 1938. What is striking about the long-term data is the slow oscillation between wet and dry conditions (Figure 4.1.3-4). This could affect groundwater recharge and groundwater salinity at the coastline. Rainfall gradually declined from 1938 to 1951 (at an average rate of 9 cm/yr [3.5 in]), gradually rose from 1951 to 1974 (at an average rate of 6.5 cm/yr [2.6 in]), and gradually declined from 1975–2014 (at an average rate of 2 cm/yr [0.8 in]). These trends are statistically significant ($p<0.001$).

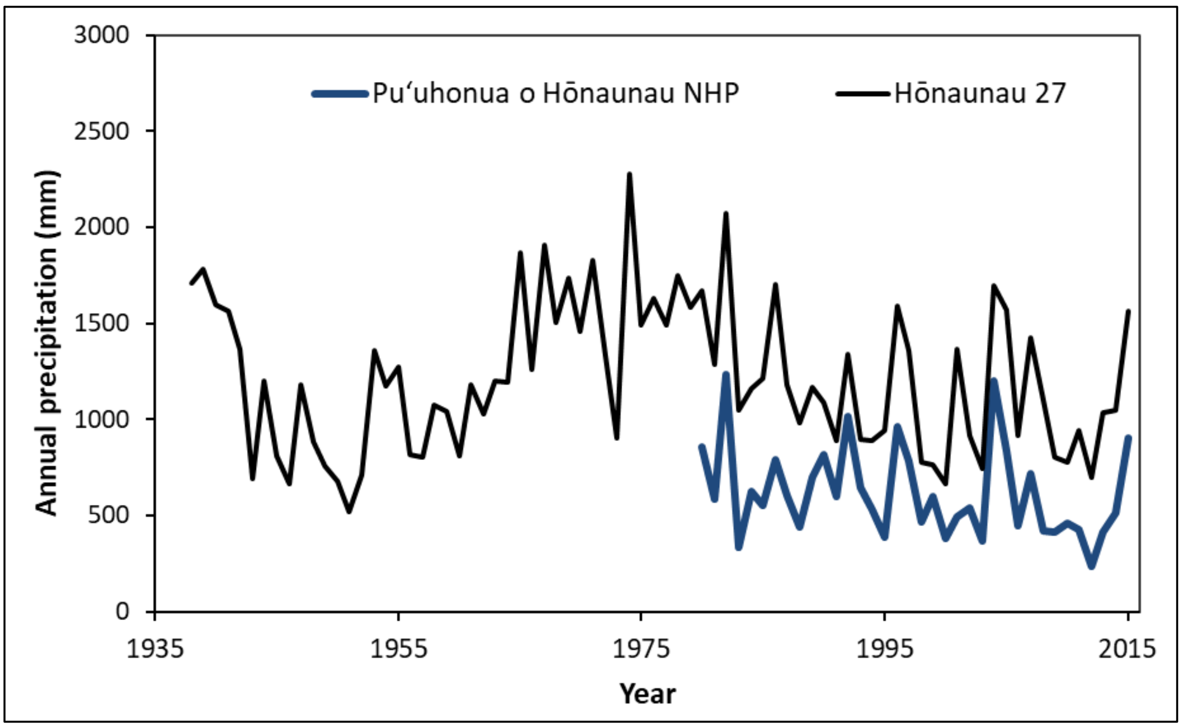


Figure 4.1.3-4. Rainfall trends at Pu‘uhonua o Hōnaunau NHP and an upslope rain gauge. The upslope station (Hōnaunau 27 – NOAA COOP 511665) is at an elevation of 281 m (922 ft). Data for the park are from NOAA COOP station 518552 and the RAWS station (beginning in 2012). Several months of NOAA data are missing; data for these months (0.7% of the period of record) were estimated.

Groundwater conditions have not been measured within Pu‘uhonua o Hōnaunau NHP, but conditions at shallow depths are expected to be similar to better-sampled locations in West Hawai‘i. The park straddles the boundary between the Kealakekua and Ka‘apuna Aquifer System Areas, both of which extend from the shoreline up to the summit of Mauna Loa.

Upslope of the park, the headwaters of Ki‘ilae stream flowed relatively consistently during the years that it was monitored Else (2006). The monitoring period (1958–1983) was relatively wet and there are no data documenting flow rates during the subsequent two decades, which were relatively dry. Also, the constancy of flow may have been true for the upper reaches but not the ephemeral lower reaches. Else (2006) also notes that upstream development and water diversions affect the infrequency of streamflow. USGS records indicate that there were no diversions above the streamgage. Agricultural diversions below the gage, if any, are undocumented.

FEMA has estimated the 10-, 50-, 100-, and 500-year flood discharges[8] at the mouth of Ki‘ilae stream as 62.4, 34.9, 375, and 631 m^3/s (2,200, 1,230, 13,200, and 22,600 ft3/s), respectively (FEMA, various years). FEMA has also mapped the areas that are inundated by the 100-year flood (FEMA, various years). Ki‘ilae's 100-year floodplain is about 13 m (42 feet wide where the stream flows over the sea cliff, and about 30–70 m (100–230 feet) wide between the sea cliff and the park boundary. Another watercourse identified as "no. 17" is north of the park and flows into Hōnaunau Bay. The floodplain of watercourse no. 17 does not extend into the park but flooding in watercourse no. 17 would deliver sediment and nutrients to Hōnaunau Bay.

Damaging floods occurred in 2004, December 2007, and October 2017. The 2007 floods resulted in erosion, deposition of sediment and debris, and extensive damage to archeological features in Ki‘ilae Village (Rumsey 2010). Examination of archeological features showed that some had been damaged in a previous flood that had, evidently, flowed in a slightly different area than the 2004 flood. The stream is not entrenched or incised and as much as 180 m (600 feet) separated the 2004 flow channels and the 2007 flow channels. Older maps show different locations for the main channel. One factor in the severity of the 2007 event was that debris in flood waters caught on the park's upstream boundary fence. This created a dam about 33 m (110 ft) wide that then burst. Rumsey (2010) suggests that the 2004 and 2007 floods were more severe than had been the case previously. He noted that damaging floods were not mentioned in the oral histories and one would not expect residences to be constructed in flood-prone locations.

It is likely that the 2007 flood resulted in the discharge of sediment to the ocean, although there are no direct measurements or observations of this phenomenon. (The photograph at the beginning of this section may not have been taken at the time of greatest sediment transport). If sediment did flow over the cliff, it is not known from where the sediment was originally eroded or how long it took to reach the sea. Studies conducted elsewhere have shown there may be a substantial time lag (years to decades) between when sediment is first eroded and when it reaches the mouth of a stream (Bierman and Montgomery 2014).

Erosion has occurred from the Royal Grounds area as the result of foot traffic (Else 2006). Sediment plumes have been observed washing out of adjacent Keone‘ele Cove (Else 2006). The paved parking lot near the Visitor Center is a source of concentrated runoff in a sensitive area. It is a source of nonpoint pollution because runoff washes away oil and other roadway pollutants originating from

[8] The 10-year flood discharge has a 1 in 10 chance of being equaled or exceeded in any year and the 100-year flood discharge has a 1 in 100 chance of being equaled or exceeded in any year.

vehicles. To resolve these issues, in the early 2000s a catch basin was installed to collect runoff, trap oil, and direct filtered water into a garden near the Visitor Center. The filtered runoff likely contains some dissolved pollutants; natural processes within the garden likely remove some of the pollutants.

The overall level of development in the watershed is low, so anthropogenic alterations to the intensity of hydrologic processes are likely focused on certain areas such as the zone of orchards and scattered residences found 2.1–3.6 km (1.3–2.2 mi) upslope of the shoreline. It is likely that runoff generation has increased as the result of clearing vegetation, compacting soil, and creating impervious surfaces. Clearing of vegetation for agricultural or other purposes also exposes the land to greater erosion. Agricultural grazing has been identified as a land use both above and below the band of orchards (UHH SDAVL 2015). The hydrologic impact of maintaining grazed pastures is unclear. In any case, the sum of anthropogenic alterations to runoff and sediment loads has not been quantified. Also undocumented are any upslope drainage "improvements" that could affect concentrated flows. As discussed on the previous page, there is evidence that suggests—but does not prove—that floods within the park were more severe in recent decades than they were in the first half of the 20th century. If this is the case, then changes to upslope land use and associated drainage "improvements" must be considered as possible causes.

Watershed processes within the Kiʻilae watershed have not been heavily influenced by fire. There is no documented history of wildfires in the Kiʻilae watershed, though fire has been used as a management tool on occasion. In the early 1960s, piles of cut vegetation were burned (NPS 1962). The vegetation that was burned had been removed for aesthetic reasons and to facilitate archeological surveys. An additional burn occurred in the Kiʻilae section of the park in 1988 in order to reduce fire fuel loads.

Coastal Flooding

FEMA flood hazard assessment addresses flooding from the ocean as well as from streams. Coastal flood zones mapped by FEMA represent inundation by the 100-year tsunami[9] and are based on hydraulic modeling and historic tsunami runups (Figure 4.1.3-5); progressive sea level rise is not included in those analyses.

On March 11, 2011, a magnitude 9.1 earthquake in Japan produced a tsunami that reached Hawaiʻi. At Puʻuhonua o Hōnaunau NHP the waves overtopped walls and traveled "hundreds of feet" inland, scattering vegetation and marine debris (Thornberry-Ehrlich 2011). Stone walls collapsed or bulged, archeological features were eroded, and sections of trail were washed out. About 80% of the sand and crushed coral fill in the Royal Grounds area were moved or removed. There are no published measurements of the tsunami runup at the park, but field surveys of high watermarks were made in nearby locations (Trusdell et al. 2012). At Hoʻokena (south of the park), the largest wave reached 3.09 m (10 feet) above mean lower low tide (MLLW). At the Nāpoʻopoʻo old Pier (north of the park) the largest wave was 4.09 m (13 feet) above MLLW and at Kealakekua Bay the highest wave was 5.35 m (17.5 feet) above MLLW. The historic record of tsunami events on the Island of Hawaiʻi goes

[9] The 100-year tsunami is a hypothetical event; in any given year there is a 1 in 100 chance of a tsunami at least as large as the 100-year tsunami.

back to 1812, but runups are recorded in only a few locations (Walker 1994, Lander and Lockridge 1989). Large runups were recorded at Kealakekua Bay in 1877 (4.5 m [4.9 yd]) and at Nāpoʻopoʻo in 1896 (5.3 m [5.8 yd]) and 1960 (4.9 m [5.4 yd]). Geologic evidence north of Kawaihae points to a prehistoric tsunami with a runup of more than 400 m (400 yd; McMurtry et al. 2004). The cause of the mega-tsunami is believed to be a giant landslide on Mauna Loa that occurred about 130,000 years ago. The source area for the landslide is near Puʻuhonua o Hōnaunau NHP.

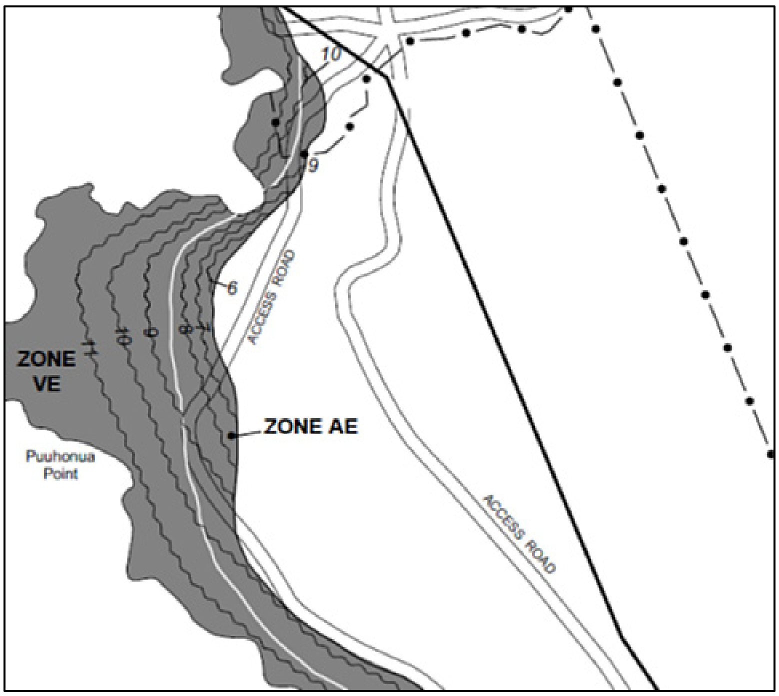


Figure 4.1.3-5. Coastal flooding as mapped by FEMA. In any year there is a 1% chance that the entire grey area will be flooded by a tsunami. The park boundary is shown with a dash-dot symbol and the shoreline is the left edge of the grey area. Wavy contours show the associated water surface elevation, in feet above mean sea level (referenced to the National Geodetic Vertical Datum of 1929). The white line separates VE zone that will be subjected to erosive waves or currents and the AE zone that does not have a velocity hazard. Not shown is a narrow VE zone that extends to the south along the park's entire shoreline (except where there is a cliff in Alahaka Bay). Map is from FEMA's 2014 LOMR for South Kona http://gis.hawaiinfip.org/fhat.

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

Erosion has threatened and continues to threaten Keoneʻele Beach and the perched sand beach near the parking areas south of Puʻuhonua Point. This problem prompted the park to undertake beach nourishment to mitigate erosion (Hoover and Gold 2006, Thornberry-Ehrlich 2011, M. Laber, oral communication, 2004, as cited in Richmond et al. 2008). The park no longer nourishes the beach in the intertidal area, however, because of the turbidity it causes in the water (M. Maigret, NPS, personal communication, 2018). Nevertheless, broad areas of imported crushed coral sand are still found above high tide in areas surrounding Keone‘ele Cove (Figure 4.1.3-2).

It is not known whether sediment discharged by Ki‘ilae stream has accumulated, even temporarily, in Ki‘ilae Bay and, if so, whether this has resulted in ecosystem degradation. Cochran et al. (2007) mapped benthic cover using data collected during 2000–2004. Their maps do not show an accumulation of sediment near the stream outlet, nor was there less reef near the stream outlet. Cochran et al. (2007) do not discuss sediment on the reef or reef degradation. Thus, it appears that during 2000–2004 stream sediment was not present on the reef (or landward of the reef) in notable quantities, nor was there a marked degradation of the benthic habitat near the stream. As discussed in the previous section it, it is likely that from time to time stream sediment has been discharged to the ocean. If so, they were removed by 2000–2004. Ki‘ilae Bay is moderately exposed to large swells from Kona storms, so removal of sediment is plausible. It is also plausible that there are times when sediment temporarily accumulates on the aggregate reef and the basalt platform.

Anthropogenic modifications of the shoreline have the potential to affect coastal processes. For example, the seawall facing Hōnaunau Bay, which protects vulnerable archeological structures from wave damage, might affect sediment dynamics in Keone‘ele Cove (Fletcher et al. 1997, Griggs 2005). Apart from the seawall, there are no other man-made alterations of the shoreline that would affect natural processes of erosion, shore-parallel sediment transport, or shore-perpendicular sediment transport

Sea Level Trends

Relative sea level (water level relative to a fixed point on shore) can vary in response to global water levels (measured relative to the center of the earth) and crustal subsidence or uplift. Also, regional oceanographic or meteorological conditions are relevant because wind pushes water, ocean currents and atmospheric pressure affect water levels, and temperature and salinity determine water density.

Submerged archeological features provide evidence of relative sea level rise at Pu‘uhonua o Hōnaunau NHP. A study in the mid-1960s indicated a relative sea level rise of about 30 cm (12 in) per century (Apple and MacDonald 1966). Drowned reefs near Kawaihae document crustal subsidence of 2.6 mm/yr (0.10 in/yr) over the last 500,000 years (Ludwig et al. 1991, Zhong and Watts 2002). Subsidence is due to the gravitational effects of loading the crust with large amounts of lava. Satellite measurements provide the most accurate measurements of *global* sea level. From 1993 to 2015, global sea level, as measured by satellite altimetry, rose 3.3 ± 0.4 mm/yr (0.13 ± 0.02 in/yr; Nerem et al. 2010 – updated data at https://sealevel.colorado.edu/). In the absence of regional effects from atmospheric and oceanographic variables, relative sea level rise on Hawai‘i Island should be on the order of to 5.9 ± 0.4 mm/yr (0.23 ± 0.02 in/yr; sum of global and subsidence components). This is equivalent to 59 cm (23 in) per century. Actual rates may differ, however, due to a variety of causes.

Changes to relative sea level during the modern instrumental period are measured with tide gages. Tide gage 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 onwards. At Kawaihae, sea level rise averaged 7.0 mm/yr (0.28 in/yr) from 1992–2015 ($p<0.001$), in comparison with 1.2 mm/yr (0.05 in/yr) at Hilo over the same time period ($p=0.02$; Figure 4.1.3-6). 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 Kīholo Bay earthquake (Yang and Francis 2019). The epicenter of the earthquake was about 21 km (13 mi) from the Kawaihae tide gage and 30 km (31 mi) from the park. In any case, the period of record at Kawaihae harbor is too short for robust evaluation of sea level trends. The Hilo gage has a long period of record, however, and during 1927–2015 sea level at Hilo rose 2.95 mm/yr (0.12 in/yr; 95% confidence interval ± 0.31 mm/yr). This is about half of what is expected on the basis of recent measured rates of global sea level rise (3.3 mm/yr [0.13 in/yr] from Nerem et al. 2010 - updated data at https://sealevel.colorado.edu/) and average rates of island subsidence over the last 500,000 years (2.6 mm/yr [0.10 in/yr] from Ludwig et al. 1991).

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. In addition to long-term crustal subsidence, short-term volcanic and seismic processes can affect shoreline elevation through sudden uplift, subsidence or lava flow accretion. Such rapid changes have recently occurred at Kīlauea Volcano, but there is no evidence that similar effects have recently occurred on the western slopes of Mauna Loa. Limited GPS data suggest that the subsidence rate of Hawaiʻi Island could be variable over time (Caccamise et al. 2005). A variety of atmospheric and oceanographic processes can affect regional sea level but not global sea level; these operate 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). 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). In particular, higher sea level in Hawaiʻi is associated with an increase in the strength of the Aleutian low.

Sea levels around the Hawaiian archipelago decreased during the 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). Beginning in 2012–2015 a switch occurred: sea level in the eastern Pacific rose while levels in western tropical Pacific declined (Hamlington et al. 2016). As of yet the “switch” is not seen in the Hilo or Kawaihae tide records.

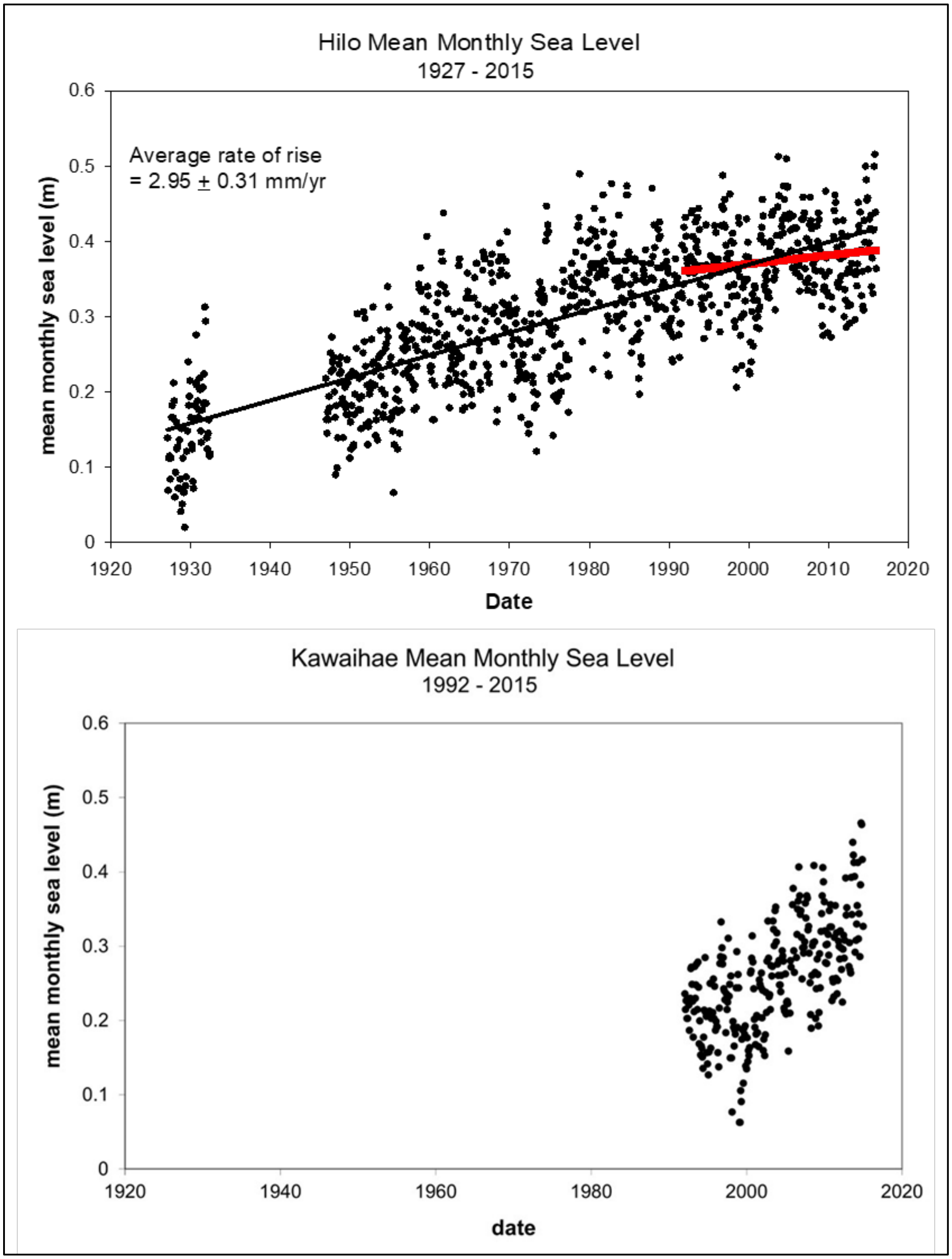


Figure 4.1.3-6. Monthly sea level data from the tide gages at Hilo (top) and Kawaihae (bottom) harbors. The heavy red line in the Hilo graph shows the linear rate of rise (1.2 mm/yr [0.05 in/yr]) during the Kawaihae period of record (1992–2015). NOAA data from https://tidesandcurrents.noaa.gov/.

Overall Condition and Trend Assessment

Rainfall, which is an important driver of hydrological processes, has been relatively low for the past three decades in comparison with the two decades prior (medium confidence). Nevertheless, several damaging floods have occurred in the past twenty years. These pose a threat to irreplaceable archeological features. While there are no systematic data with which to evaluate flood trends, there are grounds to suspect that floods in recent decades were more severe than those in the first half of the 20th century (low confidence). As of 2000–2004 there is no evidence that terrestrial sediment carried by Kiʻilae stream has damaged marine ecosystems, but relevant data have not been collected regularly, so it is possible that undocumented adverse impacts have occurred from time to time (medium confidence).

Beaches, archeological features, and anchialine pools have been affected by coastal flooding associated with relative sea level rise, tsunami, and high surf. Beach erosion has occurred, prompting the park to engage in artificial beach nourishment, although this practice has stopped because of adverse impacts to water quality. Coastal archeological features have suffered frequent damage from waves and occasionally from tsunami. Waves and tsunami impact biota in anchialine pools through temporary increases in salinity and by sweeping organisms and sediment into or out of pools.

A long-term trend of increasing sea level has affected cultural and natural resources along the shoreline of Puʻuhonua o Hōnaunau NHP (high confidence). The rate of relative sea level rise has not been measured at Puʻuhonua o Hōnaunau NHP, but measurements at nearby locations suggest historic rates of at least 3 mm/yr (0.1 in/yr). Future rates are likely to be higher than in recent decades.

4.1.3.5 Threats and Stressors

Hazard Overview

Fletcher et al. (2002) compiled a state-wide risk map for coastal areas, providing an overall assessment of risk from any extreme natural disturbance and a breakdown of risk from the seven different types of disturbances (Table 4.1.3-1). Puʻuhonua o Hōnaunau NHP was assigned an overall hazard of five on a scale of one (least hazardous) to seven (most hazardous), corresponding to a moderate to high risk of impact by a natural disaster. High or moderately-high risks were assessed for tsunami, earthquakes, volcanic eruptions, rising sea level, effects of storms, and stream flooding. Coastal erosion risk was assessed moderately low because of the rocky shoreline and the fact that most beaches are perched.

The greatest risk was assigned to seismic activity. The largest earthquakes on the island tend to occur towards the south, but moderate earthquakes can also occur towards the north. The most recent notable earthquake was a M6.7 event that occurred in Kīholo Bay on October 15, 2006. This earthquake caused some structural damage to archeological features within the park (Richmond et al. 2008).

Table 4.1.3-1. Natural hazards and associated risk categories. From Fletcher et al. 2002.

Hazard	**Low (1)**	**Moderately low (2)**	**Moderately high (3)**	**High (4)**
Tsunami	No history of tsunami flooding; steep coastal zone slope (≥45%)	History of tsunami flooding; steep coastal zone slope (≥45%)	History of tsunami flooding; historical damage; steep coastal zone slope (≥45%)	**History of tsunami flooding; historical damage; gentle coastal zone slope (<45%)** [1]
Stream flooding	No history of coastal stream flooding and no reasonable basis for expected flooding due to low seasonal rainfall in watershed (<4.9 in per month); or steep coastal slope (>45%)	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	**Abundance of streams and high seasonal rainfall in watershed (>7.9 in per month) and history of damaging floods with partial mitigation or no mitigation where slope >20% and <45%** [1]	Historically high flood damage on gentle slope, high watershed rainfall (>7.9 in per month) and no mitigation efforts or improvements since last damaging flood
High waves	No reasonable basis to expect high waves	**Seasonal high waves 4–6 ft** [1]	Seasonal high waves 6–8 ft with hazardous run-up and currents	Seasonal high waves >12 ft, characterized by rapid onset
Storms	No history of overwash or high winds and no reason to expect them	Minor historical overwash (<10 and/or high winds (~40 mph gust)	**Historical overwash >10 ft on steep slope, and/or high winds; localized (isolated cases) structural damage (~40 mph sustained)** [1]	Historical overwash >10 ft on moderate to gentle slope and/or high winds; widespread structural damage (~75 mph gust)
Erosion	Long-term accretion (>10 yr) with no history of erosion, or dynamic cycles with consistent annual accretion	**Long-term stable or minor erosion/ accretion cycles; erosion recovered by accretion; low rocky coasts; perched beaches** [1]	Long-term erosion rate <1 ft/yr or highly dynamic erosion/ accretion cycles with significant lateral shifts in the shoreline	Chronic long-term erosion >1 ft/yr, beach is lost, or seawall at water line for portions of the tidal cycle
Sea level	Steep coastal slope where rise >0.04 in/yr or gentle slope where rise <0.04 in/yr	Gentle or moderate slope where rise >0.04 in/yr or steep slope where rise >0.08 in/yr	**Gentle or moderate slope, where rise >0.08/yr or steep slope where rise >0.12 in/yr** [1]	Gentle or moderate slope where rise >0.12 in/yr.
Volcanic/ seismic	No history of volcanic or seismic activity, Uniform Building Code seismic zone factor ≤ 2	No volcanic activity in historical times; Uniform Building Code seismic zone factor ≤ 2, minor historic seismic damage	Limited history of volcanism, Uniform Building Code seismic zone factor ≥ 2 recommended, historic seismic damage	**Frequent volcanism, Uniform Building Code seismic zone factor ≥ 2 recommended, frequent historic damage** [1]

[1] Risk level for Puʻuhonua o Hōnaunau NHP indicated by bold text.

Hurricanes, tropical storms, and Kona storms were rated by Fletcher et al. (2002) as natural hazards posing a moderately-high risk. As illustrated by Hurricane Iniki, large damaging hurricanes do enter Hawaiian waters and make landfall. There is a small but real risk that a destructive hurricane will make landfall on Hawaiʻi Island. The height of the island does not deter oncoming storms but a storm making landfall on one side of the island will lose power before reaching the opposite shore. Historic storms entering Hawaiian waters tend to track to the west of Hawaiʻi Island. Associated high surf can therefore damage the shoreline even if the storm does not make landfall. No hurricane has made landfall on Hawaiʻi Island during the era of modern record keeping, although tropical storms (Iselle) have. Dolan and Dougherty (2009), citing Emory (1986), note that a hurricane occurring after the mid-1800s is thought to be responsible for damage to the Great Wall.

Stream Flooding and Anthropogenic Stresses

Factors that exacerbate flooding and erosion in the Kiʻilae watershed are threats that will increase the delivery of sediment to Kiʻilae Bay. From this perspective, fire, drought, and some forms of increased development are threats. Vegetation changes may make the watershed more susceptible to fire or erosion.

According to the Kona Community Development Plan, it is very likely that the population of the North and South Kona Districts will increase, and that new development will occur in the future (County of Hawaiʻi 2008). Notably, the Kona Community Development Plan stresses that future development should be directed to the area north of Kailua Kona. Growth north of Kailua Kona would not directly affect Puʻuhonua o Hōnaunau NHP, but there could be indirect stress in the form of more people recreating at Hōnaunau Bay or visiting the park. The areas near and upslope of Puʻuhonua o Hōnaunau NHP are lightly populated at present, and it appears likely that these areas will grow more slowly than other areas of the island. Growth is likely to take the form of scattered new homes, agricultural expansion, and possibly new residential subdivisions.

The areas adjacent to the park and upslope of the park are within the agricultural land district (except for a narrow strip along Hōnaunau Bay). In the past, land within Hawaiʻi Island's agricultural land district was subdivided into residential lots, but it is less clear if this practice will continue. The Land Use Pattern Allocation Guide (LUPAG) is a part of the County of Hawaiʻi General Plan and is intended to guide future growth (County of Hawaiʻi, 2005). The current LUPAG (available at https://planning.Hawaii.gov/gis/download-gis-data) shows that proposed land uses for Kiʻilae watershed are a mixture of conservation, extensive agriculture, and important agricultural lands.

Although mitigation measures can be expected to reduce adverse hydrologic impacts of new development, there is still reason for concern. Potential issues include an increase in the amount of runoff (and the speed with which it travels downhill), enhanced erosion, polluted stormwater runoff, septic tanks, and groundwater pollution. Suburban developments are likely to mitigate surface water impacts by installing dry wells; this could lead to groundwater pollution, however. Agricultural development is not necessarily more benign than residential development because the agriculture can lead to erosion and because agricultural pesticides and fertilizers may enter stream waters or groundwater. Groundwater pollution could affect anchialine pools or Hōnaunau Bay.

Rising Sea Level and Coastal Flooding

Sea level rise is being driven by thermal expansion of warming water and enhanced melting of glaciers and ice caps (Stammer et al. 2013). Global mean sea level is expected to rise between 0.2 m (8 inches) and 2.0 m (87 inches) by 2100[10] (Parris et al. 2012, IPCC 2013), with maximum estimates of 2.5 m (200 inches) by 2100 (Sweet et al. 2017). Sweet et al. also argue that the lower bound of plausible sea level rise should be 0.3 m (12 inches) by 2100. It is widely anticipated that rising seas will eventually have profound effects on coastal geography, ecosystems, and human activities (IPCC 2014). It is worth emphasizing that rising sea level will, over time, increase the frequency and/or increase the severity of flooding from storm waves, exceptional tides, and tsunami. Rising sea level will also contribute to salinization of anchialine pools. Consequently, 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 [0.05 in/yr], $p=0.02$) than in 1927–1991 (3.5 mm/yr [0.14 in/yr], $p<0.001$; Figure 4.1.3-6). In contrast, analysts of *global* sea level have noted a recent acceleration and the most recent study shows "strong evidence of a recent acceleration commencing around 1982–1985" (Watson 2016). Predicting future trends in local relative sea level is more difficult than predicting future trends in global sea level. Decadal-scale shifts in local or regional atmospheric and oceanographic conditions may shed light on the apparent discrepancy between Hilo sea level trends (decelerating and only moderate rises despite subsidence) and global sea level trends (accelerating). As noted earlier, Hawaiian sea levels can be affected by episodic changes in the strength of the trade winds, local anomalies in water temperature and salinity, and the strength of the Aleutian low (Caccamise et al. 2005, Merrifield and Maltrud 2011, Stammer et al. 2013). The recent switch from highest rates of rise in the western topical Pacific to highest rates of rise in the eastern tropical Pacific may be a pattern that is likely to "persist in the coming years" (Hamlington et al. 2016). In other words, it is possible that certain regional conditions have temporarily protected the Island of Hawaiʻi from the accelerated rates of sea level rise that were observed in other parts of the world beginning in the early to mid-1980s.

Sea level rise is an issue that affects all shorelines in the state of Hawaiʻi. Geological evidence indicates that each island is moving vertically at a different rate. Dating of drowned or uplifted reefs indicates that the Island of Hawaiʻi is subsiding the most rapidly (Ludwig et al. 1991) and the Island of Oʻahu is rising very slightly (McMurtry et al. 2010). These differences are particularly important for reefs. Response policies appropriate for Oʻahu (lower rate of relative sea level rise but more

[10] There are several other studies providing managers with estimates of future sea level rise. NOAA has recently published a new projection of anticipated global mean sea level rise and regional factors that will determine relative sea level rise for entire U.S. coastline (Sweet et al. 2017). The Department of Defense commissioned a review of regionalized sea level and extreme water level scenarios for three planning horizons (Hall et al. 2016); site-specific projections have not yet been released to the public, however.

infrastructure at risk) may therefore be different than response policies appropriate for the Island of Hawai‘i.

Tides and storms are superposed on average water levels, so sea level rise will first be felt as more frequent periodic flooding. Marrack and O‘Grady (2014) took tides into account when they mapped coastal inundation at the park for global sea level rise scenarios using high-resolution topographic data derived from LIDAR measurements (Figure 4.1.3-7).

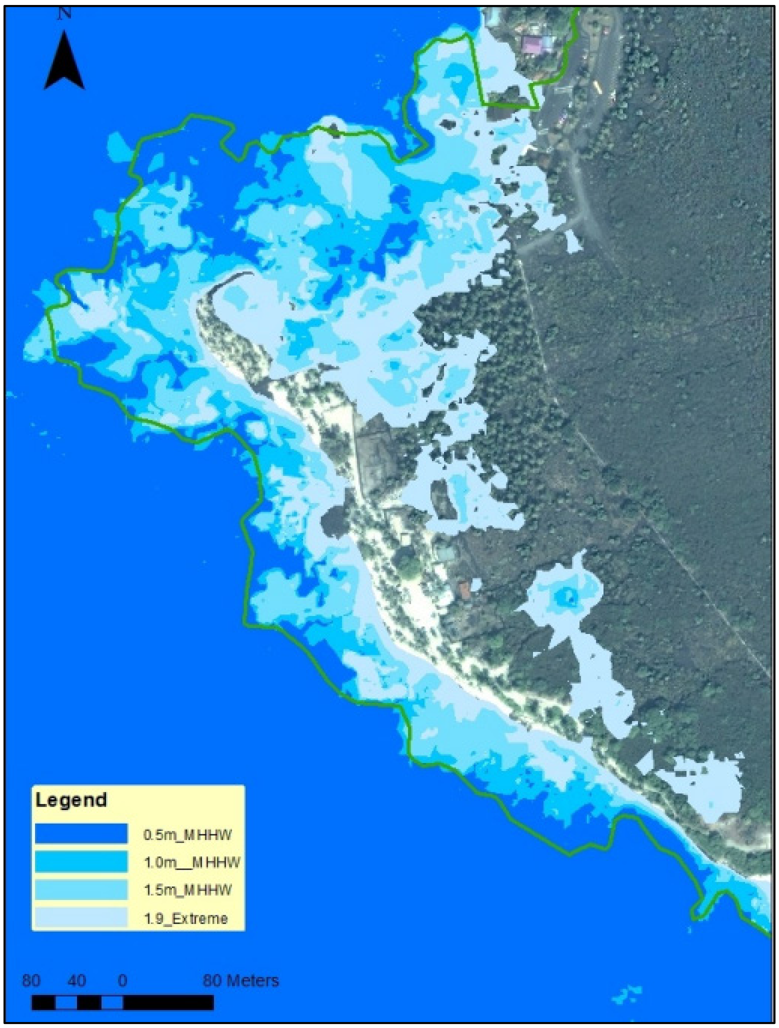


Figure 4.1.3-7. Coastal inundation along the north and northwest coast of the park under sea level rise scenarios. The deep blue regions are expected to be inundated at mean higher high tide (MHHW) and 0.5 m relative sea level rise. The lightest blue regions are expected to be inundated under an extreme tide and 1.9 m of relative sea level rise. Colors in-between represent 1.0 and 1.5 m of relative sea level rise and MHHW. Figure from Marrack and O’Grady (2014).

They considered scenarios ranging from 0.5 to 1.9 m (1.6 to 6.2 feet). The 0.5 m scenario is about the same as best-case relative sea level predictions for the 21st century (0.2–0.3 m global + 0.26 m subsidence) and the 1.9 m scenario is lower than worst-case relative sea level predictions for the 21st

century (2.0–2.5 m global + 0.26 m subsidence) [11]. Results showed that a 1.0 m (3.3 feet) relative sea level rise would flood 50% of the park's anchialine pools at high tide. Other pools not yet indicated would become more saline. Marrack and O'Grady (2014) noted that new anchialine pools may form when the water table, which rises in step with the sea, intersects depressions that were previously dry.

4.1.3.6 Data Gaps and Research Recommendations

There is no documentation of the occurrence or duration of streamflow at the mouth of Kiʻilae Stream. A crest stage gage would be an inexpensive method of documenting the maximum water height of floods, assuming that a suitable location can be found for installing such a device. Background rates of runoff and erosion are not known, nor are there estimates of the additional runoff and sediment loads that are attributable to anthropogenic activities. Upslope drainage works that might affect flood flows have not been inventoried. There are no data on groundwater discharge, salinity, or water table elevation. Observations of the amount of sediment delivered by Kiʻilae stream to the ocean are lacking. We do not know if stream sediment has settled on the reef and, if so, how thick the sediment layer was or how long it remained.

Several aspects of the coastal environment have not been characterized or monitored. The composition and grain size of beach sand and marine benthic sediment has not been scientifically characterized. Turbidity in Kiʻilae Bay and in Keoneʻele Cove is relevant to the adverse impacts of sediment loading but has not been monitored. Near the ocean, sediment can be washed from the ground by waves or runoff. There is no systematic record of such occurrences nor of sand loss from Keoneʻele Beach. The final resting spot of crushed coral washed from the coastal trail and Royal Grounds has not been investigated.

There is not a systematic record of the high-water marks associated with high surf, extreme tides, and tsunami. Natural processes often result in the inland migration of beaches as sea level rises, but there are no data to indicate whether this has occurred at Puʻuhonua o Hōnaunau NHP.

Trends in relative sea level are driven by island subsidence, global sea level trends and local to regional scale fluctuations in meteorological or oceanographic conditions. The relative contributions of these factors may vary on scales of decades. A systematic evaluation of these factors for the historic period has not been conducted for Hawaiʻi Island.

Recommendations for Research on Coastal Dynamics

- Conduct a study analyzing historic changes to the shoreline, in particular Puʻuhonua Point and the beach in Keoneʻele Cove. A compilation of dates of disturbances (especially damaging high surf, large tsunami, beach nourishment) would aid in interpretation of these data.
- Conduct a study mapping and analyzing future coastal flooding over the next 20, 50, 100, and 150 years. This should address (separately and in combination):
  - Sea level scenarios
  - Nuisance flooding from exceptional tides

[11] Global rates based on predictions made by Parris et al. (2012), IPCC (2013) and Sweet et al. (2017).

    - Runups from exceptional storm waves
- Considering inundation, erosion, and sand migration, evaluate the future of Keone‘ele Beach (with and without nourishment), the Royal Fishpond, and archeological structures on Pu‘uhonua Point under scenarios drawn from the proceeding research project.
- Evaluate options, including but not limited to imported crushed coral and flagstones, for paving trails and walkways and stabilizing trees and archeological features. The evaluation should address cost, aesthetics, cultural appropriateness, longevity, erosion, and fate of eroded materials, including where on the ocean flood eroded materials come to rest.

4.1.3.7 Sources of Expertise

- Charles Fletcher of the University of Hawai‘i at Mānoa contributed to recommendations for future research.

4.2 Terrestrial Ecosystem Integrity

North-northeast view of the park with two endemic maiapilo (*Capparis sandwichiana*) shrubs in the foreground and groves of coconut palms (*Cocos nucifera*) along the shoreline. Much of the landscape is nonnative *Leucaena leucocephala* (NPS photo circa 2003).

Vegetation and vertebrate faunal resources were selected to assess terrestrial ecosystem integrity. Species richness, composition and structure of native, Polynesian-introduced, and nonnative plants describe the terrestrial plant communities important in the natural and cultural landscapes of Pu‘uhonua o Hōnaunau National Historical Park. Terrestrial vertebrate fauna indicators include birds (both native and nonnative), native mammals, and invasive mammals.

Native coastal, upland dryland forest or grassland, and culturally important Polynesian-introduced species are focal resources described herein. The relative importance of native vegetation restoration is considered along with plants' ability to persist in the presence of perturbations such as feral ungulates, changing coastlines and increasing fire occurrence. Native and Polynesian introduced plants are a critical part of the park's story and landscape; these components are highlighted as ways for visitors to experience a natural setting (NPS 2017). The vegetated landscape is a result of land use change over time from pre-contact, to the end of the Kapu system in 1819, to the 1850s – early 20th century ranching and fishing era, to management and use as park land beginning in the 1900s, first as a county park in 1921, then as a National Park in 1961.

Three bird surveys conducted at the park were used to assess bird species proportion and diversity of native to nonnative species. Monk seals and Hawaiian hoary bats are the only two native mammals in

Hawai‘i and they are both federally listed as endangered. Data are limited to the number of recorded occurrences (monk seals), or acoustic recordings (bats) for a narrow time frame. However, these animals are important resources to bring attention to because of their low population numbers, importance to the ecosystem and to traditional culture. Invasive mammals are such a major threat to native plant and animal species and to cultural resources, that while not a typical “resource,” they are covered here in a dedicated section in order to consider threats to other focal resources thematically.

4.2.1 Terrestrial Plant Communities

By Pamela Scheffler, Hawai'i Community College and Rebecca Ostertag, University of Hawai'i at Hilo

Pōhuehue (*Ipomoea pes-caprae* subsp. *brasiliensis*) flowers amongst 'ākulikuli (*Sesuvium portulacastrum*), both indigenous, near the Royal Fishponds (NPS photo).

Condition Summary

The condition of terrestrial vegetation at Pu'uhonua o Hōnaunau National Historical Park warrants significant concern due to the paucity of native and Polynesian plants outside of the coastal strand and presence of disease in coconut palms. The assessment is made with moderate confidence. Ongoing vegetation management, including controlling nonnative vegetation and planting and maintaining Polynesian and native species, justifies the finding that the vegetation trend is improving.

4.2.1.1 Description

Pu'uhonua o Hōnaunau NHP includes native-dominated vegetation types from coastal strand vegetation to wetland environments (Cogan et al. 2011). The NPS objective for Pu'uhonua o Hōnaunau NHP is "to restore and maintain the historic scene of the Pu'uhonua, [Royal] Grounds, and house complexes in the park to the year 1819...and to restore and maintain Ki'ilae Village as a transition village" (Shimoda 1991). Achieving this objective requires supporting the existence and expansion of native (i.e., plants that arrived before humans) and Polynesian (i.e., plants that arrived before 1778) vegetation, removal of nonnative invasive vegetation, and restoration of period-era vegetation (Else 2006). Nonnative vegetation from most of the park was cleared or burned in the early 1960s and coconut and pili grass was replanted (Apple 1962, Bishop Museum 1963). Additional control burns were conducted in the 1980s and 1990s (F. Galieto, NPS, personal communication, 2017). Else (2006) describes the coastal strand community and the rare plants in cliff refugia as the two focal plant communities of the park, both being predominantly native. Some of the less common species that find refuge in the cliffs are ‘ala‘alawainui (*Peperomia blanda* var. *floribunda*, formerly known as *P. leptostachya*) and ‘ilie‘e or Hawaiian leadwort (*Plumbago zeylanica*). Several species of loulu, or Hawaiian fan palm, have been planted in the upland parcel of the park; *P. maideniana* (formerly *P. affinis*), an endangered lowland loulu, has been planted near the coast. Tree molds (the impressions left behind when trees are destroyed by new lava flows) from loulu groves can be found in a lava flow in the park (J.P. Lockwood, retired USGS, personal communication, 2015).

Cogan et al. (2011) identified 14 vegetation associations within Pu‘uhonua o Hōnaunau NHP (Table 4.2.1-1). Most of the 14 vegetation associations found in Pu‘uhonua o Hōnaunau NHP are not found in the two other National Parks on the west coast of Hawai‘i Island (Cogan et al. 2011). Only five (36%) of the associations were also found at the other West Hawai‘i parks.

We classify the vegetation as upland, coastal, or wetland, descriptors that can be used consistently among the three west Hawai‘i parks, based on elevation and hydrology.

Upland Vegetation

Upland vegetation of the park is dominated by species introduced post-European arrival. As early as 1957, botanists were describing the vegetation as “monotonous, thorny, and introduced” (Greenwell 1986). With the exception of the maintained area around the Visitor Center and the coastal strand, the vegetation is dominated by introduced forage grasses and koa haole (*Leucaena leucocephala*), classified by Cogan et al. (2011) as *Leucaena leucocephala/Urochloa maxima* Semi-natural Shrubland and as *Leucaena leucocephala* Lowland Dry Semi-natural Shrubland, which makes up 43% of their surveyed plots. Else (2006) noted that nine native species were found in this predominantly nonnative shrubland but were uncommon and scattered.

Coastal Vegetation

The coastal areas of Pu‘uhonua o Hōnaunau NHP remain the most native and/or Polynesian introduction dominated portion of the landscape. Else (2006) describes the native shoreline vegetation to include milo (*Thespesia populnea*), hala (*Pandanus tectorius*), and naupaka kahakai (*Scaevola taccada*). In this area, Cogan et al. (2011) describes the *Cocos nucifera* Strand Woodland, *Fimbristylis cymosa* Coastal Dry Herbaceous Vegetation, *Waltheria indica-Sida fallax* Shrubland, and *Scaevola taccada* Coastal Dry Shrubland. The coconut groves and much of the native and Polynesian-introduced vegetation is maintained by park staff. Although this area maintains the most intact ecosystems, it is also subject to strong environmental pressures; for example Bryan and Emory (1957) describe an “isolated stand of pua kala (*Argemone glauca*) [which] was washed away by the high surf of February 1957”; however, this species is still present in the park.

Table 4.2.1-1. Summary Plant Associations and Park Specials (associations unique to this Park) for Puʻuhonua o Hōnaunau NHP with indication of the dominant (native/nonnative) cover. Data are from Cogan et al. (2011). "Semi-natural" vegetation is a term specific to the International Vegetation Classification, and describes plant communities with anthropogenically altered species composition, where there is no clear natural analogue.

Plant communities of Puʻuhonua o Hōnaunau	**Native/Polynesian elements**
Cocos nucifera Strand Woodland [1]	*Yes*
Fimbristylis cymosa Coastal Dry Herbaceous Vegetation [1]	*Yes*
Leucaena leucocephala - Pithecellobium dulce Semi-natural Shrubland [Park Special]	*No*
Leucaena leucocephala / *Urochloa maxima* Semi-natural Shrubland [2]	*No*
Leucaena leucocephala Lowland Dry Semi-natural Shrubland	*No*
Melinis repens Semi-Natural Herbaceous Vegetation	*No*
Urochloa maxima [2] Lowland Dry Semi-natural Herbaceous Vegetation [2]	*No*
Pithecellobium dulce Semi-natural Woodland	*No*
Prosopis pallida Coastal Dry Semi-natural Woodland	*No*
Samanea saman - Schinus terebinthifolius Semi-natural Woodland [Park Special]	*No*
Scaevola taccada Coastal Dry Shrubland [1,3]	*Yes*
Sida urens [4] Semi-natural Herbaceous Vegetation [Park Special]	*No*
Thespesia populnea / Sparse Understory Woodland [1]	*Yes*
Waltheria indica - Sida fallax Shrubland [1]	*Yes*

[1] Native or early Polynesian-introduced naturalized types.

[2] Formerly Panicum maximum.

[3] rUSNVC name modified based on Wagner and Herbst (2003) and Wagner et al. (1999).

[4] Misidentified in Cogan et al. (2011) as *Sida cordifolia* (L. Pratt, retired USGS, personal communication, 2018).

Wetland Vegetation

The wetland habitat at Puʻuhonua o Hōnaunau NHP is not extensive and is dominated by native makaloa (*Cyperus laevigatus*), which grows on the edges of the anchialine pools (Cogan et al. 2011). This coastal and brackish pond area contained eight indigenous species during the 1992–1993 study; of these, makaloa, ʻahuʻawa (*Cyperus javanicus*), pōhuehue (*Ipomoea pes-caprae*), ʻākulikuli (*Sesuvium portulacastrum*), and milo were the most common in the wetland area around the ponds (Pratt and Abbott 1996). In this area, Else (2006) found that the native sedges near the ponds and the Great Wall consisted of makaloa and mauʻu ʻakiʻaki (*Fimbristylis cymosa*).

Definitions of Species' Origins

For vegetation, we grouped species into three classes:

1. 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).
2. Polynesian species are those that were introduced by Polynesians prior to 1778; species arrival during the Polynesian times was likely ongoing through hundreds of years of two-way voyaging.
3. Nonnative species are those that were introduced to Hawaiʻi after Western contact in 1778.

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 (NRCA 2019) and/or rated as "High Risk" by the Hawaiʻi Pacific Weed Risk Assessment (Daehler et al. 2004, HPWRA 2019). The Hawaiʻi Pacific Weed Risk Assessment is a screening tool, and is by far a more comprehensive list, with over 1700 plants screened to date (HPWRA 2019). 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 Pacific 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.

4.2.1.2 Indicators, Data and Methods

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

The vegetation at Puʻuhonua o Hōnaunau NHP has been fairly well studied, with reports published on an irregular basis from 1957 to 2011 (Bryan and Emory 1957, Smith et al. 1986, Pratt and Abbott 1996, Cogan et al. 2011). Neal (in Bryan and Emory 1957) surveyed the vegetation in the park and listed species that occurred in similar habitats but were missing in the park. Yen (1971) conducted an ethnobotanical survey of the park. Leishmann (1986) created a vegetation map using infrared aerial photographs to determine community boundaries, followed by ground-truthing. Smith et al. (1986) surveyed the park in wet and dry seasons over three years to determine a checklist of established species. Pratt and Abbott (1996) employed 10 x 20 m plots established at 100 m intervals, along five east-west running transects. Species composition was recorded for each plot, percent cover was estimated using a Braun-Blanquet scale, and the number of native and Polynesian plant species was determined over a 100 m portion of the transect then extrapolated for the park. In addition, they surveyed native species along the coastal 1871 trail. They compiled a checklist for the park. Waite (2009) surveyed native and culturally important plants along unmarked transects within three survey areas: the Keawe Residential Complex, Kiʻilae Village, and the Sewage Treatment Plant. Cogan et al. (2011) mapped the vegetation in the park using satellite imagery and ground truthing. Cogan et al.'s (2011) report will be emphasized here since it is the most recent vegetation survey of the area and most current account of the vegetation present, however, its primary objective was to survey and map all plant communities rather than conduct a full species inventory, so does not necessarily capture every species present in the park.

4.2.1.3 Reference Condition

Vegetation reference condition is 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 750–1,500 year-old flows in dry habitats and coastal strand forest with pockets of much older flows dating from 3,000–5,000 years before present (Lockwood and Lipman 1987, Lockwood et al. 1988, Trusdell et al. 2006). Culturally important nonnative species would include those mentioned in Hawaiian moʻolelo (stories) or medicines. The conditions referenced here imply a time period of use by Native Hawaiians and post-lava flow.

4.2.1.4 Current Condition and Trend

The vegetation at Puʻuhonua o Hōnaunau NHP has been "a far cry from its pre-Captain Cook representatives," (Bryan and Emory 1957) with over 72% of the species identified being nonnative species introduced to Hawaiʻi in historic times (Cogan et al. 2011, Pratt and Abbot 1996). An overview of the current condition of vegetation at Puʻuhonua o Hōnaunau NHP is presented in Table 4.2.1-2.

Table 4.2.1-2. Summary of the vegetation resource conditions of Puʻuhonua o Hōnaunau NHP based on the data discussed 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 most likely higher than during the 1800s when vegetation was sparse. Since the 1950s, nonnative vegetation has established in the park and Polynesian and native plant species have been planted.
Density	The number of individuals occurring per square unit of land	Density is only available for native and Polynesian species. Density varies between species; most occur at densities of under 1 plant/1000m^2 but they are as common as 74/1000m^2.
Species composition (presence/ absence)	The presence of native and Polynesian species in relation to the total number of species	The managed vegetation in the developed areas of the park has a few Polynesian plant species and the coastal strand habitat has a higher percentage of native species than the majority of the park habitats, and is considered in the best overall condition.
Structure (percent cover and frequency)	Percent cover is a measure that accounts for how much space a species is occupying 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	The majority of the plant cover in the park is nonnative; nonnative grasses and several tree species occur throughout the majority of the park with percent cover that ranges from under 1% to over three-quarters of the cover in the area. The coastal strand has the highest cover of native and Polynesian species.

Bryan and Emory (1957) describe numerous edible species of recent and prehistoric introduction found in small numbers near house sites. They describe the area above the beach road as being dominated by introduced forage grasses but having been "covered with pili grass (*Heteropogon contortus*)" fifty years prior to the survey. They also identify the tree molds in the Mauna Loa flow at the Paumoa shoreline as probable loulu and kou (*Cordia subcordata*), attesting to a very different species make-up around the time of human arrival. Else (2006), using numbers from Pratt and Abbott (1996) survey, reports that vegetation surveys in the park have recorded a total of 134 vascular plant species, 96 species (nearly 75%) of which were alien to Hawaiʻi. Twenty-three species (17%) are indigenous, six species (4%) are endemic, and 15 species (11%) are Polynesian introductions. The NPSpecies database records 180 vascular plants, of which 56 (31%) are native and 124 (69%) are nonnative (irma.nps.gov/NPSpecies/Search/SpeciesList, 22 Dec 2016).

Bryan and Emory (1957) found 21 native species in their 1956 park survey but observed the flora to be dominated by eight exotic species, not including the exotic forage grasses that made up the majority of the understory. In 1986 Smith et al. found 21 native species, 91 historically introduced species (74%), and ten Polynesian introductions. They found four species for which the source of introduction was uncertain. The 1992 (Pratt and Abbott 1993) survey found 23 native (6 endemic and 17 indigenous) species, 96 historically introduced species, and 15 species introduced by Polynesians. Cogan et al. (2011) found 25 native species and 71 nonnative species in the park. Thus, it appears that the number of native species within the park is increasing; however, the trend is weak, and due to different sampling methodologies, the addition of the Ki'ilae parcel in 2006, and inclusion of different lifeforms, an accurate trend is difficult to discern. Because the park is in an important agricultural area that remained inhabited until about 1926 (NPS 1977), the area has undergone a progression from purely Polynesian introductions to historical introductions of useful species and the introduction of forage grasses for cattle (*Bos taurus*) and goat (*Capra hircus*) ranching.

Bryan and Emory (1957) provided a table of the plant species suggested for re-establishing at Puʻuhonua o Hōnaunau NHP (natural_cultural_history.pdf (nps.gov)). This table includes 96 native and Polynesian introduced plants that likely occurred in the pre-contact period and are suggested for reintroduction to the park. Fifty-four years later, Cogan et al. (2011) found 22 of these species (23%) during their survey of plant communities within the park. Many of the species that were not found after this time are cultivated, culturally important species such as kō or sugar cane (*Saccharum officinarum*), and ʻuala or sweet potato (*Ipomea batatas*). The NPSpecies reports 180 vascular and non-vascular plants in Puʻuhonua o Hōnaunau NHP, many of which are nonnative.

Cogan et al. (2011) classified the Puʻuhonua o Hōnaunau NHP vegetation into 14 vegetation types, five of which were dominated by native or Polynesian-introduced species (Table 4.2.1-1). Of the 54 plots sampled only 10 (18%) were dominated by either native or Polynesian introductions. Cogan indicates that the four most common native species in the park are ʻuhaloa (*Waltheria indica*), a small woody shrub, naupaka kahakai (*Scaevola taccada*), a common coastal shrub, and two sedges: makaloa (*Cyperus laevigatus*) and mauʻu ʻakiʻaki (*Fimbristylis cymosa*). All four species are indigenous to Hawaiʻi with a pan-tropical distribution (Wagner et al. 1999). Native and culturally important species are planted around the Visitor Center and coastal strand areas and include: kī

(*Cordyline fruticosa*), kō (*Saccharum officinarum*), wauke (*Broussonetia papyrifera*), pili (*Heteropogon contortus*), the loulu (*Pritchardia maideniana*, formerly *P. affinis*), noni (*Morinda citrifolia*), and niu (*Cocos nucifera*) (Cogan et al. 2011).

Focal Native Communities

The small areas of native plant communities tend to be clustered around the anchialine pools, in the cliff refugia, and in the coastal area dominated by coconut, naupaka kahakai, and mauʻu ʻakiʻaki. ʻUhaloa is often co-dominant with invasive grass species in the area near the park access road (Pratt and Abbott 1996). The only other vegetation communities dominated by native species are almost all found in the northeast portion of the park, with a thin strand of coconut palm woodland and mixture of other native dominated vegetation types extending southward along the north coast of Kiʻilae Bay (Figure 4.2.1-1).

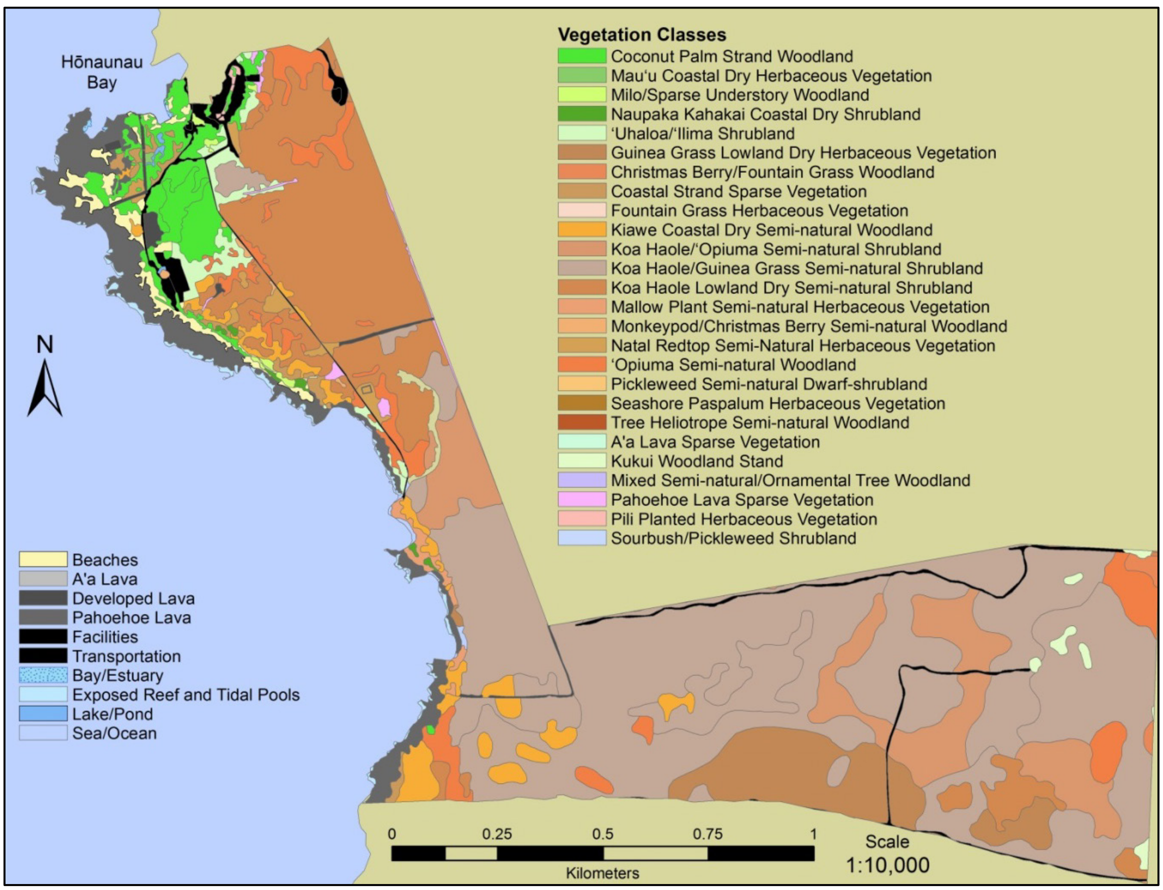


Figure 4.2.1-1. Distribution of vegetation classes at Puʻuhonua o Hōnaunau NHP. Data and nomenclature come from Cogan et al. (2011). Native dominated classes shown in shades of green. Nonnative dominated classes shown in shades of orange and brown. Vegetation classes not evaluated by Cogan et al. shown in pastel colors. Other habitat types depicted in yellow (beaches), shades of grey (lava and developed areas) or blue (water features, including anchialine pools and fishponds).

Else (2006) states that the majority of the 23 native species in the park were found in the "developed part of the park near the Visitor Center or were growing near the brackish pools or along the coast."

In addition, she found that the only common native species were the "low-growing shrub ʻuhaloa (*Waltheria indica*), makaloa sedge of the ponds, and the coastal naupaka kahakai and *Fimbristylis cymosa*."

4.2.1.5 Threats and Stressors

Smith et al. (1986) described the dangers of allowing the large number of alien species to persist in the park. They expressed concern that the plants will increase the incidence of fire and disrupt the archeological sites around which the park was established. The park's Master Plan (1977) and Natural and Cultural Resources Management Plan and Environmental Assessment (1978) called for removal of nonnative vegetation, reintroduction of selected native plants, and vegetative clearing of the archaeological sites. In addition, nonnative mammals threaten native vegetation and are likely to increase the abundance of nonnative vegetation in multiple ways (e.g., ungulate browsing, native seed predation by rats).

For palms, fungal disease monitoring is an important aspect to vegetation management. Different diseases present different symptoms. For example, *Thielaviopsis* fungi cause sudden crown collapse, often without other warning signs (Elliot 2012) and may pose a safety hazard. Several coconut trees in the coastal strand forest near the visitor center have been diagnosed with disease caused by infections with fungal pathogens and insects. The most common causes of infection were the fungal pathogens *Thielaviopsis paradoxa* and *Lasiodiplodia theobromae*. From June 2013 through August 2014, twelve trees were tested for pathogens. Of those, 11 were tested for *T. paradoxa*, all of which tested were positive. Most trees infected with *T. paradoxa* were also infected with *L. theobromae* (7/11) or the banana moth, *Opogona sacchari* (5/11) with 36% (4/11) of *T. paradoxa* trees suffering from co-infections of all three. One palm was examined in 2012 after suddenly uprooting and falling and was found to be co-infected by *T. paradoxa* and an incipient *Phytophthora* species that was suspected to be *P. katsurae* (U. H. Agricultural Diagnostic Service Center report, Uchida and Aragaki 1992) but is now believed to be *P. cocois* (Weir et al. 2015).

4.2.1.6 Data Gaps and Research Recommendations

The unique communities around the anchialine pools deserve special management to keep them as intact as possible. In addition, as recommended by Smith et al. (1986), it is important to manage the large numbers of alien species, especially those that respond favorably to fire in order to preserve the archaeology of the park. They recommend salt water treatments and manual removal of nonnative trees, shrubs and grasses in order to suppress wildfires. Pratt (1998) suggests concentration on removal of particularly noxious and/or recently established nonnative species. This will require regular monitoring of vegetation and continued research into effective control treatments. Areas of historic importance and those with high densities of native and important Polynesian species should be targeted for restoration to the 1819 landscape. There is potential to learn about this earlier landscape by examining the range maps of Price et al. (2012), which help determine native species that may have previously found in the park but are no longer present. Such an approach might be promising for learning about rare and endangered species, for which the park may not have a record. However, it is also important to consider if the 1819 landscape is a realistic target, given climate change. Removal of nonnative plants, conservation of existing, and re-establishment of missing native and Polynesian species should be targeted (Pratt 1998). Continuing to monitor and treat pathogens and pests of palm trees should also be a priority for management. Comprehensive monitoring of the park's vegetation should be conducted on a regular basis to allow for assessment of indicators and needs. In addition, the Puʻuhonua o Hōnaunau NHP palms should be monitored regularly for disease and insect infestation.

4.2.2 Birds

By Brian Hudgens, Institute for Wildlife Studies

Young ‘auku‘u (*Nycticorax nycticorax hoactli*) at the Royal Fishpond in ‘ākulikuli (*Sesuvium portulacastrum*) and surrounded by milo (*Thespesia populnea*; NPS photo circa 2011).

Condition Summary

The condition of the bird community Pu‘uhonua o Hōnaunau NHP warrants moderate concern. Most of the species observed in the park are nonnative but native (including migratory) species are present. The assessment is made with low confidence due to the absence of any formal surveys since 2005, and no known intensive surveys of the entire avian community. Consequently, data are also not available to determine a trend.

4.2.2.1 Description

Birds play an important role in both Hawaiian cultural history and modern environmental education. Prior to European contact, Hawaiians used birds for their meat and plumage (Kirch 1982). ‘Ahu ‘ula, 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).

Hunting, clearing of lowland forests, predation by introduced Polynesian rats, and interactions with and habitat changes mediated by pigs and fowl (*Gallus gallus*) were associated with the local extinction of dozens of bird species prior to European contact (Kirch 1982, Boyer 2008). Since

European contact, habitat loss, introduced predators and disease have been associated with the loss of dozens more bird species (Boyer 2008). At present, most birds encountered in the park are nonnative passerines (Morin 1996a), which are typical of lowland areas of West Coast Hawaiʻi Island. Most native species encountered are shorebirds (Waddington 2005a).

4.2.2.2 Indicators, Data and Methods

A general description of the avian community along the West Coast Hawaiʻi Island reference region is provided by data from the National Audubon Society Christmas Bird Count (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. All available data (1996–2001, 2006–2015) collected from the North Kona survey circle[12], which is centered 1.5 km east of the Moanuiahea radio facility on Hualālai[13], were downloaded from the National Audubon Society website (National Audubon Society 2016). The area and routes covered by this circle do not include Puʻuhonua o Hōnaunau NHP but does reach the shoreline. Because this area is much larger than Puʻuhonua o Hōnaunau NHP, we excluded rare birds from analyses. 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 Puʻuhonua o Hōnaunau NHP, as a 15 mi (24km) diameter survey area is sufficient to go from shore to a much higher elevation than the park and span a number of different habitats. The condition at Puʻuhonua o Hōnaunau NHP 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 the park are sparse. The available data come from baseline surveys done in 1992 and 1993 (Morin 1996a), shorebird and seabird surveys conducted in 2003–2005 (summarized in Waddington 2005a, 2005b), and species lists maintained by the NPS (NPS NPSpecies 2020), which includes species observations recorded at the park. This list includes the lists observed by Morin (1996a) and Waddington (2005a, 2005b), as well as unverifiable observations reported to the park.

4.2.2.3 Reference Condition

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 not associated with water include the ʻio or Hawaiian hawk (*Buteo solitarius*), and ʻamakihi honeycreeper (*Chlorodrepanis virens*). There were ten native wetland and shore birds commonly encountered on Christmas bird counts, including three species listed under the Endangered Species

[12] Image of survey circle is available at https://arcg.is/0XDnm1.

[13] Moanuahea Radio Facility is located at 3222 ft in elevation (USGS 7.5' quadrangle, Kailua 1996) and is about 30 driving miles north of the park, and about 6 miles up Hualalai mountain from the coastline. The summit of Hualālai is 8278 ft (2523 m).

Act: nēnē or Hawaiian goose (*Branta sandvicensis*), aeʻo or Hawaiian stilt (*Himantopus mexicanus knudseni*), and ʻalae keʻokeʻo or Hawaiian coot (*Fulica alai*).

4.2.2.4 Current Condition and Trend

The NPS species list suggests a species richness greater than that suggested by the other two sources alone (Morin 1996a, Waddington 2005a). Overall, the avian community at Puʻuhonua o Hōnaunau NHP was similar to that reflected in the Kona Christmas bird counts in that the terrestrial bird community is dominated by nonnatives and the shorebird community is dominated by natives. Of the 29 species listed as present at the park (Appendix A), ten (34.5%) were native. While the percentage of native birds was lower than among birds commonly encountered on the Kona Christmas bird counts, the difference is not statistically significant (χ^2=0.55, p=0.46). Most (8) of the native birds on the Puʻuhonua o Hōnaunau NHP species list are water or shore birds, and no nonnative water/shore birds are known from the park. Two species of sea birds have been observed in the park, one of which, the ʻiwa or great frigate bird (*Fregata minor*), was not encountered on any of the Christmas bird counts. In addition, koaʻe kea or white-tailed tropicbirds *(Phaethon lepturus*) are known to roost at the cliffs approximately 6.5 km (4.0 mi) to the north and 6.0 km (3.7 mi) to the south of the park (Waddington 2005b). In contrast to birds associated with the park's waters and shorelines, landbirds observed at Puʻuhonua o Hōnaunau NHP are almost exclusively nonnative, the only exceptions being rare sightings of ʻio and pueo (Morin 1996a, Waddington 2005a; see Appendix A).

4.2.2.5 Threats and Stressors

Predation by nonnative mammals poses the primary threat to bird populations at Puʻuhonua o Hōnaunau NHP. During 17 bird surveys in Puʻuhonua o Hōnaunau NHP conducted from 2003–2005, six mongooses and nine cats were observed (Waddington 2005a), and rat presence was confirmed along the shoreline during sea bird surveys (Waddington 2005b). The potential for these three species to decimate native island bird populations has been well documented (Towns et al. 2006, Hays and Conant 2007, Medina et al. 2011). Other biotic interactions, such as competition with nonnative birds may be reducing utilization of the park by native species and impacting the potential for native species to return following restoration of the native vegetation community. Diseases, such as avian malaria, avian pox, and avian botulism have had decimating impacts on native Hawaiian bird populations, especially in mesic lowland sites (van Riper III 1986, 2002, Morin 1996b). These factors likely continue to limit the recovery of native species in and around Puʻuhonua o Hōnaunau NHP. Future recovery of native species may be impacted by emerging diseases such as West Nile virus and knemidokoptic mange, and changes in habitat availability associated with increasing storm surge and sea level rise (P. Banko, USGS personal communication, December 7, 2018).

4.2.2.6 Data Gaps and Research Recommendations

Bird data for Puʻuhonua o Hōnaunau NHP are sparse and poorly replicated. The last formal survey of birds was conducted over 20 years ago (Morin 1996a). Ideally, regular surveys should take place that characterize both the breeding and migratory bird communities using the park and population trends for native species. This could be accomplished with semi-annual surveys. Repeated coverage of the park within surveys— for example, walking survey transects two or three days in a row— is recommended to allow detection probabilities to be estimated and to reduce the uncertainty that unencountered species are present in the park but overlooked by surveyors. Due to the small size of Pu‘uhonua o Hōnaunau NHP relative to bird home ranges, survey and restoration efforts within the park will be most effective if coordinated with efforts at a larger landscape scale.

The bird community has changed over time from pre-human, to arrival of Polynesians, to Western contact, but to what extent is unknown. Bird bones associated with archeological sites (e.g., in North Kona) could provide insights about birds found along the coast during Polynesian settlement.

4.2.3 Native Mammals

By Brian Hudgens, Institute for Wildlife Studies

Condition Summary

The condition of the native mammal community at Puʻuhonua o Hōnaunau National Historical Park warrants low to moderate concern. Neither ʻilio-holo-i-ka-uaua (Hawaiian monk seal, *Neomonachus schauinslandi*) nor ʻōpeʻapeʻa (Hawaiian hoary bat, *Lasiurus cinereus semotus*) use the park for breeding, and observations of both are rare. However, ʻōpeʻapeʻa detection rates were higher at Puʻuhonua o Hōnaunau NHP than at any other site on Hawaiʻi Island where bat surveys were reported, and ʻilio-holo-i-ka-uaua are currently present in low numbers on the Island of Hawaiʻi. Any concerns for both species would be due to range-wide concerns rather than conditions at the park. However, a lack of formal surveys at Puʻuhonua o Hōnaunau NHP in recent years for both species and generally poor understanding of the ecology of both species means that this assessment is made with low to moderate confidence. No trend data are available.

4.2.3.1 Description

Two endemic mammals can be seen on lands in Hawaiʻi, ʻilio-holo-i-ka-uaua or Hawaiian monk seal (*Neomonachus schauinslandi*) and ʻōpeʻapeʻa or Hawaiian hoary bat (*Lasiurus cinereus semotus*), and both can be found at Puʻuhonua o Hōnaunau NHP. Although neither species lives wholly within the park, ʻilio-holo-i-ka-uaua swim in the waters adjacent to the park and haul out along the shoreline, while ʻōpeʻapeʻa forage in the park. Both species are listed as endangered under the Endangered Species Act.

ʻilio-holo-i-ka-uaua or Hawaiian monk seal (*Neomonachus schauinslandi*) basking at Paumoa at Puʻuhonua o Hōnaunau NHP (NPS photo).


‘Ōpe‘ape‘a or Hawaiian hoary bat roosting at Pu‘uhonua o Hōnaunau NHP (NPS photo).

‘Ilio-holo-i-ka-uaua is one of the rarest marine mammals in the world. ‘Ilio-holo-i-ka-uaua spend 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 feet) deep (NOAA 2016). The entire range of ‘ilio-holo-i-ka-uaua is within U.S. waters. The majority of ‘ilio-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 have composed an increasingly large part of the total population (NOAA 2016).

‘Ōpe‘ape‘a is mostly a solitary, tree-roosting bat that ranges from sea level to nearly 4,270 meters in elevation (Bonaccorso 2010). ‘Ōpe‘ape‘a may fly more than 19 km (12 mi) one way to foraging grounds and return to its original roost (Bonaccorso 2010, Bonaccorso et al. 2015). ‘Ōpe‘ape‘a 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 ‘ōpe‘ape‘a roost or breed (Gorresen et al. 2013, Bonaccorso et al. 2015).

4.2.3.2 Indicators, Data and Methods

For both species of native mammals, we assessed use of the park as the relevant metric of their status within the park. Neither species is known to breed in Pu‘uhonua o Hōnaunau NHP. Rather, individuals have been recorded using the park as a temporary resting ground (‘ilio-holo-i-ka-uaua) or foraging grounds (both). Data were compiled from observations of ‘ilio-holo-i-ka-uaua within Pu‘uhonua o Hōnaunau NHP compiled by NOAA (Pacific Islands Fisheries Science Center 2016). Although it generally cannot be determined from these reports if multiple observations come from the same individual, we assumed that trends in the number of sightings through time indicated usage patterns over the same time period. Data for ‘ōpe‘ape‘a were collected from acoustic surveys conducted by Fraser et al. (2007) and Bonaccorso et al. (reported in Gorresen et al. 2013 and unpublished data).

4.2.3.3 Reference Condition

An indicator of how ʻilio-holo-i-ka-uaua respond to the Puʻuhonua o Hōnaunau NHP 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. While the overall stock of ʻilio-holo-i-ka-uaua has continued to decline, numbers observed on the Main Hawaiian Islands appear to be increasing. Using life table analysis, Baker et al. (2011) estimated an intrinsic population growth rate of 6.5% per year based on data available through 2008 and an updated analysis (Carretta et al. 2017) yielded an estimated 5.2% annual growth rate of the ʻilio-holo-i-ka-uaua population within the Main Hawaiian Islands in recent years in the NOAA Hawaiian Monk Seal Stock Assessment 2016. 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 6, 2017).

An indicator for ʻōpeʻapeʻa is consistency of use of foraging grounds, measured as detection rates during acoustical surveys. Fraser et al. (2007) conducted repeated surveys for ʻōpeʻapeʻa at Hawaiʻi Volcanoes NP, Kaloko-Honokōhau NHP, Puʻukoholā Heiau National Historic Site, and Puʻuhonua o Hōnaunau NHP. Detection rates at repeated survey points varied among the parks but were typically <5% (Table 4.5.2-1). Gorresen et al. (2013) conducted repeated acoustic surveys at 23 sites, including Puʻuhonua o Hōnaunau NHP over five years. They did not report separate occupancy or detection rate data for individual sites, but data were available from Puʻuhonua o Hōnaunau NHP for 2007 (Bonaccorso et al. unpublished data). The average occupancy rate for sites in 2007 was ~75% during June–October, when detection rates are highest (Gorresen et al. 2013).

4.2.3.4 Current Condition and Trend

From 2009–2016 there have been 20 recorded occurrences of ʻilio-holo-i-ka-uaua in Puʻuhonua o Hōnaunau NHP (Pacific Islands Fisheries Science Center 2016). These include an observed molting ʻilio-holo-i-ka-uaua in February 2010 and two observations of ʻilio-holo-i-ka-uaua pups in 2013. There is not a temporal trend in ʻilio-holo-i-ka-uaua sightings. There were five occurrences in 2009, eight in 2013, and between one and three a year in 2010, 2012, 2015, and 2016. There is little information about how many individuals are represented in the number of known occurrences, other than that at least two individuals, an adult and a pup, were observed in Puʻuhonua o Hōnaunau NHP in 2013.

ʻŌpeʻapeʻa were detected at all stations surveyed in both 2005 and 2007. In 2005, ʻōpeʻapeʻa were detected a total of ten times at the four stations monitored for 11 days, for a naïve detection rate nearly ten times that observed at any of the other parks surveyed (Table 4.2.3-1; Fraser et al. 2007). Occupancy of sites surveyed in July and September 2007 was 72.7%, indistinguishable from the overall average occupancy reported by Gorresen et al. (2013). Ōpeʻapeʻa were detected year-round during the 2007 survey (Bonaccorso et al. unpublished data). While there have not been any formal surveys since 2007, anecdotal observations of ʻōpeʻapeʻa at Puʻuhonua o Hōnaunau NHP in more recent years have been common.

Table 4.2.3-1. Bat detection rates reported in Fraser et al. 2007.

Park	Stations	Surveys	Detections	Detection rate
Hawai‘i Volcanoes NP	12	41	11	0.022
Pu‘ukoholā Heiau National Historic Site	6	12	0	0.000
Kaloko-Honokōhau NHP	8	15	2	0.017
Pu‘uhonua o Hōnaunau NHP	4	11	10	0.227

4.2.3.5 Data Gaps and Research Recommendations

No formal ongoing monitoring for either species is currently being conducted within the park. It is particularly difficult to draw meaningful conclusions from these observations due to the anecdotal nature of the data and the small numbers of individual ‘ilio-holo-i-ka-uaua known from the waters surrounding the Island of Hawai‘i. The surveys reported by Gorresen et al. (2013) may provide an opportunity to periodically assess status of ‘ōpe‘ape‘a in the region using previously monitored stations in and around Pu‘uhonua o Hōnaunau NHP.

Another data gap for both species is general information of the life-history and ecology of populations with individuals using Pu‘uhonua o Hōnaunau NHP. Basic questions such as, how much time individuals spend in or near Pu‘uhonua o Hōnaunau NHP, what do they use the park for, what are their prey resources, and where do they spend the remainder of their time remain unanswered. Without this basic information about ‘ōpe‘ape‘a and ‘ilio-holo-i-ka-uaua, it is not possible to determine if their relative abundances in Pu‘uhonua o Hōnaunau NHP is a reflection of the condition of the park, or is to be expected given its location and surrounding habitat.

4.2.4 Invasive Mammals

By Brian Hudgens, Institute for Wildlife Studies

Goats on basalt outcrop within Pu‘uhonua o Hōnaunau NHP (IWS Photo, B. Hudgens).

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‘uhonua o Hōnaunau National Historical Park and have significant impacts on both the ecological community and cultural resources within the park. The impacts of invasive mammals at Pu‘uhonua o Hōnaunau NHP warrant significant concern. Feral goats, cats, and mongooses appear to be abundant within the park, as would be expected given their abundance throughout the Kona coast. Anecdotal evidence suggests that pigs are relatively abundant compared to lowland areas of the Nāpu‘u Conservation Project, which may reflect the distance of each area to agricultural upland where pigs tend to be relatively abundant. This assessment is made with moderate confidence for pigs and goats due to lack of data (but abundant anecdotal observations), and high confidence for cats and mongooses based on trapping records. Trend data are not available.

4.2.4.1 Description

Nonnative vertebrates, particularly mammals, are included in this assessment because they have enormous ecological impacts on Hawaiian ecosystems by depredating native fauna, decimating native vegetation, spreading invasive nonnative vegetation, and facilitating erosion (Nogueira-Filho et al. 2009, Chynoweth et al. 2013). Invasive mammals have an especially high potential to transform Hawaiian landscapes. Predators, such as Pacific or Polynesian rats (*Rattus exulans*), Norwegian rats (*Rattus norvegicus*), black rats (*Rattus rattus*), small Indian mongooses (*Herpestes javanicus* syn. *H. auropunctatus*), and feral cats (*Felis catus*) are widely implicated in declines of native birds and reptiles, particularly on islands (Towns et al. 2006, Hays and Conant 2007, Medina et al. 2011). Rodents can exacerbate native plant declines by consuming seeds (e.g., Shiels and Drake 2015). Rodents can also provide prey, bolstering feral cat and mongoose numbers (P. Banko, USGS personal communication, December 2018). Ungulates contribute to native plant declines through overgrazing, trampling, and creating favorable conditions for invasive nonnative plants (Yocum 1967, Chynoweth et al. 2013, Leopold and Hess 2016).

The first nonnative mammals reaching Hawaiʻi were brought by Polynesian settlers approximately 1000 years ago. Pacific rats are believed to have been introduced by Polynesians as stowaways (Kirch 1982, Hess and Jacobi 2011). Pig (*Sus scrofa*) skeletons were found in the earliest archaeological sites of the Hawaiian Islands (Kirch 1982), with additional varieties from European stock brought by Captain James Cook in 1778 (Stone and Anderson 1988). The current population represents an admixture of animals from both lineages (Linderholm et al. 2016). Other rodents were introduced by Europeans in the 1800s (Hess and Jacobi 2011). Small Indian mongooses were introduced to the Hawaiian Islands in 1883 in an attempt to control rodent populations in sugar fields (Hays and Conant 2007). Tomich (1986) deduced that goats (*Capra hircus*) were introduced to Hawaiʻi Island by Captain James Cook in the winter of 1778–1779. Cattle (*Bos taurus*) were introduced to Hawaiʻi as a gift to Kamehameha I by Captain George Vancouver in 1793 (Tomich 1986, Maly and Wilcox 2000), and sheep (*Ovis aries*) were introduced in the same period (Tomich 1986, Stone and Anderson 1988). Currently, feral cattle, and sheep are found primarily in forested and higher elevation habitats and are rarely reported from the dry lowlands of the West Hawaiʻi coast. This section focuses on nonnative mammals common to West Hawaiʻi coast lowlands: mice (*Mus musculus*), rats, mongooses, feral cats, pigs, and goats.

4.2.4.2 Indicators, Data and Methods

Indices of abundance of invasive mammals served as an indicator of invasive mammal community condition, with higher abundances associated with worse conditions. Abundance indices were estimated from removal trapping. Trapping has been conducted sporadically since 2001. Trap effort was only reported for a one-week trapping session in 2002. For this period, catch per unit effort is reported. Otherwise, only the annual numbers of animals captured are reported. This measure is severely limited as trapping effort and baiting methods— both of which heavily influence numbers of captures— were not reported.

Ideally invasive mammals would be absent from Puʻuhonua o Hōnaunau NHP. However, the small size of the park and continual influx of animals from neighboring lands means that park management could substantially reduce the impact of nonnative mammals without achieving complete and sustained eradication. We therefore used the abundance of nonnative mammals in the lands surrounding Puʻuhonua o Hōnaunau NHP as the reference condition as it serves as a point of comparison to measure the effectiveness of existing or future control efforts by the NPS. In general, few studies have measured density of nonnative species in western Hawaiʻi. Therefore, we present as reference conditions ranges reported for indices of population abundance where such data are available from the island of Hawaiʻi. When data are available from multiple locations, we used the location that most closely matched the environmental conditions experienced at Puʻuhonua o

Hōnaunau NHP 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.

4.2.4.3 Reference Condition

The best available data describing the population size 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 4.2.4-1). Hansen et al. (2008; in Hess et al. 2008) report trap success for both mongooses and feral cats at two locations within Hawaiʻi Volcanoes NP. 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 Hawaiʻi Volcanoes NP 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 Hawaiʻi Volcanoes NP. Pitt et al. (2015) reported mongoose densities of 0.7–3.9 mongoose/hectare at two sites near Hilo.

Table 4.2.4-1. Occurrence of invasive mammals on Hawaiʻi Island based on trapping and captures.

Species	Location	Metric	Index	Citation
Mongoose	Hawaiʻi Volcanoes NP	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	Hawaiʻi Volcanoes NP	trap success	0.02 captures/trap day	Hess et al. 2008
	Hawaiʻi Volcanoes NP	N_e [1]	24–25 cats	Hess et al. 2008
Polynesian rat	Hawaiʻi Volcanoes NP	trap success	.024 captures/trap day	Scheffler et al. 2012
Black rat	Hawaiʻi Volcanoes NP	trap success	.021 captures/trap day	Scheffler et al. 2012
Norwegian rat	Hawaiʻi Volcanoes NP	trap success	0 captures in 6400 trap days	Scheffler et al. 2012
Mouse	Hawaiʻi Volcanoes NP	trap success	0.99 captures/100 trap days	Scheffler et al. 2012
Feral goat	Kawaihae watershed	number	eradicated (0)	Purell 2015
Feral pig	Nāpuʻu Conservation Project Area	Annual take	200 taken in 2000	Hawaiʻi DLNR 2015

[1] N_e = Effective population size: the number of individuals in a population who contribute offspring to the next generation.

The best information on rodent population size comes from Scheffler et al. (2012; Table 4.2.4-1) on a five-year trapping study in Hawaiʻi Volcanoes NP. Although Polynesian rats are reported to dominate lowland areas (Tomich 1981), in the lowland sites surveyed in Hawaiʻi Volcanoes NP, Polynesian rats composed 37–45% of the capture, black rats composed 34–62%, mice composed 1–21%, and Norwegian rats were 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 NP site most similar to Pu‘uhonua o Hōnaunau NHP would have been Kamoamoa, which ranged in elevation from 90–180 amsl. At this site, black rats composed nearly ⅔ of the capture, mice less than 1%, and the remainder came from 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 Department of Land and Natural Resources (DLNR 2015). At the Nāpu‘u Conservation Project area, they found pigs occurring as low as 762 m (2500 ft), but they were most commonly found above 1067 m (3500 ft). Goats were most commonly found in the low elevations below Māmalahoa Highway in the near-coastal habitat. In this same study, pig populations (indexed by the number of pigs removed) have been declining since 2000 when 200 were taken, while goat take in Nāpu‘u has been increasing since 2004 to a maximum annual take of approximately 450 goats. Goats have been eradicated from the 2700 ha (6600 ac) Kawaihae watershed by fencing and animal control (Purell 2015).

4.2.4.4 Current Condition and Trend

There was little quantitative data on the abundance of nonnative mammals in Pu‘uhonua o Hōnaunau NHP. The species list for the park lists mongoose, mice and rats as “common” and breeding within the park, feral dogs (*Canis familiaris*) as “uncommon,” feral pig and cats as “occasional,” and feral goats as “rare” (NPSpecies 2020). However, there is evidence that pigs, cats and goats are more common than was reported in the NPS species list. Pig tracks and signs of rooting have been observed near at least three anchialine pools. Numbers of animals captured during NPS trapping efforts varied widely from year to year (Figure 4.2.4-1). Trap effort was only reported for a one-week trapping session in 2002, in which 14 mongooses and 6 cats were captured in 32 trap nights, and 0 rodents were captured in 24 trap nights. The trap success rates of 18% (cats) and 44% (mongooses) during this effort were an order of magnitude greater than observed at reference sites. While visitor interactions with feral cats have gone down from 2010–2013 after animal-proof trash cans were installed in 2009 (NPS 2014), there is no evidence, in terms of lower catch per effort, of reduced cat activity in the park. Trapping records from 2015–2016 indicate that at least one cat and 5–12 mongooses were trapped every night traps were set. Goats were trapped in 2001 and 2003 and were reported during shorebird surveys in 2004. Over 400 goats were removed from the park in August 2021 in a joint effort by the State of Hawai‘i Department of Land and Natural Resources Division of Forestry and Wildlife and the National Park Service.

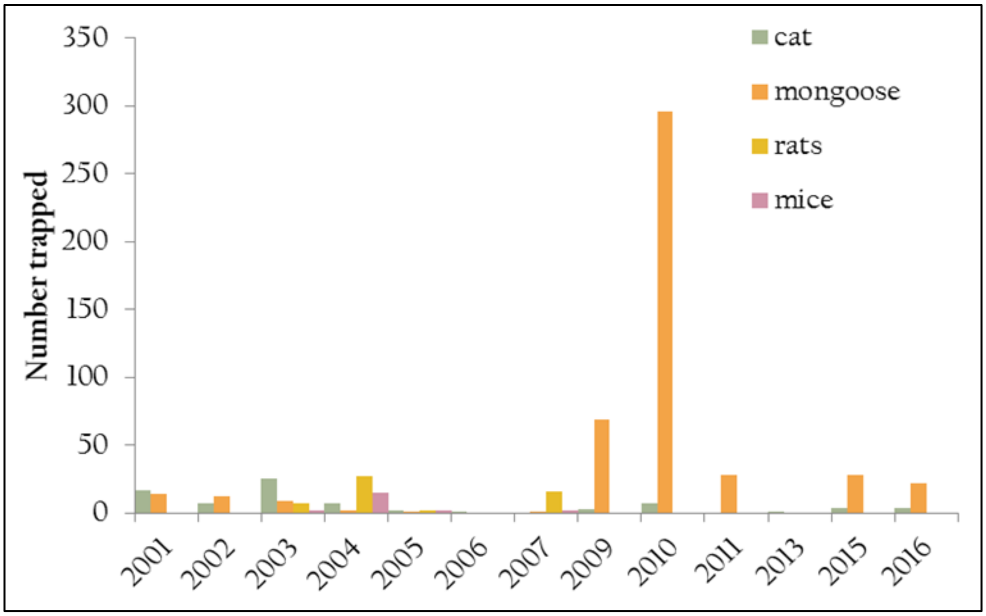
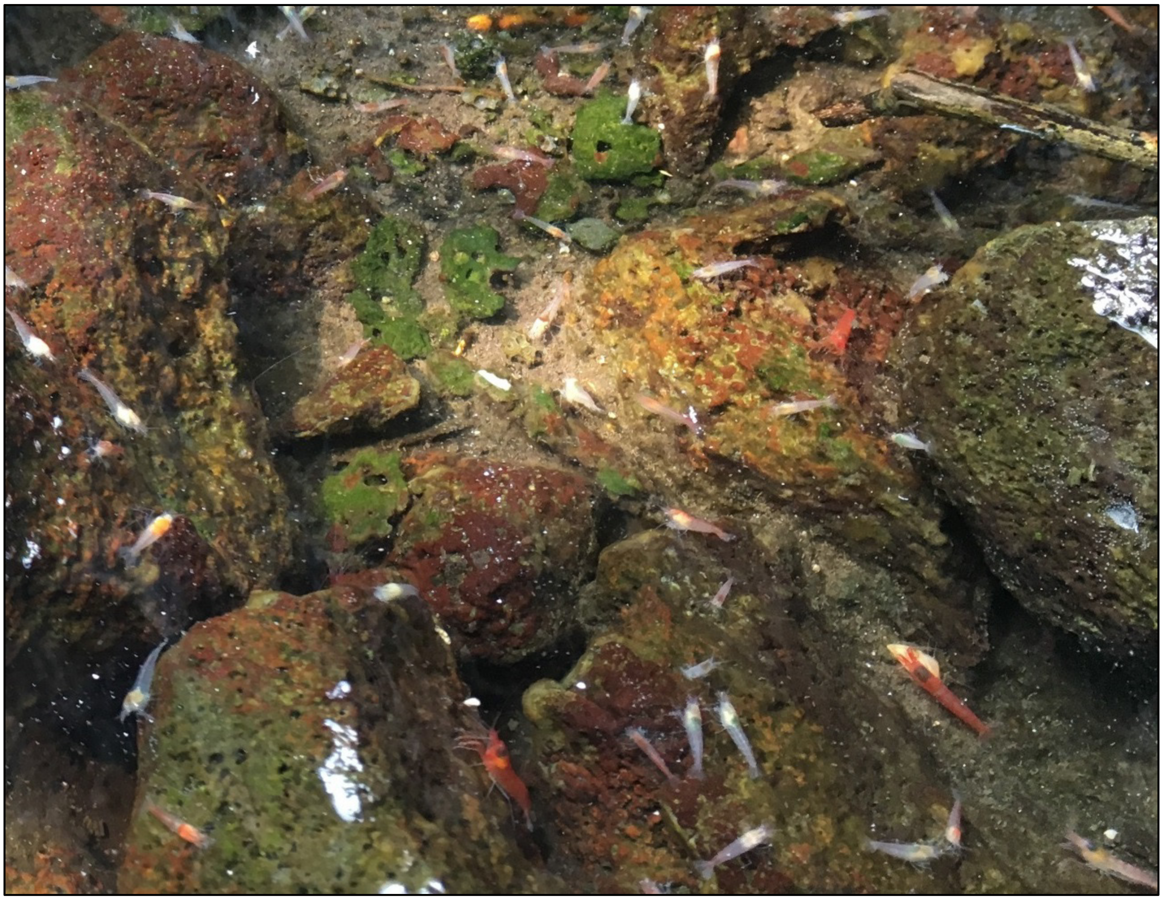


Figure 4.2.4-1. Number of invasive mammals reported trapped from Pu‘uhonua o Hōnaunau NHP 2001–July 2016. Years in which no animals were reported are omitted from the graph. NPS data.

4.2.4.5 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 Pu‘uhonua o Hōnaunau NHP. 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. Occupancy monitoring methods, such as track plates or camera traps, may also be used to determine relative abundances of rodents or mongooses in different habitats or following removal efforts (MacKenzie et al. 2018). 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, including regular fence monitoring, repair and modification, as needed, to ensure fence specifications meet requirements to effectively exclude target pests. Priority should go to those species that are likely to heavily impact cultural, vegetation and anchialine pool 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 mongooses) will likely require ongoing efforts to counter immigration from surrounding lands due to difficulty in preventing reintroductions from the surrounding landscape.

4.3 Aquatic Ecosystem Integrity



‘Ōpae ‘ula: the herbivorous *Halocaridina rubra*, foraging on algae-covered rocks in a very shallow sub-pool of the southern Royal Fishpond without nonnative fish, 2018 (NPS photo).

Anchialine pools are brackish water systems fed by fresh groundwater and seawater, with no surface connection to the ocean. These pools provide habitat for rare invertebrate species including shrimp, snails, and odonates. Although anchialine pools occur around the world, these habitats tend to be small, isolated, and threatened by human development and introduced nonnative species. The NPS and the U.S. Fish and Wildlife Service have identified anchialine pools as priority ecosystems in need of research to better understand the habitat requirements of endemic pool biota and how they will respond to current and future changes in pool ecosystems. There are 14 documented anchialine pools at Pu‘uhonua o Hōnaunau NHP. The north and south Royal Fishponds, which are adjacent anchialine pools separated by a manmade walkway, are the most prominent water bodies in the park.

4.3.1 Anchialine Pool Water Quality

By Jené Michaud, University of Hawai'i at Hilo

Condition Summary

Water quality in the anchialine pools of Pu'uhonua o Hōnaunau NHP warrants moderate concern due to high turbidity, high chlorophyll, low dissolved oxygen, and likely long-term increase in salinity. Algal blooms occur occasionally in the Royal Fishponds and episodes of reduced dissolved oxygen occur frequently enough to constitute a possible ecological impairment. With the exception of a pool next to a green waste collection area, nutrient concentrations are broadly similar to those observed in Kaloko-Honokōhau NHP in the 1990s. Water quality at Kaloko-Honokōhau NHP in the 1990s is thought to represent a low level of anthropogenic disturbance. Apart from a decrease in nitrate in one pool, nutrient concentrations do not show consistent trends over the past decade. No trends in chlorophyll, turbidity, oxygen or salinity were observed in the last decade, with the exception of a very slight increase in salinity within one of five monitored pools. Salinity has likely increased over the past four and a half decades, however.

4.3.1.1 Description

Water quality in anchialine pools is affected by groundwater quality, physical processes acting across the atmosphere-water interface, and biologic activities that recycle nutrients, produce organic sediment, and affect pH and oxygen. Water chemistry can be expected to vary between pools based on distance to the ocean (affecting salinity and tidal flushing), amount of sunlight (one pool is covered, inhibiting algae), and types of organisms that are present. Bottom sediment can originate from geological or biological processes and can restrict flushing of pools. In 1992, the average sediment thickness was 13 cm and 28 cm (5 in and 11 in), respectively, in the north and south Royal Fishponds (Oceanic Institute 1992a,b). Anoxic decay within the sediments of the north pool was noted.

4.3.1.2 Indicators, Data and Methods

Water quality indicators for anchialine pools include dissolved oxygen (DO), turbidity, nutrients (nitrogen and phosphorus) and chlorophyll in the water column. These indicators address the cause (excess nutrients), result (chlorophyll, a measure that can indicate algal blooms), and impact (low DO) of eutrophication, which is an ecological threat in fresh, brackish, and marine waters in Hawai'i and around the world. Algal blooms can consist of phytoplankton or benthic macro algae, yet only the former can be detected by chlorophyll measurements of the water column. In spite of this limitation, chlorophyll (along with nutrients and DO) is an indicator used in all major methods of assessing eutrophication (Ferreira et al. 2011). Because photosynthetically active tissues take up CO_2, and thus reduces the presence of carbonic acid, an increase in pH (decreased acidity) can corroborate occurrence of an algal bloom. High turbidity is stressful to most aquatic and marine organisms and can result from an algal bloom in the water column, from suspended sediments, or other uncommon chemical and biological events. High turbidity is the most common cause of Clean Water Act (CWA) impairment of Hawaiian waters (HDOH 2014). Low DO is widely recognized as stressful for some aquatic organisms and is most likely to develop in calm waters with restricted circulation.

Salinity is an additional water quality indicator because different species tolerate salinity differently. There are relatively few species of fish and invertebrates that can tolerate brackish water or fluctuating salinity; consequently, salinity has a direct bearing on environmental conditions from the viewpoint of organisms. In a given pool, salinity can vary according to natural processes such as sea spray, overwash from unusually large waves, concentration by evaporation, dilution by rainfall, relative sea level rise, and tidal fluctuations that affect the direction and rate of groundwater flow. While salinity can be affected by anthropogenic disturbances such as groundwater pumping or wastewater injection, it is unlikely that these activities have affected anchialine pools at Puʻuhonua o Hōnaunau NHP.

Sediment accumulation in pools reduces exchanges with groundwater, which could be detrimental to ecosystem health. Sediment thickness in pool bottoms has not been monitored, however, and is therefore not used as an indicator in the present study.

The NPS Inventory and Monitoring (I&M) Program has collected nutrient data and physical parameters at six anchialine pools using protocols described in Jones et al. (2011). Bacterial concentrations were not measured. Nutrient samples were collected in triplicate from the center surface of the pool; replicates were averaged prior to data analysis. DO, salinity, temperature and chlorophyll were measured with a sonde near the pool surface. Data were collected on a quarterly basis beginning in November 2007, published in a database (Pacific Island Network 2015b), and summarized in reports (Raikow and Farahi 2014, 2016). A duplicate set of these data are available from an EPA database (https://www.waterqualitydata.us/). Monitoring sites are described in Table 4.3.1-1. There were 29 sample days but not every pool was sampled on every day. For example, sampling at Pool HA_Kiilae_001 was discontinued after April 2013 due to safety reasons and sampling at pool HA_Keokea_004 did not begin until September 2013. Data from 2015 onward were not yet available for this NRCA.

Trends over time were examined using linear regression. Trends could not be examined for HA_Keokea_004, however, because the period of record is too short. There are several historic measurements from the period 1969–1999 that were used to evaluate the possibility of long-term trends (Doty 1969, Maciolek and Brock 1974, Oceanic Institute 1992a,b, Chai 1999). There are enough measurements to make a statistical comparison between 1992 observations and 2007–2014 observations. The difference between sample medians was evaluated using the Mann-Whitney rank sum test. (Because the data were not normally distributed, a t-test could not be used.)

Both groundwater and seawater feed anchialine pools so their water chemistry influences conditions in anchialine pools. There are no groundwater monitoring wells within Puʻuhonua o Hōnaunau NHP nor directly uphill from it, however, so direct observations of groundwater conditions were not made. Water quality of marine waters are discussed in section 4.4.1.

Table 4.3.1-1. Anchialine pools sampled by the NPS Inventory and Monitoring (I&M) Program.

Park ID	I&M ID	Traditional name(s)	Description & location
HA_Kiilae _001	FPUHO01_ap	Ka Wai Ku'i o Kekela or Kekela's well	Coastal well in the southern portion of the park (Kiʻilae Village)
HA_Keokea_ 003	FPUHO02_ap	Part of Waikulu Springs complex	Excavated well, about 350 m SSE of Royal Fishpond; near HA_Keokea_004
HA_Honaun_003	FPUHO03_ap	Royal Fishponds, Kaloko, Heleipalala, King's Fishponds, South Fishpond	South Royal Fishpond
HA_Honaun_004	FPUHO04_ap	Makaloa pond	About 35 m W of the S. Royal Fishpond; within the puʻuhonua
HA_Honaun_002	FPUHO05_ap	Royal Fishponds, Kaloko, Heleipalala, King's Fishponds, North Fishpond	North Royal Fishpond
HA_Keokea_004	FPUHO08_ap	Waikulu waterhole	About 350 m SSE of Royal Fishponds;. Near HA_Keokea_003; adjacent to green waste collection area

4.3.1.3 Reference Condition

Water quality reference values were selected to serve as benchmarks to place measurement values in context, with a view towards 1) assessing whether observed values are low, moderate, or high, 2) identifying whether there are trends in eutrophy, and 3) characterizing environmental conditions experienced by organisms. Reference conditions do not automatically represent the boundary between pristine and degraded conditions, nor are they intended to assess compliance with the Clean Water Act (CWA).

Reference values for anchialine pools were set as follows:

- Although there are no true temporal or spatial reference conditions for anchialine pools with which long term trends can be evaluated, a benchmark standard can be used to assess general ecosystem health. Here, a dissolved oxygen concentration of at least 75% saturation is used as a benchmark for ecosystem health based on general aquatic ecosystem standards set by the State of Hawaiʻi under requirements of the Clean Water Act (HAR 11-54).
- Reference values for nutrients, turbidity, and chlorophyll are based on measurements made in ten anchialine pools on six occasions in 1994–1996 in Kaloko-Honokōhau NHP (Brock and Kam 1997). Data from Kaloko-Honokōhau NHP were used because comparable data are not available for Puʻuhonua o Hōnaunau NHP. The selected reference values are the best available in terms of representing water nutrients at early stages of anthropogenic disturbance, but they do not necessarily represent pristine conditions (Hoover and Gold 2006).
- A second reference value was used for chlorophyll: above 30 µg/l algal blooms are evident (Raikow and Farahi 2016).
- Salinity reference values are based on historic observations made within the park 24–44 years ago (Oceanic Institute 1992a,b, Maciolek and Brock 1974). These early observations are

described and analyzed by Hoover and Gold (2006), who note that historic salinity measurements were taken with an instrument that is less accurate than instruments used in the last decade. Reference values are specific to particular pools because conditions controlling salinity vary between pools.

4.3.1.4 Current Condition and Trend

Nutrients and Physical Parameters

Nutrient concentrations in Hōnaunau's anchialine pools during the last decade were broadly similar to those in Kaloko-Honokōhau's pools twenty years ago (the reference condition; Table 4.3.1-2). There were exceptions, however:

- Nitrate[14] concentrations in three pools (the Royal Fishponds and a nearby pool) were 75–90% lower than reference values.
- Pool HA_Keokea_004 was unusual because it was associated with an organic waste pile (coconut fronds, for example), contains organic soil and possibly animal feces, and experiences low rates of tidal flushing. In this pool, total dissolved phosphorus (TDP) was almost an order of magnitude larger than in the other pools, total dissolved nitrogen (TDN) was slightly elevated, and nitrate concentrations were comparable to other pools.

In most pools chlorophyll and turbidity were an order of magnitude higher than conditions in Kaloko-Honokōhau's pools twenty years ago (the reference condition). The pool in the south portion of the park (Kekela's well), which is in a small cave with a skylight, was an exception; it exhibited low turbidity and low chlorophyll (both an order of magnitude below the reference values). In contrast, turbidity in the pool (HA_Keokea_004) associated with a green waste collection area was nearly two orders of magnitude above the reference value. Relatively minor algal blooms may have occurred in February 2011 in the Royal Fishponds and pool HA_Honaun_004, as indicated by elevated chlorophyll concentrations. Another bloom was detected in the north Royal Fishpond in February 2012.

Twenty-three percent of the oxygen measurements made during 2007–2014 were less than 75% saturation, suggesting that some aquatic organisms could have experienced oxygen stress part of the time in some pools. In the south Royal Fishpond, 46% of measurements were less than 75% saturation. There were no large-scale trends in oxygen over time. Notably, low oxygen conditions were also observed in the south Fishpond in 1992 and may have contributed to fish kills (Hoover and Gold 2006). In 1969, Doty described the Fishponds as "polluted." At the time there were two cesspools located nearby. Cesspools are a source of nutrients, organic matter that leads to oxygen depletion, and pathogens such as bacteria. The two cesspools were closed in 1971 and it is not known how their closure affected nutrient, oxygen and bacterial levels (Hoover and Gold 2006).

[14] In all I&M monitoring, the sum of nitrate and nitrite was measured, reflecting common laboratory procedures. Typically nitrate concentrations are much higher than nitrite concentrations. For convenience, in this report the term "nitrate" refers to nitrate+nitrite.

Table 4.3.1-2. I&M monitoring data (2007–2014) for nutrients, turbidity, and chlorophyll. Values represent the mean ± the standard deviation across dates. Nitrate refers to the sum of nitrate plus nitrite, TDN refers to total dissolved nitrogen, and TDP refers to total dissolved phosphorus. Data are from Pacific Island Network (2015) and Raikow and Farahi (2014, 2016; 1 mg/l = ppm).

Pool	Days sampled	Nitrate mg/l as N	TDN mg/l	TDP mg/l	Turbidity NTU	Chlorophyll µg/l
HA_Honaun_002 N. Royal Fishpond	24	0.18 ± 0.11	0.30 ± 0.10	0.065 ± 0.029	4.86 ± 8.6	8.96 ± 9.24.
HA_Honaun_003 S. Royal Fishpond	28	**0.07 ± 0.06** (3)	0.28 ± 0.07	0.080 ± 0.021	4.07 ± 9.85	6.04 ± 5.04
HA_Honaun_004	27	0.11 ± 0.09	0.31 ± 0.09	0.068 ± 0.030	4.35 ± 4.49	6.86 ± 9.12
HA_Keokea_ 003	26	**0.93 ± 0.52** (3)	**1.02 ± 0.56** (3)	0.094 ± 0.018	2.61 ± 10.03	1.13 ± 2.55
HA_Keokea_004	6 (1)	0.39 ± 0.31	**1.34 ± 0.50** (3)	**0.608 ± 0.341** (3)	**26.8 ± 39.26** (3)	8.86 ± 9.71
HA_Kiilae_001 Kekela's well	20 (2)	0.43 ± 0.07	0.45 ± 0.09	0.096 ± 0.016	**0.04 ± 0.13** (3)	**0.07 ± 0.16** (3)
Reference value	–	0.72	0.84	0.095	0.36	0.61
Reference value representing threshold for algal blooms	–	–	–	–	–	30

[1] started 9/2013

[2] ended 4/2013

[3] Pools with unusually high or low values, also shown in bold text.

Linear regression indicated small but statistically significant increasing trends in nutrients in some pools over the period 2007–2014. Pools HA_Kiilae_001, which is located near the southern boundary of the park, and HA_Keokea_003, which is in the middle of the park, experienced increases in nitrate and TDP. The statistical results do not necessarily indicate robust trends, however. Trends at HA_Kiilae_001 were primarily driven by low values in 2007–2008, and trends at HA_Keokea_003 were influenced by particularly high values in the summer of 2014; concentrations declined to background levels by the end of the year. Nitrate was the dominant component of TDN, so trends in TDN mirrored those of nitrate, except for pool HA_Honaun_004 where TDN increased but nitrate did not. Nitrate decreased in the south Royal Fishpond. There were no changes over time in turbidity or chlorophyll.

Long term trends in nutrients were examined using a small number of measurements made in the Royal Fishponds during 1969 (Doty 1969, Hoover and Gold 2006) and 1992 (Oceanic Institute 1992a,b). Nitrate concentrations during 2007–2014 were distinctly higher than the value measured in 1969, but distinctly lower than those measured in the same pools in 1992 (Figure 4.3.1-1). It is impossible to know if nutrients observed on one day in 1969 were characteristic of that year.

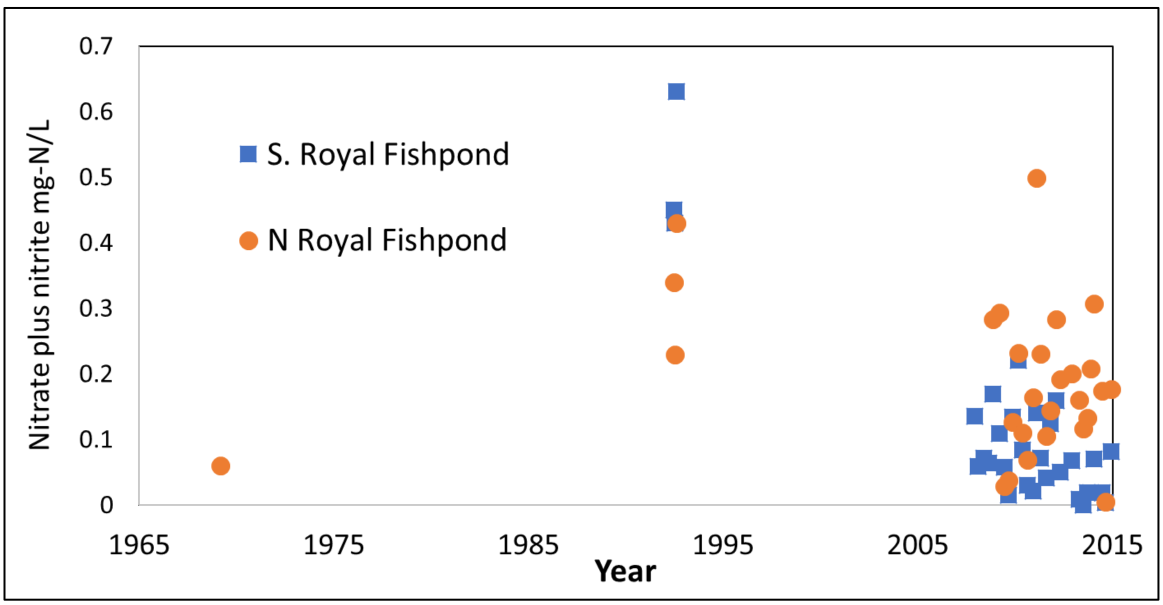


Figure 4.3.1-1. Nitrate concentrations in the Royal Fishponds. Recent data are from the NPS Inventory and Monitoring (I&M) network, 1992 data are from Oceanic Institute 1992a,b and the 1969 datum is from Doty 1969. Reviewed in Hoover and Gold (2006).

Comparisons between the 2007–2014 TDP observations and the earlier phosphate observations are complicated because we do not know how the TDP is apportioned into phosphate and dissolved organic phosphorus. It is clear, however, phosphate concentrations in 1992 were considerably higher than phosphate in 2007–2014; phosphate concentrations were five times larger in 1992 than TDP concentrations in 2007–2014. Combining all measurements made in the two pools, the observed values were 0.36 ± 0.17 mg-P/l of *phosphate* in 1992[15] and 0.073 ± 0.026 mg-P/l of *TDP* in 2007–2014.

Salinity

Salinity was greatest and most variable in the three pools near the Royal Compound and Visitor Center, moderate in the pools in the central section of the park, and least (and least variable) in the southern pool (Table 4.3.1-3). Variability in salinity was dominated by sharply elevated salinity in January 2014 and June 2014. These excursions were associated with seawater added by high surf that inundated pools and produced salt spray (Raikow and Farahi 2016). By the end of 2014 salinity returned to background levels. Tsunami are another disturbance that affects salinity. Runup from a tsunami in March 2011 was 5.3 m (17 ft) at Nāpoʻopoʻo Point, 4.5 km (2.8 mi) north of Puʻuhonua o Hōnaunau NHP and 3.1 m (10 ft) at Hoʻokena, 3.8 km (2.4 mi) south of the park (Trusdell et al. 2012). The Royal Fishpond and pool HA_Honaun_004 were inundated with seawater and marine fish were washed into some pools. Nevertheless, salinity values and nutrients in sampled pools returned to background values within 16 days.

Table 4.3.1-3. I&M salinity data (2007–2014) for anchialine pools. Values represent the mean ± the standard deviation across dates. Data are from (Pacific Island Network (2015) and Raikow and Farahi (2014, 2016). N.A. = not available.

Pool	Days sampled	Salinity ppt	Salinity with two high surf days excluded ppt	Historic reference value ppt
HA_Honaun_002 N. Royal Fishpond	25	13.88 ± 4.5	12.85 ± 1.79	8 (in 1969), 10.8 (in 1992)
HA_Honaun_003 S. Royal Fishpond	28	15.03 ± 5.5	13.64 ± 1.8	12.5 (in 1992)
HA_Honaun_004	27	14.53 ± 5.88	13.11 ± 2.8	N.A.
HA_Keokea_ 003	26	8.35 ± 2.42	7.67 ± 0.19	N.A.
HA_Keokea_004 green waste pool	6 (1)	8.84 ± 4.27	6.68 ± 1.87	N.A.
HA_Kiilae_001 Kekela's well	20 (2)	5.26 ± 0.13 (2)	–	3 (in 1974)

1 started 9/2013

2 ended 4/2013 before the two high surf days

Trends in salinity were examined after the strongly elevated high surf values were removed. From November 2007 through December 2014, one pool (HA_Keokea_003) experienced a very small but statistically significant increase in salinity between 2007 and 2014 ($p=0.04$, adjusted $r^2=0.15$, increase of 0.04‰ per year; ‰ = parts per thousand). The other four pools showed no long-term trend in salinity.

[15] These numbers are minimums as one measurement was a minimum value.

Three pools have historic salinity observations made 22–45 years ago (Figure 4.3.1-2). Taken at face value, the data show a long-term increase in mean salinity, with the rate of increase about 0.10‰ per year for the Royal Fishponds and about 0.06‰ per year for the relatively fresh HA_KIILAE_001 pool. Between 1992 and 2007–2014, there is a statistically significant increase in median salinity. The amount of increase was 3.8‰ and 2.2‰ in the south and north Royal Fishponds, respectively (S pond $P<0.001$ $U=207$; N pond $P=0.03$ $U=152$). It should be noted, however, that historic data were made with instruments that were less accurate than those used today. Further, salinity fluctuates rapidly with the tides, weather and salt spray from high surf. It is therefore difficult to precisely measure the mean or median unless large numbers of measurements are made. Corroborating the quantitative data are historic accounts that indicate lower salinity prior to 1969. Jackson (1966) recounts the story of Ka Wai Ku'i o Kekela (or Kekela's well, HA_KIILAE_001) – surprised by their dog returning wet, residents built fires to heat the basalt, weaken, and hammer through several feet of rock to expose the freshwater source beneath. This pool has since been known by that name and means "the pounded water of Kekela"; it was further modified with a rock wall to separate the washing area from the freshwater seep used for drinking. Bryan and Emory (1986) also report that parts of the south Royal Fishpond were once fresh enough for cattle to drink.

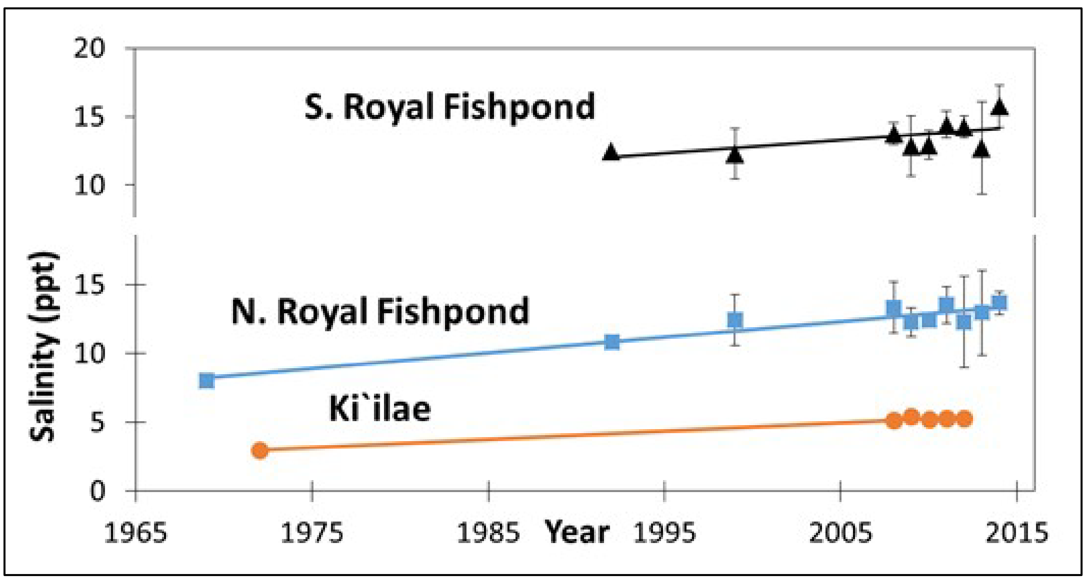


Figure 4.3.1-2. Long term trends in salinity at anchialine pools. Recent data is from the NPS Inventory and Monitoring (I&M) network and data from 1969–1999 is from Doty 1969, Maciolek and Brock, 1974, Oceanic Institute 1992a,b, and Chai 1999. Error bars are the standard deviation (unavailable for 1992 and too small to see for the Ki'ilae_001 pool).

In summary, over the last four and a half decades there is evidence that salinity has increased at a moderate rate of about 0.1‰ per year. Even though the early data is of unknown accuracy, the trends are consistent between three pools and the increase between 1999 and 2007–2014 is statistically significant in the two pools that have sufficient data for statistical testing. During the period 2007–2014 only one of five pools showed a statistically significant increase in salinity; possibly the noisy nature of the data makes trend detection difficult over short intervals of time.

Overall condition and trend assessment

Nutrient concentrations are broadly similar to those measured Kaloko-Honokōhau NHP during the mid-1990s. Chlorophyll and turbidity, however, are roughly an order of magnitude greater than those measured in Kaloko-Honokōhau NHP during the mid-1990s. Chlorophyll and turbidity showed no trends during 2007–2014. During the period 2007–2014 nitrate concentrations declined in the south Royal Fishpond but otherwise there was not a consistent trend in nutrient concentrations. Recent nutrient concentrations in the Royal Fishponds are lower than in 1992, which might reflect the upgrade to the park's sewage system in 2000. It is likely that salinity has increased over the past four and a half decades, but recent trends were weak or not detectable. Oxygen levels were below Clean Water Act benchmarks nearly a quarter of the time. Whether or not this a concern depends on the tolerance of species inhabiting the ecosystem.

4.3.1.5 Threats and Stressors

Water quality in the anchialine pools is affected by hydrologic processes and anthropogenic activities adjacent to and upslope from these waterbodies. For example, groundwater recharge patterns, which are affected by climate and land use, affect water levels and salinities within the anchialine pools. Global sea level rise and island subsidence pose a threat insofar as these events can be expected to gradually increase pool salinity and eventually expose pools to the open ocean. As of yet the low level of development upslope of the park has limited the amount of saltwater intrusion, if any, caused by groundwater pumping. Future intensification of upslope development could alter recharge and pumping patterns and increase pollutant loadings. Pollutants could potentially be transported to anchialine pools via groundwater, depending on solubility and mobility.

Limited amounts of farming and scattered residences occur upslope of the park. Future agricultural and residential development upslope of the park has the potential to degrade the quality of groundwater that feeds the anchialine pools. Agriculture is a source of nutrients and pesticides. Residences can also be sources of agricultural nutrients and pesticides. Pesticides vary in their toxicity and mobility; mobility is determined by solubility, the susceptibility to adsorption[16], and soil properties. Residences rely on septic systems or cesspools. Effluent from these systems contains dissolved nutrients, oxygen-depleting organic matter, and pathogens. Effluent (and recharge from fertilized areas) trickles downwards and can contaminate groundwater. Some pollutants in effluent (phosphorus, pathogens) tend to adsorb to rocks or soil and may be removed, to some degree, from flowing groundwater, at least initially (Fetter 2001). Nitrate, on the other hand, is mobile and is a pollutant of concern in anchialine pools and marine waters.

Runoff from the highway and roadways within or adjacent to the park have the potential to transport nonpoint pollutants, including metals and hydrocarbons, into the park's groundwater and therefore into anchialine pools. Runoff from the visitor center parking lot is captured and filtered, reducing the potential for contamination. From time to time the park uses herbicides to manage vegetation (Hoover and Gold 2006). Owing to the shallow water table, it is possible that herbicides could be

[16] Adsorption is a process in which substances contained in a fluid adhere to solid surfaces, either for short or long periods of time

transported to anchialine pools; risks to the ecosystem depend on the mobility and toxicity of the herbicides used.

Sewage has the potential to affect water quality in groundwater, anchialine pools, and nearshore marine waters. Sewage from the park's main visitor facility is pumped uphill to a modern septic system that was updated in 2000. In the event that the septic system is overwhelmed or incapacitated, untreated waste is stored in an overflow tank immediately south of the visitor center bathrooms. The overflow tank is equipped with a safety valve to prevent leakage to the environment. The NPS is currently in the planning process for an upgraded onsite wastewater system that will enhance nutrient removal, with construction planned for 2023. A single flush toilet attached to a cesspool is located about 350 m (1150 feet) south of the Royal Fishponds. It is a remnant of a demolished building and is scheduled for eventual removal. To the immediate north of the park is a school with its own septic system. About a dozen private residences on the shore of Hōnaunau Bay rely on individual cesspools (Hoover and Gold 2006, Else 2006). The scattered residences upslope of the park rely on either septic systems or cesspools.

To date, problems with algal blooms are mostly confined to the Royal Fishponds. The possibility that blooms could occur in other pools should be considered a threat. Rising temperatures will decrease the oxygen-holding capacity of the water, exacerbating oxygen stress in eutrophic pools.

<u>4.3.1.6 Data Gaps and Research Recommendations</u>

Groundwater levels and groundwater nutrients have never been monitored. Pool sedimentation is not well characterized. Concentrations of pesticides in groundwater, anchialine pools, and sediments are unknown. The variations in dissolved oxygen over the diurnal cycle and with water depth are poorly characterized.

Species vary in their tolerance to variations in salinity, turbidity, oxygen, and presence of algae. It would be helpful to better understand how species of concern—and the ecosystem as a whole—respond to these variables.

4.3.2 Anchialine Pool Biota

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

Condition Summary

The condition of the anchialine pool biota at Puʻuhonua o Hōnaunau NHP warrants moderate concern, with some pools being relatively pristine and others inundated with invasive introduced fish. Even if efforts to remove tilapia and *Gambusia affinis* are successful, continual effort will be required to watch for new invasive fish and remove them as part of an integrated pest management program. Climate variability and groundwater pumping have the potential to alter the freshwater/saltwater composition of the pools, which could change key habitat characteristics including salinity and temperature. In addition, upslope development and local anthropogenic activities could contaminate groundwater that may affect the pools. With these potential threats, the conditions continue to be of moderate concern. This assessment is made with a high degree of confidence. Sufficient data were not available to assess a trend.

4.3.2.1 Description

The biota in anchialine pools consists of native crustaceans, neritid snails, and both damselflies and dragonflies. Native crustaceans include ʿōpae ʻula *Halocaridina rubra* and *Metabetaeus lohena.* Other invertebrate reference biota include pīpīwai (neritid snails) of the species *Theodoxus cariosus*, the native estuarine shrimp species *Macrobrachium grandimanus* (endemic) and *Palaemon debilis* (indigenous). Pinao (Odonata) species include the endemic dragonfly *Anax strenuus*; the endangered damselfly *Megalagrion xanthomelas;* and two indigenous dragonflies, the globe skimmer (*Pantala flavescens*) and the giant green darner (*Anax junius*; Polhemus and Asquith 1996, Englund 1999). Marine fish may wash into, or out of, the Royal Fishpond during high surf events. Anchialine pool communities may be affected by changes in water quality (such as temperature and salinity) with climate variability and sea level rise and groundwater withdrawal, and to invasion by nonnative plants, fish, and invertebrates.

4.3.2.2 Indicators, Data and Methods

Anchialine pools were assessed based on their community composition (presence/absence data) and in some studies, the relative abundance of both native and introduced species.

Three sources were utilized for this assessment; the NPS PACN Database 2008–2011 (PACN 2015a), Tango et al. (2012), and Seidel et al. (2016) were used to ascertain current conditions of the biota in anchialine pools at Puʻuhonua o Hōnaunau NHP. Data from the PACN database 2008–2011 (2015) and Seidel et al. (2016) were collected using the same protocol (Brasher et al. 2015). Both studies used minnow traps to determine presence and absence data for fishes and smaller traps to collect shrimp. Fish traps were baited (cat treats) and five traps were placed haphazardly in each pool for 30 minutes. Species of fish observed during the survey were noted as present, even if they were not caught in the fish traps. Shrimp traps designed to be comparable to those used by the State Division of Aquatic Resources were baited (cat treats) and five traps were placed in each pool haphazardly for 15 minutes. Native species were placed back into pools unharmed after surveys; introduced species were sacrificed (Seidel et al. 2016). Visual odonate surveys were conducted for three minutes during each survey. The total number of individuals observed by species was recorded.

Native snails (pīpīwai) were counted and measured along transects concurrent with the collection of water depth, substrate size and detritus data. Other species visually observed (i.e., thiarid snails and crabs) were recorded as present or absent during surveys.

Seidel et al. (2016) studied six anchialine pools at Puʻuhonua o Hōnaunau NHP from May to September 2014. Each pool was surveyed five times during the daytime and three times at night (Seidel et al. 2016). PACN surveys were conducted during the daytime and the number of surveys completed varied by year from 2008 – 2011 (PACN 2015a). Two surveys were conducted in 2008, five surveys in 2010, and six surveys in 2011. Number of pools and the specific pools selected varied among their surveys (PACN 2015a).

Tango et al. (2012) surveyed eight anchialine pools at Puʻuhonua o Hōnaunau NHP using different types of traps specific to the organisms they were interested in for species presence and absence information. Pitfall traps for orthoptera were placed overnight in four different zones (splash zone, strand vegetation, poolside habitat, and an ʻaʻā lava field). Pan traps were used to observe diptera presence or absence in pools (Tango et al. 2012). Plankton surveys were conducted by collecting water and pouring it through a plankton net (Tango et al. 2012). Visual surveys were conducted for odonates and mollusks.

Presence and absence data of certain species that Maciolek and Brock (1974) suggested to be representative species of anchialine pools are used as the historical reference conditions for anchialine pools located along the entire Kona coast, including those in Puʻuhonua o Hōnaunau NHP. Maciolek and Brock (1974) conducted an aquatic inventory of anchialine pools along the Kona Coast in 1973. This initial survey included 304 pools having either a surface connection or no surface connection to the ocean. They covered approximately 160 km (100 mi) 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. Maciolek and Brock did not include the 14 pools located at Puʻuhonua o Hōnaunau NHP in their survey; however, the reference condition species should generally be the same for pools across the entire Kona coast. A study conducted by Oceanic Institute (1992) provides one of the earliest documented surveys of the Royal Fishpond.

4.3.2.3 Reference Condition

The reference condition for biota in anchialine pools is the presence of biotic communities comprised of native crustaceans, neritid snails, damselflies and dragonflies, the native plant *Ruppia maritima*, and native estuarine fish. These taxa were chosen based on several past studies, however none have comprehensively recorded all taxa. Maciolek and Brock (1974) report presence of odonates (dragonflies and damselflies), but they are grouped with other insects and include a "tally of Odonata, Hemiptera, and other orders" in 53 ponds (17% of all ponds surveyed), hence Table 4.3.2-1 lists reference condition biota, except odonates. Even among so-called pristine anchialine pools, the composition of native species is expected to vary under the influence of a number of factors, including location relative to the shoreline, surrounding vegetation, and successional stage. Of special interest (because they commonly occur at Puʻuhonua o Hōnaunau NHP but are often absent from many pools along the Kona coast) are the native crustaceans or ʻōpae ʻula *Halocaridina rubra* and *Metabetaeus lohena.* Other invertebrate reference biota include the neritid snail pīpīwai, *Theodoxus cariosus* (endemic), the native estuarine shrimp species ʻōpae ʻoeahaʻa *Macrobrachium grandimanus* (endemic) and ʻōpae huna *Palaemon debilis* (indigenous). Pinao (Odonata) species include the endemic dragonfly *Anax strenuus*; the endangered damselfly *Megalagrion xanthomelas;* and two indigenous dragonflies, the globe skimmer (*Pantala flavescens*) and the giant green darner (*Anax junius*; Polhemus & Asquith 1996, Englund 1999). The historic biota of the Royal Fishpond reported by Oceanic Institute (1992) is summarized in Table 4.3.2-2.

Table 4.3.2-1. Reference condition species of anchialine pools. Data from Maciolek and Brock's (1974) initial inventory along the Kona Coast, Hawaiʻi Island (n = 291).

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

Table 4.3.2-2. Historic species reported for the Royal Fishpond located at Puʻuhonua o Hōnaunau NHP (HA_HONAUNAU_002), reported by Oceanic Institute in 1992. A=abundant, S=several, F=few or one.

Category	Taxa	Presence
Fish	*Gambusia affinis*	A
	Kuhlia sandvicensis	F
	Mugil cephalus	F
	Tilapia	A
Snails	Thiaridae (*Thiara granifera*)	A
	Theodoxus cariosus (Neritidae)	S
Crustaceans	*Halocaridina rubra*	–
	Metabetaeus lohena	–
	Palaemon debilis	–
	Metopograpsus thukuhar (crab)	S

4.3.2.4 Current Condition and Trend

Species data collected from nine of the 14 pools located at Puʻuhonua o Hōnaunau NHP in the years 2008–2011 (PACN 2015a; Tango et al. 2012), and 2014 (Seidel et al. 2016) show that anchialine pools at Puʻuhonua o Hōnaunau NHP do contain the majority of the reference condition species (Table 4.3.2-3 and 4.3.2-4). These data sources are summarized to describe current condition; data are insufficient to determine a trend. The most common species was *H. rubra*, observed in seven anchialine pools. Two other native shrimp species, *M. lohena* and *Palaemon debilis*, were less common, being observed in five and two pools, respectively. The native snail pīpīwai *T. cariosus* was observed in three pools. The native estuarine fish āholehole *Kuhlia sandvicensis* was observed in two pools. The native plant *Ruppia maritima* and the native fish ‘o‘opu ‘akupa *Eleotris sandwicensis* were not observed in any of the pools surveyed at Pu‘uhonua o Hōnaunau NHP. Pan-tropical thiarid snails were also observed in six pools.

Several additional native species were also observed in the park during recent surveys. Eight native fish species were observed in the south Royal Fishpond (HA_HONAUN_003) (Table 4.3.2-3) and eight odonate species were observed throughout the park, five of which are native. The endangered native damselfly, *M. xanthomelas*, was observed near two pools. Both introduced tilapia and the introduced poeciliid mosquito fish (*Gambusia affinis*) were observed in three pools: south Royal Fishpond (HA_HONAUN_003), Makaloa Pond (HA_HONAUN_004) (Table 4.3.2-3), and the north Royal Fishpond (HA_HONAUN_002) (Table 4.3.2-4).

Recent surveys (Table 4.3.2-4) of the Royal Fishponds and other pools within the park show similar results to those of the 1992 Oceanic Institute study. Tango et al. (2012) conducted comprehensive invertebrate surveys in pools at Pu‘uhonua o Hōnaunau NHP, however their survey grouped a number of pools as “complexes” for reporting purposes, so it was not always possible to discern from their data results specific to the Royal Fishponds. In addition, two species of Orthoptera, 14 species of Diptera, nine taxa of plankton, 12 species of water-associated ants and 11 other taxa were observed or trapped from throughout both pool complexes (Tango et al. 2012).

Table 4.3.2-3. Native and nonnative species reported for selected anchialine pools located at Puʻuhonua o Hōnaunau NHP in the PACN (2015) Database (2008–2011 data), Tango et al. 2012[1], and Seidel et al. 2016 (data collected in 2014). An "X" indicates that the species was reported and an en-dash (–) indicates that it was not.

Category	Species	HA_HONAUN_003 (S. Royal Fishpond)			HA_HONAUN_004 (Makaloa pond)			HA_HONAUN_005 (near Kaʻahumanu Stone)			HA_HONAUN_007 (near Hale o Papa)			HA_KEOKEA_001 (spring in Wainoni)		
		2008–2011	2012	2014	2008 – 2011	2012	2014	2008–2011	2012	2014	2008–2011	2012	2014	2008–2011	2012	2014
Fish[2]	*Acanthurus triostegus*	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Abudefduf sordidus	–	–	X	–	–	–	–	–	–	–	–	–	–	–	–
	Chaetodon lunula	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Diodon hystrix	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Gambusia affinis [3]	–	X	X	–	X	X	–	–	–	–	–	–	–	–	–
	Gobiidae	X	–	X	X	–	–	–	–	–	–	–	–	–	–	–
	Kuhlia sandvicensis	X	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Kuhlia sp.	X	–	–	X	–	–	–	–	–	–	–	–	–	–	–
	Mugil cephalus	–	–	–	X	–	–	–	–	–	–	–	–	–	–	–
	Sphyraena sp.	X	–	X	–	–	–	–	–	–	–	–	–	–	–	–
	Tilapia [3]	X	X	X	X	X	X	–	–	–	–	–	–	–	–	–
	unknown fish	X	–	–	X	–	–	–	–	–	–	–	–	–	–	–
Snails	Thiaridae [4]	X	X	X	X	X	X	X	–	–	X	X	X	–	–	–
	Neritidae	X	X	X	X	X	X	–	–	–	–	–	–	–	–	–
	Crustaceans	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Halocaridina rubra	–	–	–	–	–	–	X	X	X	X	X	X	X	–	–
	Metabetaeus lohena	–	–	–	–	–	–	–	X	X	X	X	X	–	–	–
	Palaemon debilis	–	–	–	X	–	–	–	–	–	–	–	–	–	–	–

[1] Tango et al. 2012 generally presented their data grouped into two complexes: "Royal Fishpond complex" (seven pools) and "Waikulu Springs complex" (two pools). The study focused on invertebrates; observations of native fish were not recorded.

[2] Some marine fish species listed here include those that were transported into the pools during the 2011 tsunami and/or during high surf storm events.

[3] nonnative

[4] pan-tropical

Table 4.3.2-3 (continued). Native and nonnative species reported for selected anchialine pools located at Puʻuhonua o Hōnaunau NHP in the PACN (2015) Database (2008–2011 data), Tango et al. 2012[1], and Seidel et al. 2016 (data collected in 2014). An "X" indicates that the species was reported and an en-dash (–) indicates that it was not.

		HA_HONAUN_003 (S. Royal Fishpond)			HA_HONAUN_004 (Makaloa pond)			HA_HONAUN_005 (near Kaʻahumanu Stone)			HA_HONAUN_007 (near Hale o Papa)			HA_KEOKEA_001 (spring in Wainoni)		
Category	**Species**	**2008 – 2011**	**2012**	**2014**	**2008 – 2011**	**2012**	**2014**	**2008 – 2011**	**2012**	**2014**	**2008 – 2011**	**2012**	**2014**	**2008 – 2011**	**2012**	**2014**
Snails (continued)	unknown crab	X	–	X	X	–	X	–	–	–	–	–	–	–	–	–
	Odonates	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Anax junius	X	–	X	X	X	X	–	–	–	X	–	–	–	–	–
	Anax strenuus	–	–	–	–	–	–	–	–	–	X	–	–	–	–	–
	Ischnura posita [3]	–	–	–	X	–	–	–	–	–	–	–	–	–	–	–
	Ischnura ramburii [3]	X	–	X	X	X	X	–	–	–	X	–	–	–	–	–
	Megalagrion xanthomelas	–	–	–	–	X	–	–	–	–	–	–	–	–	–	–
	Megalagrion sp.	–	–	–	–	–	–	–	X	–	–	–	–	–	–	–
	Pantala flavescens	X	–	X	–	–	X	–	–	–	X	–	X	–	–	–
	Orthemis ferruginea [3]	–	–	–	X	–	–	–	–	–	–	–	–	–	–	–

[1] Tango et al. 2012 generally presented their data grouped into two complexes: "Royal Fishpond complex" (seven pools) and "Waikulu Springs complex" (two pools). The study focused on invertebrates; observations of native fish were not recorded.

[2] Some marine fish species listed here include those that were transported into the pools during the 2011 tsunami and/or during high surf storm events.

[3] nonnative

[4] pan-tropical

Table 4.3.2-4. Native and nonnative species reported for selected anchialine pools located at Puʻuhonua o Hōnaunau NHP in the PACN (2015) Database (2008–2011 data), Tango et al. 2012[1], and Seidel et al. 2016 (data collected in 2014). No fish were recorded in these pools. An "X" indicates that the species was reported and an en-dash (–) indicates that it was not.

Category	Species	HA_KEOKEA_002 (Near "Pohakuloa")			HA_KEOKEA_003 (Waikulu spring)			HA_KEOKEA_004 ("water hole")			HA_KIIALAE_001 (Wai-kuʻi-o-Kekela)		
		2008 – 2011	2012	2014	2008 – 2011	2012	2014	2008 – 2011	2012	2014	2008 – 2011	2012	2014
Snails	*Thiaridae* [3]	–	–	–	X	–	X	–	X	X	–	–	–
	Neritidae	–	–	–	–	–	–	–	–	–	–	–	–
Crustaceans	*Halocaridina rubra*	X	–	–	X	X	X	–	–	X	X	–	–
	Macrobrachium lar [2]	–	–	–	–	–	–	–	–	–	X	–	–
	Metabetaeus lohena	–	–	–	X	X	X	–	X	X	X	–	–
	Palaemon debilis	–	–	–	–	–	–	–	–	–	X	–	–
Odonates	*Anax junius*	–	–	–	X	–	–	–	–	–	–	–	–
	Ischnura posita [2]	–	–	–	–	–	–	–	–	–	–	–	–
	Ischnura ramburii [2]	–	–	–	X	–	–	–	–	–	–	–	–
	Megalagrion xanthomelas	–	–	–	–	–	–	–	X	–	–	–	–
	Megalagrion sp.	–	–	–	X	–	–	–	X	–	–	–	–
	Pantala flavescens	–	–	–	–	–	–	–	–	X	–	–	–
	Orthemis ferruginea [2]	–	–	–	–	–	–	–	–	–	–	–	–

[1] Tango et al. 2012 generally presented their data grouped into two complexes: "Royal Fishpond complex" (seven pools) and "Waikulu Springs complex" (two pools). The study focused on invertebrates; observations of native fish were not recorded.

[2] nonnative

[3] pan-tropical

4.3.2.5 Threats and Stressors

Predation and competition for resources by introduced species (Tables 4.3.2-5 and 4.3.2-6) pose serious threats to native biota in anchialine pools (Havird et al. 2013). Maciolek and Brock (1974) estimated that about 15% of the pools along the Kona coast contained introduced species. By 1985 almost 50% of these pools contained introduced species (Yamamoto and Tagawa 2000). In 2000 more than 95% of anchialine pools along the Kona coast of Hawaiʻi Island contained introduced species (Yamamoto and Tagawa 2000). A recent survey by Marrack et al. (2015) of 398 anchialine pools along the Ala Kahakai National Historical Trail (which includes Puʻuhonua o Hōnaunau NHP) in 2012 and 2013, including 68 pools surveyed by the National Park Service Inventory and Monitoring Program from 2007 to 2009, showed 25% of those pools to contain introduced fishes (tilapia and poeciliids). A study conducted by Oceanic Institute (1992) provides one of the earliest documented surveys of the Royal Fishpond. At that time, they reported the introduced invasive fishes, tilapia (which they identified as *Oreochromis mossambicus*) and mosquito fish (*Gambusia affinis*), to be abundant.

Table 4.3.2-5. Native and nonnative species reported for the north Royal Fishpond located at Puʻuhonua o Hōnaunau NHP are summarized from PACN (2015), 2008 – 2011 data, Seidel et al. 2016 (data collected in 2014), and Tango et al. 2012[1]. An "X" indicates that the species was reported and an en-dash (–) indicates that it was not.

Category	Species	HA_HONAUN_002 (north Royal Fishpond) 2008 – 2011	2012[1]	2014
Fish [2]	*Abudefduf abdominalis*	X	–	X
	Abudefduf sordidus	–	–	X
	Acanthurus triostegus	X	–	X
	Gambusia affinis [3]	–	X	X
	Gobiidae	X	–	X
	Kuhlia sandvicensis	–	–	X
	Kuhlia sp.	X	–	–
	Mugil cephalus	X	–	X
	Thalassoma duperrey	X	–	–
	Tilapia [3]	X	X	X
	unknown wrasse	X	–	–
Snails	Thiaridae [4]	X	X	X
	Neritidae	–	X	X

[1] The 2012 data presented represent seven pools grouped as the "Royal Fishpond complex;" the study focused on invertebrates; observations of native fish were not recorded (Tango et al. 2012).

[2] Some marine fish species listed here include those that were transported into the pools during the 2011 tsunami and/or during high surf storm events.

[3] nonnative

[4] pan-tropical

Table 4.3.2-5 (continued). Native and nonnative species reported for the north Royal Fishpond located at Puʻuhonua o Hōnaunau NHP are summarized from PACN (2015), 2008 – 2011 data, Seidel et al. 2016 (data collected in 2014), and Tango et al. 2012[1]. An “X” indicates that the species was reported and an en-dash (–) indicates that it was not.

Category	Species	HA_HONAUN_002 (north Royal Fishpond)		
		2008 – 2011	**2012[1]**	**2014**
Crustaceans	*Halocaridina rubra*	–	–	–
	Metabetaeus lohena	–	–	–
	Palaemon debilis	–	–	–
	unknown crab	X	–	–
Odonates	*Anax junius*	X	X	X
	Ischnura posita [3]	–	–	X
	Ischnura ramburii [3]	X	X	–
	Pantala flavescens	–	X	X

[1] The 2012 data presented represent seven pools grouped as the “Royal Fishpond complex;” the study focused on invertebrates; observations of native fish were not recorded (Tango et al. 2012).

[2] Some marine fish species listed here include those that were transported into the pools during the 2011 tsunami and/or during high surf storm events.

[3] nonnative

[4] pan-tropical

Table 4.3.2-6. Introduced species which pose serious threats to native biota in anchialine pools on Hawaiʻi Island.

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 and fragile environment (Eldredge 2000, Carey et al. 2011, Marrack et al. 2015, Nico et al. 2015, Seidel et al. 2016). For example, when introduced fish are present, native shrimp species display a diel migration behavior to avoid predation, in which they hide during the day but are active at night, which can alter their grazing rates. Studies have shown that in pools without introduced fishes, native shrimp species are active both day and night (Capps et al. 2009, Carey et al. 2011, Havird et al. 2013, Seidel et al. 2016). Interestingly, the introduced prawn, which is nocturnal, influences migration in the opposite direction with ‘ōpae becoming less active during the night when *M. lar* is present (Troy Sakihara, Hawai‘i DAR, personal communication, 2018). Tilapia alter pool habitats by digging pits for brooding and covering rocks under a thick layer of excrement. This layer hinders algal growth, which is a vital food resource for many native species (Seidel et al. 2016). High silt cover may also block access to subterranean passages and restrict movement of shrimp (Marrack et al. 2015).

Introduced tilapia are also responsible for the loss of *Ruppia maritima* (Wigeongrass) over much of its range in Hawai‘i (Smith and Peyton 2006). *R. maritima* is one of the very few brackish-water flowering plant species native to Hawai‘i, and alone among the flowering plants tolerant of high salinity waters (Kantrud 1991). As such, loss of this species has rippling effects throughout anchialine pool communities. *R. maritima* provides habitat for native insects, crustaceans, snails, and small fishes. Native damselflies have been observed laying eggs in mats of it. Native wetland birds, such as ‘alae ke‘oke‘o or Hawaiian coot (*Fulica alai*) build nesting material out of *R. maritima*.

Habitat conditions of anchialine pools may also change with predicted sea level rise due to climate change, resulting in increased salinity and temperature. In addition, upslope development may potentially increase transport of contaminants to the pools as well as decrease fresh water inputs with increased groundwater pumping (Marrack and O´Grady 2014). Although adult *Halocaridina rubra* and *Metabetaeus lohena* are able to withstand a large range of salinity, it is unknown if all life-cycle stages of native biota will be able to adapt to these changes (Tango 2010, Marrack et al. 2015).

4.3.2.6 Data Gaps and Research Recommendations

With the exception of the 1992 data for the Royal Fishpond, data for biota in anchialine pools at Pu‘uhonua o Hōnaunau NHP are only available for recent years and not before 2008. Furthermore, some anchialine pools have been surveyed only once or twice (HA_KEOKEA_001, HA_KEOKEA_002, HA_KIIALAE_001) by the NPS I&M program. Thus, trend analysis is not yet possible. A long-term biological monitoring protocol is in development by the I&M program for the anchialine pools in Pu‘uhonua o Hōnaunau NHP. This is particularly important for *M. xanthomelas* as it is listed as endangered under the Endangered Species Act and the IUCN Red List (Polhemus and Asquith 1996, Russ et al. 2010, Tango et al. 2012).

Additional information is needed on life history characteristics and habitat preferences of native crustaceans and snails, and additional study on impacts of invasive introduced fish on native biota would be valuable for management decision-making. Competition, predation, and alteration of food web structure are all potential impacts, which should be evaluated. In addition, it would be important to assess the response of the native biota to the removal of invasive fish. Also, it is unclear whether ‘ōpae ‘ula can coexist with marine fishes in these anchialine pools. At present, marine fish may wash into and out of the Royal Fishpond during high surf events. Depending upon the park management strategy, marine fish may be placed in the pond to replicate Native Hawaiian cultural practices. Because the marine fish may act as top predators; before and following placing marine fish in the pond to restore it as a functioning fishpond, food web structure of the pond should be documented. In addition, an evaluation of how physical and chemical characteristics of individual pools influence the biotic composition of pools would inform restoration efforts.

4.4 Marine Ecosystem Integrity

View of the ocean at ʻĪlio Point, so named for the underwater dog-shaped rock formation shown above, 2005 (NPS photo).

Puʻuhonua o Hōnaunau National Historical Park does not include marine boundaries, however it is adjacent to well-developed coral reefs in Hōnaunau Bay to the north and Alahaka and Kiʻilae Bays to the south. 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 within the watershed, ahupuaʻa, district (moku), and island. The natural resources in the marine waters adjacent to Puʻuhonua o Hōnaunau NHP affect the visitor experience and are integral to the cultural resources preserved within the park. Because Puʻuhonua o Hōnaunau NHP does not have a marine boundary, we followed Beets et al. (2010) in using an assessment polygon to include all marine areas within a 0.5 mi (0.8 km) buffer around the boundary of the park. The assessment of marine natural resources surrounding Puʻuhonua o Hōnaunau NHP examines water quality and two ecological communities that continue to play significant roles in Hawaiian economic and cultural practices as well as providing important ecosystem services: benthic invertebrates and nearshore marine fishes.

4.4.1 Marine Water Quality

By Jené Michaud, University of Hawai'i at Hilo

Condition Summary

Marine water quality merits moderate concern due to high turbidity; there was a deteriorating trend between 2006 and 2015. Confidence in this assessment is medium. There were insufficient data available to determine the current condition or trend in nutrient levels. During 2006–2015 waters were well-oxygenated. Repeated measurements (since approximately 2010) of indicator bacteria suggest that sewage contamination, if present, does not occur frequently or is within limits set by the Clean Water Act for swimmer safety.

4.4.1.1 Description

The west-facing coastline of Pu'uhonua o Hōnaunau National Historical Park is subjected to waves from the open ocean. The north-facing coastline opens onto Hōnaunau Bay, which has calm water, a tiny shoreline community, and is popular for ocean recreation. The Hawai'i Department of Health (HDOH), which administers the Clean Water Act (CWA), has designated marine waters adjacent to the park as Class AA. Class AA marine waters are protected with the goal of remaining "in their natural pristine state as nearly as possible with an absolute minimum of pollution or alteration of water quality from any human-caused source or actions" (Hawai'i Administrative Rules § 11-54.).

4.4.1.2 Indicators, Data and Methods

Water quality indicators for marine waters adjacent to the park are nitrogen and phosphorus nutrients, turbidity, chlorophyll in the water column, and dissolved oxygen (DO). These indicators address the cause (excess nutrients), result (algal blooms can increase chlorophyll), and impact (low DO) of eutrophication, which is an ecological threat in fresh, brackish, and marine waters in Hawai'i and around the world (Ferreira et al. 2011). High turbidity is stressful to most marine organisms and is the most common cause of CWA impairment of Hawaiian marine waters (HDOH 2014). High turbidity can result from algal blooms in the water column, suspended sediments, or other uncommon chemical and biological events.

Counts of fecal indicator bacteria are relevant to swimmer safety and may result from sewage contamination or from naturally-occurring soil bacteria (Byappanahalli et al. 2012). While bacteria were not selected as an indicator for this NRCA, the results of bacterial measurements were nevertheless reviewed. Measurements of indicator bacteria (*Enterococci)*, turbidity, and oxygen were made by the HDOH as part of its CWA monitoring program. CWA monitoring is conducted for the purpose of assessing which locations should be placed on the 303(d) list of impaired water bodies. In 2006 and 2010 to the time of writing the HDOH made monthly to bimonthly measurements at the Hōnaunau Two-step Station (HI246644), which is about 150 m (492 feet) north of the park. In 2006, measurements were also made at the Hōnaunau Boat Ramp Station (HI246645), which is immediately adjacent to the Two-step Station. The HDOH protocol is to take multiple measurements along a transect that begins at the shoreline and extends outwards; published data are the geometric means of these multiple measurements.

Measurements of water quality indicators were compiled through a search of NPS, federal, and HDOH databases and publications. The search found no recent Federal or NPS data, however. Publications that describe and summarize historic data (NPS 1999b, Hoover and Gold 2006) were also consulted. The data search located the following:

- CWA 303(d) lists of impaired waters (HDOH 2006, 2010, 2012, 2014)[17].
- DO and turbidity data from CWA monitoring. Data were obtained from federal water quality database, which are also available from the HDOH Clean Water Branch website. Data from 2016 were excluded as only a partial year was available at the time of analysis.
- Turbidity and nutrient data collected during 1973–1977 in Keone‘ele Cove. These data, which were likely collected by the HDOH, are reviewed in NPS (1999b) and Hoover and Gold (2006). The turbidity data was used for trend analysis; nutrient data was not reviewed for this NRCA because of its age and the fact that there is no recent data with which to compare it.

4.4.1.3 Reference Condition

Under the CWA, the marine waters adjacent to Pu‘uhonua o Hōnaunau NHP are subject to water quality standards described in Chapter 11-54 of the Hawai‘i Administrative Rules. Numerical standards for "Kona" waters are the reference condition for the park's marine waters.

4.4.1.4 Current Condition and Trend

The CWA 303(d) reports focus on bacteria, nutrients and turbidity. Water quality at any given site is designated as meeting standards, not meeting standards, or unknown (insufficient data). The 2006 and combined 2008/2010 reports state that water quality at Hōnaunau stations is unknown (insufficient data to evaluate whether standards are met). Starting with the 2012 report, data are available to assess conditions at Hōnaunau Two-step Station (HI246644)[18]. In the 2012 report, bacteria levels met water quality standards; turbidity and nutrients were not measured. The 2014 report listed Hōnaunau as impaired for turbidity; bacteria met water quality standards and nutrients were not measured. Hōnaunau Two-step Station is still listed for turbidity[19]. Hōnaunau Bay station HIW00176 (precise location unknown) remains on the CWA 303(d) list even though there has been only one measurement since 2005; data are not sufficient to determine if it should be delisted.

In the spring of 2004, the HDOH issued a warning to Hōnaunau Bay swimmers because of high levels of indicator bacteria (Else 2006). It is not known whether these bacteria originated from sewage or from soil.

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[17] The 303(d) lists are normally published every-other year but the 2008 publication was folded into the 2010 publication.

[18] The applicable water quality standards (geometric means) are 0.1 NTU for turbidity and 130 cfu/100 ml for bacteria.

[19] 2014 was the latest report available at the time this NRCA was written. The 2016 and 2018 report were available at the time this NRCA went to press; there were no changes to listings between 2014 and 2018.

Table 4.4.1-1 summarizes turbidity and dissolved oxygen (DO) measurements taken near the Hōnaunau Bay shoreline. DO was measured near the water surface; results indicated consistently well-oxygenated conditions; no measurement was below the reference value. Turbidity was high, with all measurements (including those from the 1970s) above the reference value. Turbidity tripled between 2006 (0.32 ± 0.09 NTU) and 2015 (1.05 ± 0.09 NTU); the increase was gradual and statistically significant. There was no statistical difference between 2006 turbidity at the rocky "two-step" site and 1970s turbidity in the very shallow waters of Keoneʻele Cove. From 2009 onward operators made comments regarding whether conditions during the measurement were calm, low surf, or high surf. Statistically, turbidity did not vary between calm conditions and surf conditions.

Crushed coral originating from outside the park has been used to repair the 1871 coastal trail. High surf has been known to erode the crushed coral and transport it to the ocean, creating sediment pollution (Else 2006).

Table 4.4.1-1. Turbidity and dissolved oxygen measured near the Hōnaunau Bay shoreline as part of CWA monitoring. Data were obtained from the STORET database (https://www.waterqualitydata.us/) and NPS (1999b). Keoneʻele Cove is along the northern shoreline of the park; data were collected in one foot of water. The other two stations are 130–150 m (430–490 ft) north of the park along a rocky shoreline.

Station name	Date	Dissolved oxygen (DO) (% saturation)	Turbidity (NTU)	Number of samples
Keoneʻele Cove	1973–1977	–	**0.43 ± 0.28** (1) Range 0.05–1.2	17
Hōnaunau Two Step	2006	**93.5 ± 4.5** (1) (all values > 75)	**0.32 ± 0.09** (1) Range 0.23 – 0.47	8 (DO) 6 (turbidity)
Hōnaunau Two Step	2010–2015 + Nov 2009	**100.3 ± 5.1** (1) (all values > 75)	**1.07 ± 0.35** (1) Range 0.42–2.04	56 (DO) 56 (turbidity)
Hōnaunau Boat Ramp	1996	**97.2 ± 1.8** (1) (all values > 75)	**1.8 ± 0.7** (1) Range 0.71–2.54	10 (DO) 8 (turbidity)
Reference value	–	≥ 75	0.1	–

[1] Mean ± standard deviation (also in bold).

4.4.1.5 Threats and Stressors

A small boat launch, picnic area, and popular snorkeling/dive site are only 130–150 m (430–490 ft) north of the park. Recreational users are potential sources of trash. Anyone entering the water (snorkelers, divers, swimmers) is a potential source of contamination because anything on their skin (sunscreen, cosmetics, deodorant) washes off into the water. Boating activities associated with the boat launch, and the many boats that bring snorkelers and divers to Hōnaunau Bay, are potential sources of metals, hydrocarbons, marine debris, discards from fish cleaning, as well as contaminated gear used in other water bodies.

The small shoreline community immediately north of the park disposes of wastewater using a dozen or so residential cesspools; there is also a school that uses a modern septic system (Hoover and Gold 2006, Else 2006). Portable toilets service recreational visitors. Cesspool waste is expected to percolate into groundwater that is flowing towards the ocean, creating the potential for low-volume contamination of Hōnaunau Bay. However as noted above, repeated bacterial testing suggests that contamination is not generally at a level that would impair human health. Sewage from the Park's Visitor center is not expected to pose a threat because effluent is pumped uphill to modern septic system located 350 m (1100 ft) from the ocean.

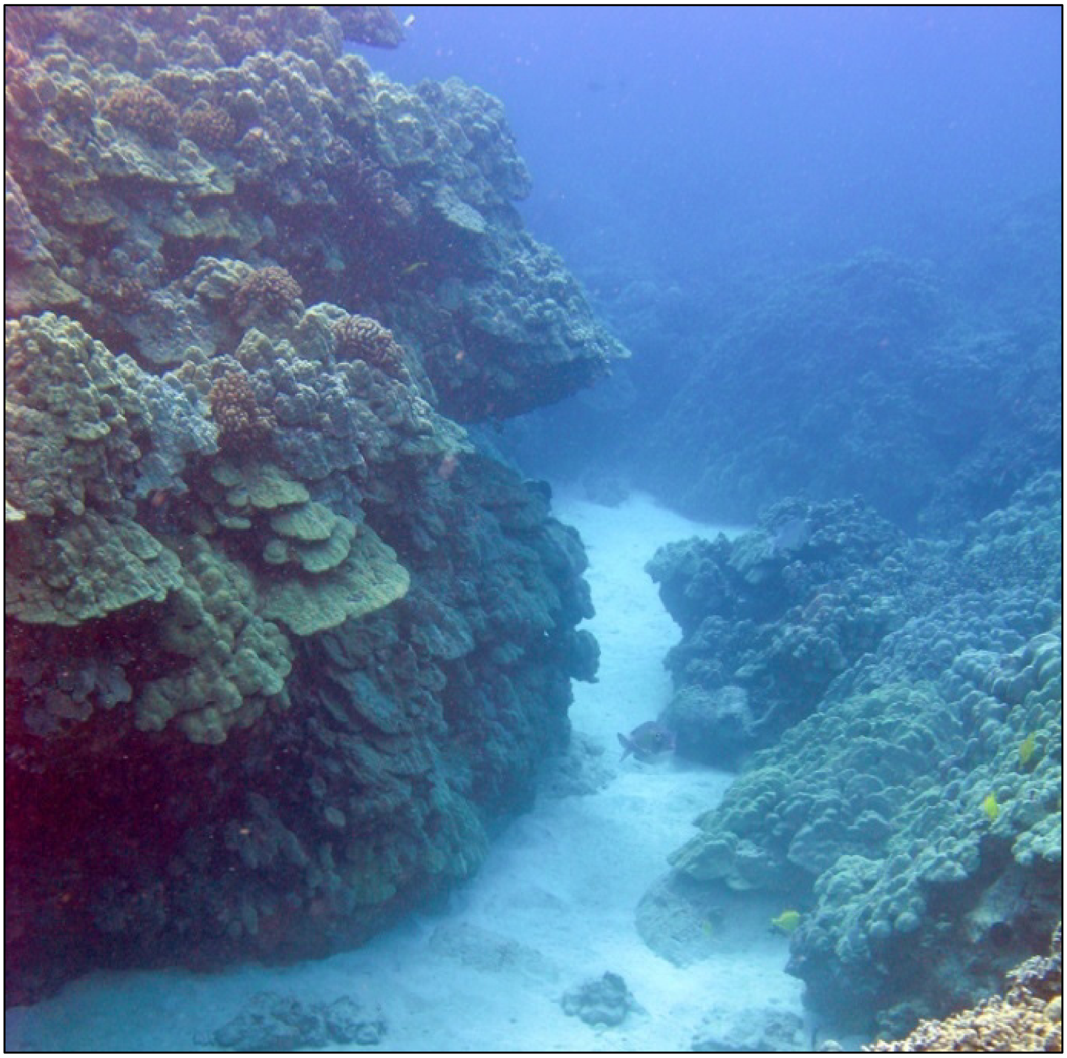
Runoff from the highway and roadways within or adjacent to the park has the potential to transport nonpoint pollutants, including metals and hydrocarbons, into the park's groundwater and into marine waters fronting the park. Runoff from the visitor center parking lot is captured and filtered, reducing the potential for contamination. From time to time the park uses herbicides to manage vegetation (Hoover and Gold 2006). Owing to the shallow water table, it is possible that herbicides could be transported to the ocean via groundwater, but the potential for this occurrence depends on the mobility of the herbicides used. Currently, there is a low level of development upslope of the park. Intensified upslope development would be expected to increase loadings of nutrients, pesticides, and pathogens (Hoover and Gold 2006). Some of these pollutants are mobile and might be transported to the ocean via groundwater. Increased development would also lead to intensified use of the recreational facilities at Hōnaunau Bay.

4.4.1.6 Data Gaps and Research Recommendations

Nutrient concentrations have not been measured in Hōnaunau Bay for forty years. This lack of data is especially unfortunate given the high turbidity levels. Runoff and submarine groundwater discharge have been recognized as influencing waters off of Pu‘uhonua o Hōnaunau NHP (Cochran et al. 2007). Measurements of nutrients and chlorophyll are therefore a high priority.

4.4.2 Benthic Invertebrates

By Megan J. Donahue, University of Hawai'i at Mānoa and Megan Ross, University of Hawai'i, West O'ahu



Yellow lobe coral (*Porites lobata*) dominated shallow reef area at Honaunau Bay, 2008 (DAR Photo, L. Kramer).

Condition Summary

This condition assessment was initiated in 2014, before the 2014–2017 worldwide bleaching event (Skirving et al. 2019) resulted in extensive coral bleaching and subsequent mortality in the West Hawai'i 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 off Pu'uhonua o Hōnaunau National Historical Park (NHP) was comparable to surrounding reefs in the West Hawai'i region. Coral and crustose coralline algae (CCA) were more abundant in these waters than most of the West Hawai'i region, and there was no indication of high disease prevalence. However, the lack of long-term data in marine areas adjacent to Puʻuhonua o Hōnaunau NHP, particularly data during and after the 2015 bleaching event, precludes an assessment of trends, bleaching impacts, or resilience. During the 2015 bleaching event, 38–92% of all coral colonies were bleached at sites across West Hawaiʻi (Maynard et al. 2016), indicating that bleaching impacts were likely within the marine areas surrounding Puʻuhonua o Hōnaunau NHP.

4.4.2.1 Description

Hōnaunau Bay is a popular dive and snorkel site with a boat ramp that allows easy access by motorized boats and kayaks. The central portion of Puʻuhonua o Hōnaunau NHP is adjacent to a rocky intertidal habitat stretching from Puʻuhonua Point in the north to Alahaka Bay in the south. Below the tide line, the area adjacent to Puʻuhonua o Hōnaunau NHP has been characterized as consisting of volcanic pavement and boulder habitat which gives way to aggregate reef sloping steeply to deeper areas of unconsolidated sand and coral rubble (Cochran et al. 2007). Coral cover decreases beyond 15 m (49 ft), as the benthic habitat shifts from hard-bottom to unconsolidated substrate (Rodgers et al. 2004b). In 2005, the reefs off of Puʻuhonua o Hōnaunau NHP were described as “impressive coral communities” dominated by corals, coralline algae, and turf algae (Beets et al. 2010), but in 2015, West Hawaiʻi experienced a severe thermal stress event that resulted in bleaching of >60% of coral colonies. It is important to note that the marine area adjacent to Puʻuhonua o Hōnaunau NHP is not within the designated Park boundaries.

4.4.2.2 Indicators, Data, and Methods

Boundaries of the marine assessment area adjacent to the park and the West Hawaiʻi reference region

The designated boundary of Puʻuhonua o Hōnaunau NHP does not include adjacent marine habitat; therefore, following Beets et al. (2010), we defined the marine assessment area as the nearshore region within a 0.8 km (0.5 mi) buffer around the boundary of the park (Figure 4.4.2-1). Conditions in the Puʻuhonua o Hōnaunau NHP marine assessment area were compared to conditions in the West Hawaiʻi reference region, which extends from ʻUpolu Point (N 20.2°, W 156.8°) to South Point (N 18.9°, W 155.7°).

Indicators

It is critical to note that the period covered by this assessment ends prior to the 2015 bleaching event that significantly impacted the West Hawaiʻi reference region and should be considered a pre-bleaching baseline.

For coral reef communities in the marine waters adjacent to the boundary of Puʻuhonua o Hōnaunau NHP, we considered three indicators of condition: (i) benthic percent cover of coral, macroalgae, CCA, turf algae, and other substrate; (ii) coral recruitment; and (iii) coral disease. Indicators were selected based on the National Park Service Inventory & Monitoring Benthic Marine Protocol (NPS I&M, Brown et al. 2011) and recommendations made by the NPS for the waters in or adjacent to parks within the West Hawaiʻi Reference Region (WHRR). These three indicators were compared between the marine area adjacent to Pu‘uhonua o Hōnaunau NHP and the surrounding West Hawai‘i reference region.

Descriptions of the three indicators follow:

- *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, Kā‘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 Signs (Brown et al. 2011).
- *Coral Recruitment*: Settlement plates are used to assess the availability of coral recruits to replenish local populations; availability of recruits may influence recovery potential after disturbance. Coral recruitment is listed as an indicator in the NPS Marine Benthic Community Vital Signs (Brown et al. 2011).
- *Coral disease*: We report on the prevalence of the three most commonly observed diseases in West Hawai‘i for the assessment period (2004–2014; Walsh et al. 2013, Couch et al. 2014a), which have distinct etiologies: *Porites* growth anomaly (GA), *Porites* trematodiasis (TRE), and tissue loss diseases (TL).
  - *Porites* growth anomaly is 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* growth anomaly can 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 stressors.
  - 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 Hawai'i reference region from 2004 (after the last assessment, Hoover and Gold 2006) to 2014, when this assessment was initiated. Data sources and methods for available studies conducted in the West Hawai'i reference region are listed in Table 4.4.2-1. Three of these studies include benthic surveys that fall within the marine area adjacent to Pu'uhonua o Hōnaunau NHP (Figure 4.4.2-1); they are described 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 from fixed transects, only the most recent data points were included. Note that because Pu'uhonua o Hōnaunau NHP does not include marine habitat in its designated boundaries, it is not included in regular NPS Inventory & Monitoring Benthic Monitoring Program.

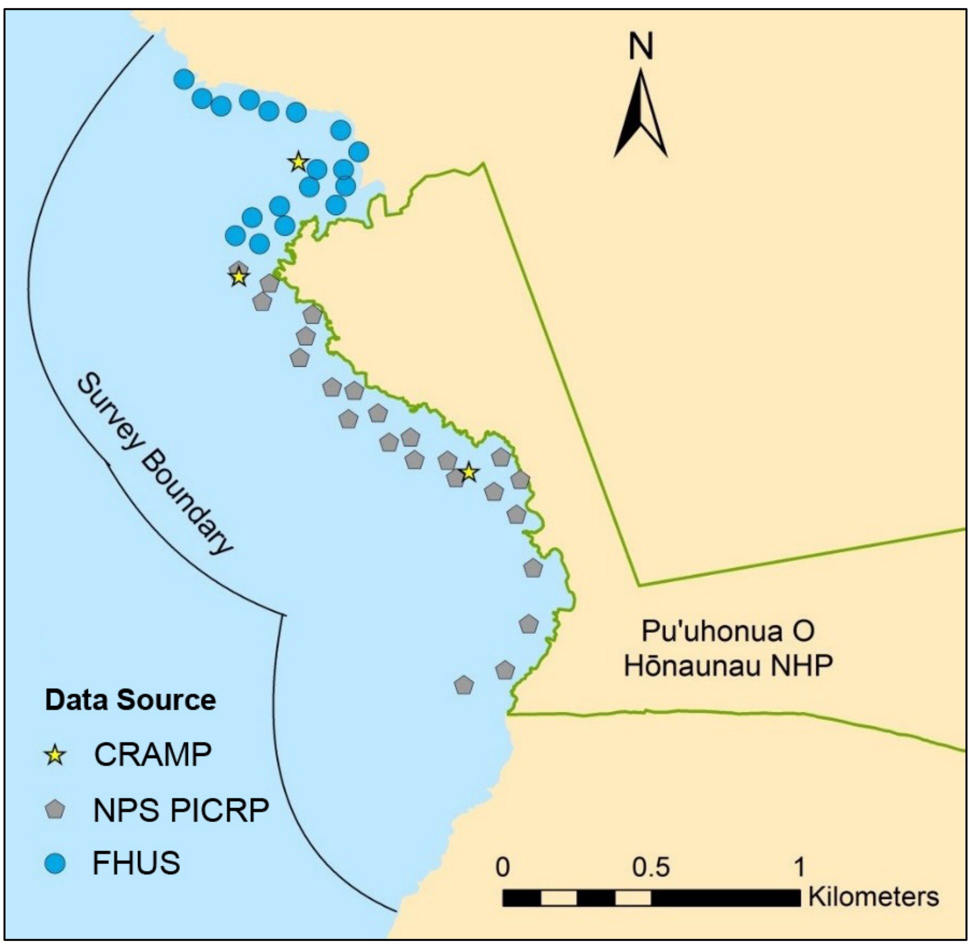


Figure 4.4.2-1. Survey points within the assessment polygon adjacent to Pu'uhonua o Hōnaunau NHP. Survey boundary set at 0.8 km (0.5 mi) from park boundaries following Beets et al. 2010. Available data points are symbolized by source (CRAMP = Hawai'i Coral Reef Assessment and Monitoring Program, NPS PICRP = Pacific Islands Coral Reefs Program, NPS FHUS = Fish Habitat Utilization Study).

Data Sources & Methods for Benthic Cover

Percent benthic cover data are available for a total of 1123 transects in the West Hawai‘i reference region from 2004–2014 (Table 4.4.2-1). This includes 58 transects with benthic cover data within the Pu‘uhonua o Hōnaunau NHP marine area from three studies, which are summarized below (see also Table 4.4.2-1 and Figure 4.4.2-1). Note that these surveys were conducted from 2004–2007.

- CRAMP: The Hawai‘i Coral Reef Assessment and Monitoring Program (CRAMP) has 32 fixed monitoring sites throughout the MHI, four of which are located in the West Hawai‘i reference region and none of which are located in the assessment area adjacent to Pu‘uhonua o Hōnaunau NHP. To increase spatial sampling, CRAMP conducts Rapid Assessment Transects in addition to their repeated measures of fixed transects. In April 2004, CRAMP surveyed **three** Rapid Assessment Transects within this area of interest (Rodgers et al. 2004b).
- FHUS: In 2005, the NPS I&M and University of Hawai‘i (UH) conducted benthic surveys at NPS sites in Hawai‘i as part of a baseline inventory of marine vertebrates and a Fish Habitat Utilization Study (FHUS; Beets et al. 2010). This study included **41** benthic transects in the Pu‘uhonua o Hōnaunau NHP marine area.
- NPS PICRP: In 2006, the NPS Pacific Islands Coral Reefs Program (PICRP) established **14** fixed transects that fell within the marine area adjacent to Pu‘uhonua o Hōnaunau NHP. These transects were designed to collect current-condition baseline data on benthic communities in Pu‘uhonua o Hōnaunau as a reference site for two monitoring projects assessing impacts of proposed development adjacent to Kaloko-Honokōhau NHP (Marrack et al. 2014) and input of groundwater from Honokōhau Harbor (Weijerman et al. 2014). These sites were last surveyed in spring 2007.

Data collected within the West Hawaii Reference Region, but outside of the marine area bordering or adjacent to Pu‘uhonua o Hōnaunau NHP, include surveys by the Division of Aquatic Resources West Hawai‘i 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 Hawai‘i (UH), and The Nature Conservancy (TNC). All data sources are listed in Table 4.4.2-1.

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

Table 4.4.2-1. Benthic survey data from the West Hawaiʻi reference region (WHRR) from 2004–2014, including the marine area adjacent to Puʻuhonua o Hōnaunau NHP (PHNHP).

Project[a]	Citation	Years	Benthic cover	Coral disease	Coral recruitment	Methods summary
WHRP	Basch et al. 2009, Martin &Walsh 2012	2004–2012	–	–	WHRR: n=8 PHNHP: n=1	Terracotta recruitment tiles were used to estimate coral recruit density from April 2004 to March 2012 at 9 sites in West Hawaiʻi, including one in the marine area adjacent to Puʻuhonua o Hōnaunau NHP. Tiles were replaced every 6–11 mos. Summarized site data were available from the published report.
DAR	Walsh et al. 2013	2007, 2011	WHRR: n=26	WHRR: n=62; PHNHP: n=2	–	Benthic cover was assessed using photoquadrats on transects at each of 26 WHAP sites located within WHRR. Raw data was available through the Hawaiʻi Monitoring and Research Collaborative (HIMARC). Coral Disease was assessed on 62 1 x 25 m belt transects at 26 sites in the WHRR including two in the marine area adjacent to the park. All colonies on the 1 x 25 m transect were assessed for disease and diseased colonies were recorded; colony density was assessed on a 1 x 10 m transect 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. 2014a, Couch 2014	2010–2011	–	WHRR: n=42 PHNHP: n=8	–	Coral disease was assessed on 42 10 x 2 m belt transects in the WHRR, including 8 transects in Puʻuhonua o Hōnaunau NHP marine area. 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. 2004b; 2015	2002, 2004	WHRR: n=28 PHNHP: n=3	–	–	Benthic cover was assessed using the analysis of 0.35 m^2 photoquadrats taken along 20 10m long Rapid Assessment Transects within the WHRR, including 3 in the marine area adjacent to Puʻuhonua o Hōnaunau NHP. 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.

Table 4.4.2-1 (continued). Benthic survey data from the West Hawai'i reference region (WHRR) from 2004–2014, including the marine area adjacent to Pu'uhonua o Hōnaunau NHP (PHNHP).

Project[a]	Citation	Years	Benthic cover	Coral disease	Coral recruitment	Methods summary
EPSCoR	Caldwell et al 2016a, Burns 2016	2011–2012	–	WHRR: n=36	–	Line-point intercept surveys on 25 m transects, where each colony 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)
NPS PICRP	Marrack et al. 2014; Weijerman et al. 2014	2005–2007	WHRR: n=85 PHNHP: n=14	–	–	Fixed transects were established at 61 sites in Kaloko-Honokōhau NHP, 14 sites in Pu'uhonua o Hōnaunau NHP marine area, and 10 at a reference site within the WHRR. Benthic cover was assessed using photoquadrats along 10m transects at each site. Macro-invertebrates including urchins and sea stars were counted along 17.5 m^2 belt transects.
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 – NPS & UH	Beets et al. 2010	2005	WHRR: n=353, PHNHP: n=41	–	–	Benthic cover was assessed at 353 transects in marine waters adjacent to (bordering) or held within the boundaries of the four parks, including 41 transects in the marine area adjacent to Pu'uhonua o Hōnaunau NHP using the *in-situ* planar point intercept quadrat method along a 25-m transect.
UH	DeMartini et al. 2013	2010	WHRR: n=6	–	–	Benthic cover was assessed using both quadrats and line point counts at 6 fixed stations at Pu'ukoholā Heiau NHS. These are included as part of the WHRR.
TNC	Minton et al. 2011	2010, 2013	WHRR: n=479	WHRR: n=8	–	Benthic cover was assessed using analysis of 0.25 m2 photoquadrats at 479 transects across 40 sites. Eight of the transects included coral disease surveys: all colonies within a 10x2 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 available through HIMARC.

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}); tiles were replaced every 6–11 months. One of the nine sites, Hoʻokena, falls within the marine assessment area surrounding Puʻuhonua o Hōnaunau NHP.

Coral Disease

Data were available from coral disease surveys conducted at 173 transects in the West Hawaiʻi reference region (Caldwell et al. 2016a; Table 4.4.2-1) including ten transects within the marine area adjacent to Puʻuhonua o Hōnaunau NHP. Of these ten transects, eight were conducted by Cornell University (Couch et al. 2014a, Couch 2014) and two were conducted by DAR West Hawaiʻi Aquarium Project (WHAP; Walsh et al. 2013).

4.4.2.3 Reference Condition

Because the period covered by this assessment ends prior to the 2015 bleaching event that significantly impacted the West Hawaiʻi reference region, reference conditions are also based on conditions prior to the bleaching event.

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. 2004b). CCA is most common benthic cover after coral; macro-algal cover was very low (Rodgers et al. 2004b).

Based on the compilation of all available data collected along the West Hawaiʻi coast from 2004 – 2014 (Table 4.4.2-1), mean benthic percent cover was composed of turf algae (41.6, SE = 0.82%), coral (25.2, SE = 0.61 %), CCA (8.1, SE = 0.31%), and macro-algae (3.0, SE = 0.31%), as well as "bare" substrate with no conspicuous cover (8.3%, SE = 0.61%). Note that these results are summarized prior to the 2015 bleaching event (Maynard et al. 2016).

Coral Recruitment Rates

The average annual recruitment rates from 2004–2012 was 25, SD = 23 recruits m^{-2} $year^{-1}$ on the West Hawaiʻi coast 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. 2014a). 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. 2014a). 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 Hawai‘i is largely explained by higher percent coral cover of *Porites* spp. (Couch et al. 2014a).

4.4.2.4 Current Condition and Trend

Percent Benthic Cover

Based on 58 transects surveyed from 2004–2007 in the marine t area adjacent to Pu‘uhonua o Hōnaunau NHP, benthic habitats surrounding the park were broadly similar to the WHRR, but had higher coral cover and less bare substrate (PERMANOVA; $R^2 = 0.007$; p= 0.001, Figure 4.4.2-2).

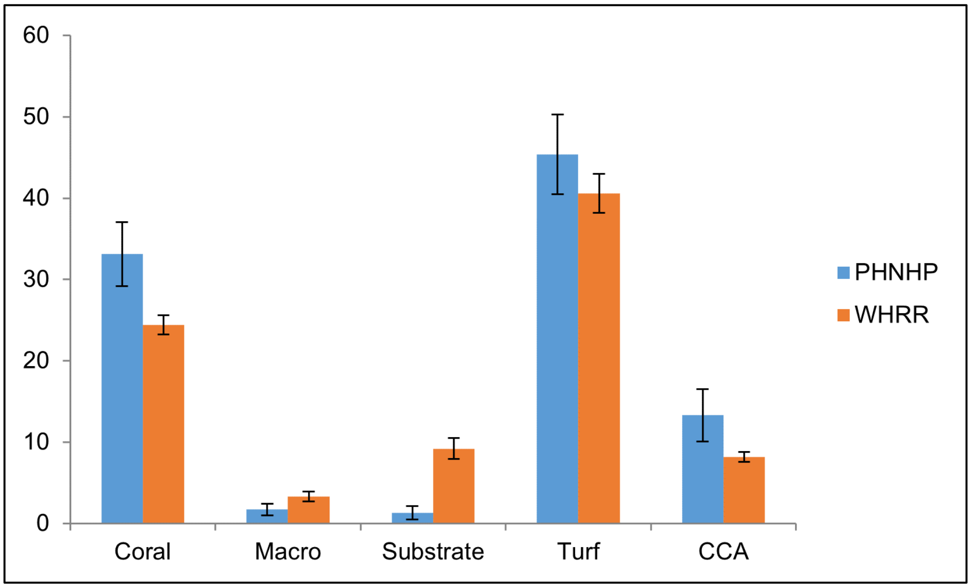


Figure 4.4.2-2. Mean percent benthic coverage (± 95% CI) of coral, macro-algae, uncolonized substrate, turf algae, and crustose coralline algae (CCA) in the marine area of interest adjacent to Pu‘uhonua o Hōnaunau National Historical Park (PHNHP; n=44) and along the West Hawai‘i coast (WHC; n=1073).

The dominant benthic cover in the Pu‘uhonua o Hōnaunau NHP marine area was turf algae, followed by coral, CCA, and macro-algae. In 2005, Beets et al. (2010) describe the reefs off of Pu‘uhonua o Hōnaunau NHP as having "impressive coral communities" with low spatial complexity. Based on surveys in 2006 and 2007, Marrack et al. (2014) and Weijerman et al. (2014) describe the northern and southernmost Pu‘uhonua o Hōnaunau NHP transects as located in boulder habitat with moderate coral cover, and the central portion of the site as aggregate reef with relatively high coral cover. Macro-algal cover was generally low.

Given the limited data available (58 transects between 2004–2007) in the marine area adjacent to Pu‘uhonua o Hōnaunau NHP, 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), it is likely that there were significant negative impacts on coral cover in the marine area adjacent to the NHP.

Coral Recruitment

One of the nine WHRP sites, Ho‘okena, fell within the Pu‘uhonua o Hōnaunau NHP marine area. Of nine sites, Ho‘okena was among four moderate recruitment sites, with a recruitment rate of 16 (±19.80) recruits m^{-2} $year^{-1}$ (Table 4.4.2-2; Martin and Walsh 2012). Martin and Walsh (2012) report that summer recruitment was higher than winter recruitment and that there was no temporal trend in recruitment at Ho‘okena from 2004–2012.

Table 4.4.2-2. Annual recruitment rates and standard deviations from 2004 – 2012 for nine sites in West Hawai‘i, including eight sites in the reference region and one site in the assessment region (Martin and Walsh 2012), see WHRP in Table 4.4.2-1.

Site	Recruits m^{-2} per year	Std Dev.	Range of Recruitment Rates
Waiaka‘īlio	72	101	0–176
Puakō	56	116	0–411
Ka‘ūpūlehu	18	15.4	0–49
Honokōhau	19	22.1	0–71
N. Keauhou	4	4.54	0–16
Ke‘ei	8	12.6	0–41
Ho‘okena	16	19.8	0–67
Miloli‘i	17	22.6	0–64
Manukā	10	16.3	0–44
Average	**25**	**23.3**	**–**

Coral Disease and Bleaching

Based on 10 transects in 2010–2011, disease prevalence in the marine area adjacent to Pu‘uhonua o Hōnaunau NHP was broadly comparable to the West Hawai‘i reference region during the 2004–2014 assessment period (Figure 4.4.2-3). Bleaching appears to be higher in marine waters surrounding the park, but this may represent temporal differences between surveys in the resource and reference areas.

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.

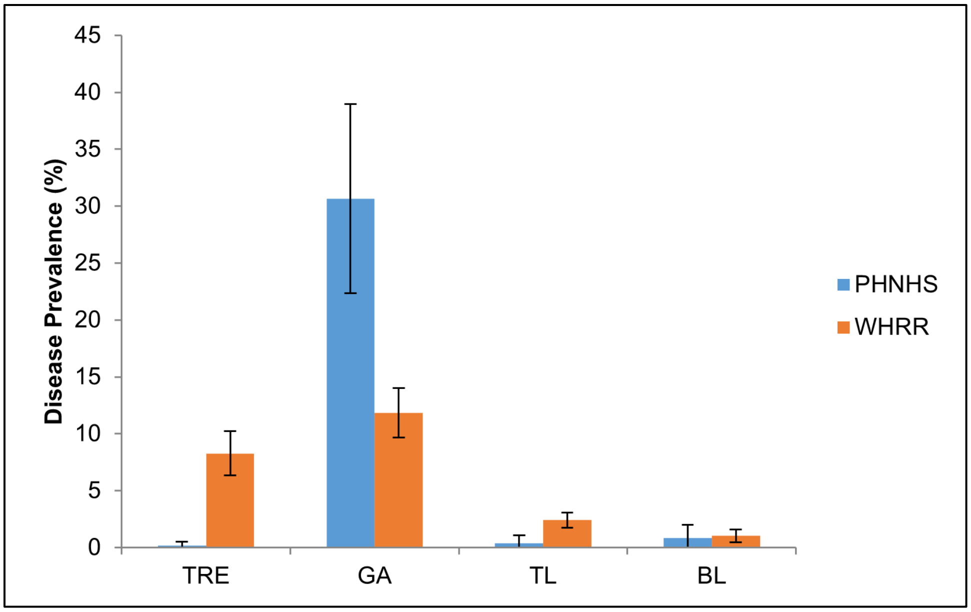


Figure 4.4.2-3. Mean prevalence (± 95% CI) of *Porites* trematodiasis (TRE), *Porites* growth anomaly (GA), tissue loss (TL), and bleaching (BL) in the marine area adjacent to Puʻuhonua o Hōnaunau NHP (PHNHP) and in the West Hawaiʻi reference region (WHRR) based data from on Cornell University and DAR WHAP (Table 4.4.2-1).

Overall condition and trend assessment

In 2014, the limited data available from the marine area adjacent to Puʻuhonua o Hōnaunau NHP indicated that it was comparable in condition to the surrounding West Hawaiʻi reference region for the 2004–2014 assessment period; the data were not adequate to make a trend assessment. More critically, the assessment period of this study ends before the 2015 bleaching event, which resulted in bleaching of 38–92% of all coral colonies at sites in West Hawaiʻi (Maynard et al. 2016). Although the southernmost site of the Maynard et al (2016) study was Keauhou Bay, significant bleaching likely occurred within the marine area surrounding Puʻuhonua o Hōnaunau NHP in 2015. Extensive bleaching, as seen in West Hawaiʻi in 2015, is often associated with significant post-bleaching mortality and a higher likelihood of disease events.

4.4.2.5 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 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) and 60% of deeper water corals (11–12 m) were partially or severely bleached across twenty sites in West Hawaiʻi, and 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 Hawaiʻi, including Puʻuhonua o Hōnaunau. Although thermal stress events will continue 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.

Two projects observed COTS on or near their survey sites in Puʻuhonua o Hōnaunau, but do not report quantitative surveys of COTS density. Rodgers et al. (2004b) observed five COTS all along a transect off of Puʻuhonua Point. Four COTS were observed along the NPS PICRP baseline transects at the Puʻuhonua o Hōnaunau reference sites (Marrack et al. 2014, Weijerman et al. 2014). COTS will continue to pose a moderate but unpredictable threat to West Hawaiʻi reefs, including Puʻuhonua o Hōnaunau.

Water Quality

In 2008, University of Hawaiʻi researchers observed an unusual bloom of the cyanobacterium *Leptolyngbya crosbyana* on the reefs adjacent to Puʻuhonua o Hōnaunau (Smith et al. 2008). Cyanobacterial blooms have been shown to have deleterious effects on coral (Kuffner et al. 2006) and were associated with mortality of the coral *Porites compressa* during this bloom (Smith et al. 2008). More broadly, increased nutrients in coastal waters are associated with higher risk of coral bleaching and disease (Vega Thurber et al. 2014, Wiedenmann et al. 2013). In West Hawaiʻi, submarine groundwater discharge (SGD) is extensive and can result in transport of anthropogenic nutrients onto nearshore reefs, despite rapid mixing (Johnson et al. 2008, Peterson et al. 2009) and has been implicated in higher prevalence of coral disease (Couch et al. 2014b). Increased development along the West Hawaiʻi coast poses a risk of increased anthropogenic nutrient loading into coastal ocean through SGD. Deterioration of coastal water quality is a significant but actionable threat the marine benthic resources of West Hawaiʻi.

Invasive species

In Hawaiʻi, 19 species of macro-algae have been introduced intentionally and unintentionally since 1950. Of these, five have become established in Hawaiʻi (Smith et al. 2002). Invasive algae are found on all of the MHI but are most abundant on the islands of Maui and Oʻahu. Macro-algal cover is generally low along the West Hawaiʻi coast. In 2005, the University of Hawaiʻi conducted surveys of algae at several sites including some in the study area adjacent to Puʻuhonua o Hōnaunau NHP, and found the introduced red alga *Acanthophora spicifera* in very low abundance with limited distribution in tide pools within the study area adjacent to the park (Cheryl Squair unpublished data, Smith et al. 2002).

4.4.2.6 Data Gaps and Research Recommendations

For the decade of 2004–2014, there were just 58 benthic surveys limited to three years (2004, 2006, 2007) and 10 coral disease surveys in 2010–2011 in the marine area adjacent to Puʻuhonua o Hōnaunau NHP, 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 highlights the need for ongoing monitoring within the resource area. Marrack et al. (2014) and Weijerman et al. (2014) established a set of 14 fixed transects in the marine area adjacent to Puʻuhonua o Hōnaunau NHP in 2006. Effective monitoring of benthic resources could be accomplished by re-establishing and monitoring these transects.

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. Therefore, coral size and growth components should be monitored. Within the marine area adjacent to the Puʻuhonua o Hōnaunau NHP, coral recruitment data were available for one site (Hoʻokena) that was surveyed by the WHRP (Martin and Walsh 2012). Coral recruitment is highly variable both spatially and temporally and is a critical component of reef resilience. The continuation of the West Hawaiʻi Recruitment Project is critical to providing recruitment rates in the marine area bordering the park. Other data gaps in the marine waters adjacent to Puʻuhonua o Hōnaunau NHP include long-term monitoring data on coral recruitment, disease outbreaks, episodic bleaching events and COTS events.

4.4.3 Nearshore Marine Fish

By Alan Friedlander, University of Hawai'i at Manoa and Megan Ross, Hawai'i Institute of Marine Biology

Ornate butterflyfish (kīkākapu, *Chaetodon ornatissimus*) swimming over yellow lobe coral (*Porites lobata*) and finger coral (*P. compressa*), 2008 (DAR Photo, L. Kramer).

<u>Condition Summary</u>

The condition of the nearshore fish community in waters adjacent to Puʻuhonua o Hōnaunau National Historical Park warrants significant concern, and is deteriorating. The waters adjacent to Puʻuhonua o Hōnaunau support a lower biomass of fish than Kalaupapa National Historical Park, and lower numerical density of fish and percentage of endemic fish than both Kalaupapa NHP and the West Hawaiʻi reference regions. Total fish biomass and the condition of each of the three fisheries assessed were similar to the heavily impacted West Hawaiʻi reference region. The condition assessment is made with a high degree of confidence. While Kalaupapa NHP resides in a different ecological regime compared to the Puʻuhonua o Hōnaunau NHP assessment polygon (Donovan et al. 2018), it has one of the healthiest fish populations in the Main Hawaiian Islands (Friedlander et al. 2018, Friedlander et al. in press). It therefore serves as a benchmark for comparisons with more impacted ecosystems and can help gauge the condition of the marine waters adjacent to the Puʻuhonua o Hōnaunau NHP and other locations around the state.

4.4.3.1 Description

The three bays adjacent to Puʻuhonua o Hōnaunau National Historical Park are characterized by coral colonized pavement giving way to aggregate reef that steeply slopes to deeper areas of uncolonized sand or coral rubble. Hōnaunau Bay is a popular dive and snorkel site, with a boat ramp for easy access by motorized boats and kayaks. The central portion of Puʻuhonua o Hōnaunau NHP is adjacent to a rocky intertidal community stretch from to Puʻuhonua Point at the north to Alahaka Bay in the south. This stretch of rocky intertidal habitat gives way to volcanic pavement and boulder habitat with low coral cover relative to the Bays to the north and south of the NHP. Fish abundance is reported to be higher at the north and southern portions of the reef adjacent to the NHP (Beets et al. 2010). The northern and southern ends of the park are associated with embayments dominated by aggregate reef which may provide more habitat for reef fish species (Beets et al. 2010).

In this assessment we assessed five focal groups: consumer group, species origin (i.e., endemic, indigenous or introduced).

Consumer Groups

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). The 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). The loss of herbivorous fishes is also of particular concern (Bellwood et al. 2004, Heenan et al. 2014). Herbivorous fishes, especially large uhu (parrotfish), help to maintain coral's competitive advantage (Hughes et al 2007, Ledlie et al. 2007, Bellwood et al. 2011). This is particularly important in situations where corals are exposed to other local (e.g. land based pollution) or global (e.g. increased temperature or acidity associated with climate change).

Introduced Nearshore Marine Fish Species

Invasive species are a growing concern for marine biodiversity, particularly in Hawaiʻi with its large proportion of endemic species (Hourigan et al. 1987, Kay & Palumbi 1987, Bowen et al. 2013). The majority of introduced species in Hawaiʻi are invertebrates; 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 & 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). 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 Northwestern Hawaiian Islands (NWHI; Oda & 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 & 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 1983, 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).

4.4.3.2 Indicators, Data and Methods

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, two focal groups were assessed: consumer group (Appendix B), and species origin (i.e., endemic, indigenous or introduced) Different indicators were used to assess the different focal groups depending on available data (Table 4.4.3-1).

Table 4.4.3-1. Indicators used to assess nearshore marine fish communities in total and by focal group (i.e. consumer group, level of endemism). An “X” indicates that the indicator was assessed and an en-dash (–) indicates that it was not.

Focal group	Biomass	Numerical density	Species richness
Overall	X	X	X
Consumer group	X	–	–
Introduced species	–	–	X

Assessments were made based on comparisons to two reference regions: Kalaupapa NHP, located on the Kalaupapa Peninsula on Molokaʻi Island, and to West Hawaiʻi Coast from Upolo Point (N 20.2°, W 156.8°) to South Point (N 18.9°, W 155.7°). Kalaupapa NHP was used as a baseline reference area because it has considerably lower fishing pressure, visitation, and recreational use than Puʻuhonua o Hōnaunau NHP and boasts some of the highest reef fish biomass and abundance of top predators found anywhere in the MHI (Friedlander et al., 2017, 2019). Despite differences in the marine habitats and environments between Kalaupapa and Puʻuhonua o Hōnaunau NHP 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 et al. 2019). The West Hawaiʻi reference region was also included as a point of reference because it serves as a point of comparison with similar marine habitats and environments, as well as a shared recent 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 Puʻuhonua o Hōnaunau NHP.

Data Sources

Data were compiled from monitoring programs conducted along the West Hawaiʻi coast and Kalaupapa NHP. Four programs included survey transects within the Puʻuhonua o Hōnaunau NHP assessment polygon (Figure 4.4.3-1), and two 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 4.4.3-2).

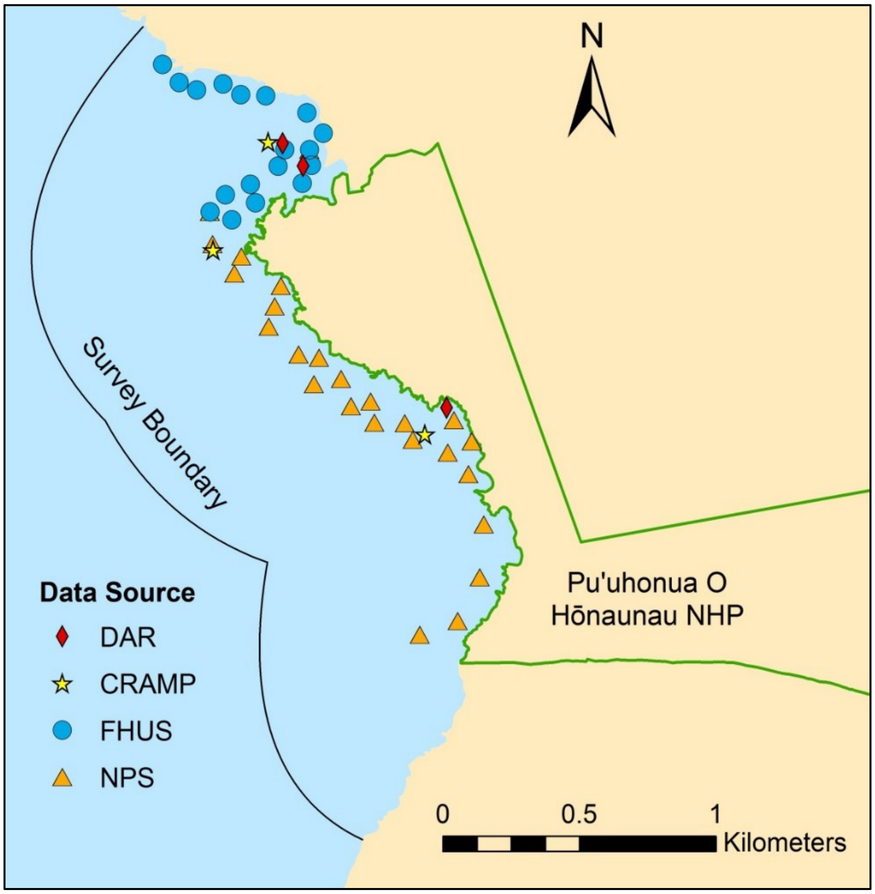


Figure 4.4.3-1. Locations of all fish transects within 0.8 km (0.5 mi) Pu‘uhonua o Hōnaunau NHP assessment polygon. Color-coded by data source. Data sources include the Hawai‘i Coral Reef Assessment and Monitoring Program (yellow star: CRAMP; Rodgers et al. 2004), the Division of Aquatic Resources West Hawai‘i Aquarium Project (red triangle: DAR; Walsh et al. 2013), the NPS Fish Habitat Utilization Study (FHUS) and the NPS (I&M) program (NPS; blue circle and orange triangle; Beets et al. 2010). NPS-FHUS and NPS-I&M fish transects are from the same data source although colored differently.

Table 4.4.3-2. Number of transects available for summary analysis in the West Hawaii Reference Region (WHRR), the area of interest adjacent to the Puʻuhonua o Hōnaunau NHP (PHNHP), and Kalaupapa NHP (KNHP).

Spatial extent	# of transects	# of transects including species level data
WHRR outside PHNHP	1067	1050
Area adjacent to PHNHP	49	46
KNHP	173	173
Total	**1289**	**1269**

The monitoring programs used in this assessment were conducted after the publication of the assessment conducted by Hoover and Gold (2006), which summarized work by Doty (1969), Kimmerer and Durbin (1975), and Madden (1980). The following programs quantified reef fish species richness, density, and biomass within the area of interest adjacent to Puʻuhonua o Hōnaunau NHP but were not included in the 2005 assessment (Table 4.4.3-3).

- In 2004, the Hawaiʻi Coral Reef Assessment and Monitoring Program (CRAMP) surveyed three transects within the Puʻuhonua o Hōnaunau NHP assessment polygon (Rodgers et al. 2004). These were one-time surveys.
- In 2005, the University of Hawaiʻi Fish Habitat Utilization Study (FHUS) in collaboration with the National Park Service Inventory and Monitoring Program (NPS I&M) conducted 43 one-time inventory surveys of near-shore marine fish in the assessment polygon adjacent to Puʻuhonua o Hōnaunau NHP (Beets et al. 2010).
- The Department of Land and Natural Resources Division of Aquatic Resources (DLNR DAR) established West Hawaiʻi Aquarium Project (WHAP) long-term monitoring program to evaluate the effectiveness of these FRAs (Tissot et al. 2004, Walsh et al. 2013). Monitoring has been conducted through annual fish surveys along fixed transects at 26 sites in West Hawaiʻi. The DAR WHAP Hōnaunau site is located within the Puʻuhonua o Hōnaunau NHP assessment polygon boundaries (Walsh et al. 2013). The Hōnaunau WHAP site has been surveyed annually since 2000. The most recent survey available was used for these analyses (2014).

Sources and methods for all surveys conducted within the West Hawaiʻi and Kalaupapa NHP reference regions are summarized in Table 4.4.3-3.

Table 4.4.3-3. Nearshore Marine Fish assessments conducted within the West Hawaiʻi reference region (WHRR; including the Puʻuhonua o Hōnaunau NHP assessment polygon), Kalaupapa NHP (KNHP), and the Puʻuhonua o Hōnaunau NHP (PHNHP) assessment polygon used to assess references conditions as well as resources condition. An "X" indicates that the parameters were assessed and an en-dash (–) indicates that they were not.

Project	Report/ publication	Years of data collection	# transects in WHRR	# of transects in KNHP	# of Transects in PHNHP	Fish abundance	Consumer group	Endemism	Methods
NPS – I&M [1]	Brown et al. 2011	2007–2011, 2014	Biomass n=162	n=120	Biomass & trophic n=25	X	X	X	Biomass and density of nearshore fishes were assessed using visual belt transects 25 x 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 cm.
FHUS – NPS & UH [1]	Beets et al. 2010	2005	n=235	n=53	Biomass & trophic n=18	X	X	X	Biomass and density of nearshore fishes were assessed using visual belt transects 25 x 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 cm.
DAR [1]	Walsh et al. 2013	2012–2013	n=46	n=0	n=3	X	X	–	Fish biomass was assessed quarterly at 23 sites along the west coast of Hawaiʻi Island. Four 25 x 4 m belt transects are surveyed at each site. Species and total length to nearest 5 cm were recorded in 5 cm bins and are recorded for each fish observed.
CRAMP [1]	Rodgers et al. 2004; 2015	2002, 2004	n=47	n=0	Biomass n=3 Trophic n=0	X	–	–	Fish abundance was assessed along six 25 x 5 m belt transects 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=0	X	X	–	Fish surveys were conducted at 40 sites between points 1500 m to the north and south of Pelekane Bay. All fish within a 25 x 5 m belt transect were identified to the lowest possible taxon and total length was estimated to the nearest 5 cm and was placed in 5 cm bins.

[1] Signifies inclusion within the Puʻuhonua o Hōnaunau NHP assessment polygon.

Table 4.4.3-3 (continued). Nearshore Marine Fish assessments conducted within the West Hawaiʻi reference region (WHRR; including the Puʻuhonua o Hōnaunau NHP assessment polygon), Kalaupapa NHP (KNHP), and the Puʻuhonua o Hōnaunau NHP (PHNHP) assessment polygon used to assess references conditions as well as resources condition. An "X" indicates that the parameters were assessed and an en-dash (–) indicates that they were not.

Project	Report/ publication	Years of data collection	# transects in WHRR	# of transects in KNHP	# of Transects in PHNHP	Fish abundance	Consumer group	Endemism	Methods
NOAA CRED	Heenan et al. 2014	2010, 2013	n= 34	n=0	n=0	X	–	–	Nearshore fish biomass and density were assessed using the SPC method. Species and total length were recorded for all fish within two 15 m diameter SPC cylinders along each 30 m transect (site) (Ayotte et al. 2015).

[1] Signifies inclusion within the Puʻuhonua o Hōnaunau NHP assessment polygon.

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 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.

4.4.3.3 Reference Condition

Assessments were made based on comparisons to two reference regions: The West Hawaii Coast, and Kalaupapa NHP. Conditions for both reference regions were used to assess the overall nearshore fish community, consumer group, and species origin.

Overall Nearshore Fish Community

Mean biomass was higher in Kalaupapa NHP than in the West Hawaiʻi reference region (t-test; t= 11.415; $p < 0.001$; Table 4.4.3-4). Mean numerical density (t-test; t = 1.585; p = 0.115; Table 4.4.3-4) and species richness (t-test; t = −1.372; p= 0.171; Table 4.4.3-4) were similar in Kalaupapa NHP and the West Hawaiʻi reference region.

Table 4.4.3-4. Backtransformed mean biomass (g m^{-2} ± 95% CI), mean numerical density (# m^{-2} ± 95% CI), mean species richness (# of species ± 95% CI), and t-test p-value comparing all data collected within the West Hawaiʻi Reference Region (WHRR) to and in Kalaupapa National Historical Park (KNHP) based on analysis of all available survey data collected within the WHRR since 2005 (Table 4.4.3-3); "n" represents the number of transects used for analysis. Statistical analyses were conducted using data transformed for normality (biomass$^{(1/3)}$, Numerical Density$^{(1/3)}$, Richness$^{(1/2)}$).

Indicator	WHRR	KNHP	p-value
Biomass	40.8 [38.8, 42.8] n=1067	121.2 [103.5, 140.8] n=173	<0.0001
Numerical density	0.96 [0.92, 0.99] n=1067	1.1 [0.94, 1.2] n=173	0.11
Richness	27.6 [26.8,28.4] n=1050	26.0 [24.0, 28.0] n=173	0.17

Consumer Groups

Biomass was higher at Kalaupapa NHP than the West Hawaiʻi reference region for all consumer groups (fish taxa are listed in Appendix B as primary, secondary, and apex consumer groups). The mean percentage of biomass in each of the consumer groups (primary consumer, secondary consumer, and top predator), varied between the West Hawaiʻi reference region and Kalaupapa NHP (PERMANOVA; R^2=0.005, p-value = 0.008), with the West Hawaiʻi reference region being composed of a relatively high proportion of secondary consumers compared to Kalaupapa NHP (Table 4.4.3-5).

Table 4.4.3-5. Mean biomass (g m^{-2} ± 95% CI), mean percentage of biomass (% ± 95% CI) of fish by consumer group, and t-test p-value comparing for all data collected within 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 since 2005 (Table 4.4.3-3); "n" represents the number of transects used for analysis.

	Biomass (g m^{-2})		% of biomass	
Consumer group	**WHRR n=1050**	**KNHP n=173**	**WHRR n=1047**	**KNHP n=173**
Top predator	3.4 ± 0.4	13.7 ± 7.0	6.2 ± 0.6	7.0 ± 2.0
Secondary consumer	20.1 ± 1.5	52.9 ± 10.4	43.1 ± 1.3	38.5 ± 3.42
Primary consumer	26.5 ± 1.7	95.9 ± 14.7	50.7 ± 1.3	54.5 ± 3.6

While our synthesis of data is not appropriate for longitudinal assessment of trends in consumer group abundance, trends over time are presented in Walsh et al. (2013). They found no apparent trends in the biomass of corallivores, planktivores, and sessile invertebrate feeders in West Hawai'i from 1999 to 2013 (Walsh et al. 2013). The biomass of herbivores and detritivores has increased during that same time period, while the biomass of piscivores and mobile invertebrate feeders, commonly targeted for food by fishers, have decreased (Walsh et al. 2013).

Introduced Nearshore Marine Fish Species

The mean percentages of endemic, indigenous and introduced species were differed between the West Hawai'i reference region and Kalaupapa NHP (PERMANOVA; R^2=0.031, p-value = 0.001; Table 4.4.3-6). Both reference regions were predominantly composed of native fish, and had a nearly identical proportion of endemic species. Kalaupapa NHP, however, had nearly eight times more introduced species than were found in surveys in the West Hawai'i reference region.

Table 4.4.3-6. Mean (± 95% CI) 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 4.4.3-1).

Nativeness	WHRR n=1043	KNHP N=170
Endemic	26.1 ± 0.004	26.6 ± 1.75
Indigenous	73.4 ± 0.004	69.5 ± 1.71
Introduced	0.5 ± 0.004	3.9 ± 0.51

Annual belt transect and free swim surveys conducted 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) hypothesize that the decline in roi abundance was associated with a fish die off event in 2006. During this event, 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 hypothesis was provided for changes in taʻape biomass.

4.4.3.4 Current Condition and Trend

Here we present a summary on the current condition based on existing data. The data assessed were collected between 2004 and 2013. The collection of data by the Coral Reef Assessment and Monitoring Program (CRAMP) preceded the last assessment by Hoover and Gold (2006), but were not available for inclusion in that assessment so we included them here. The majority of data sources were one-time measures from randomly selected points. A single data source (Walsh et al. 2013) collected repeated measures from fixed transects within the area of interest. For repeated measures, only the most recent data points were included to better summarize current conditions with the one-time measurements. We include summaries of findings from Wash et al. 2013 to represent trends over time.

Overall Nearshore Fish Community

Mean biomass did not vary significantly between the area of interest adjacent to Puʻuhonua o Hōnaunau NHP and the West Hawaiʻi Reference Region, but these values were less than one third of the biomass measured in Kalaupapa NHP, (ANOVA; $F_{2,1285}$=156.2, $p < 0.001$; Figure 4.4.3-2a). Mean numerical density was significantly lower in the area of interest adjacent to Puʻuhonua o Hōnaunau than in the West Hawaiʻi reference region and in Kalaupapa NHP (ANOVA; $F_{2,1286} = 5.8$, $p=0.003$; Figure 4.4.3-2b), but species richness did not differ among the three groupings (ANOVA; $F_{2,1265} = 1.12$, $p=0.33$; Figure 4.4.3-2c).

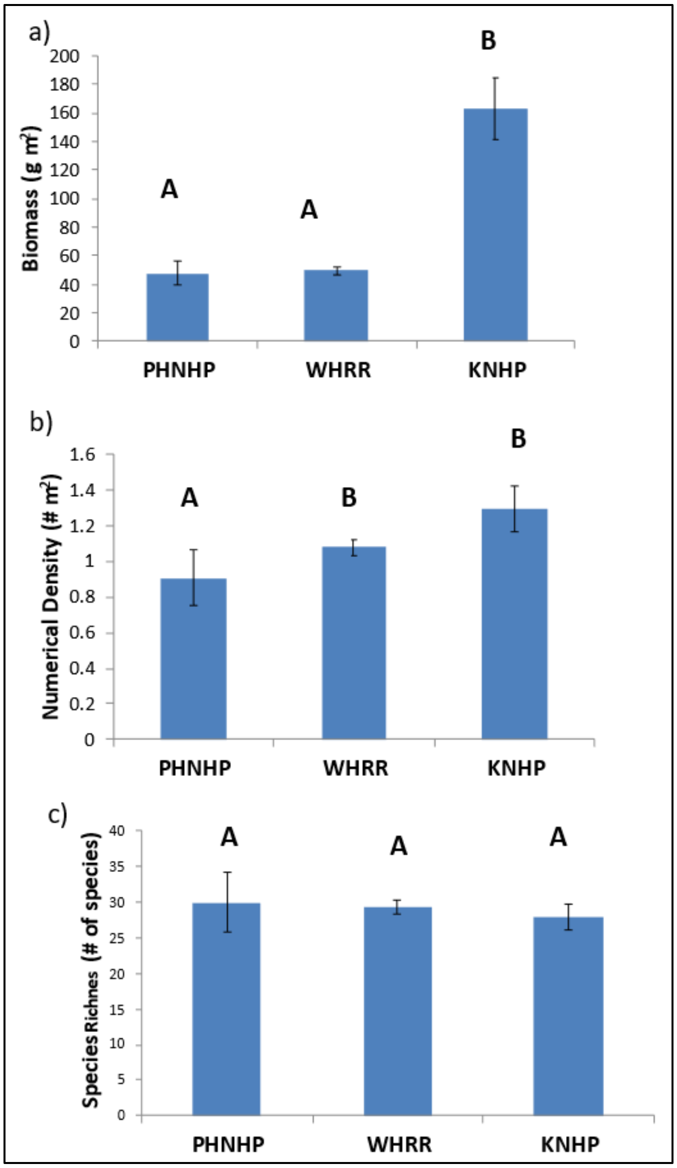


Figure 4.4.3-2. a) Mean biomass (g m^{-2} ± 95%CI), b) mean numerical density (# m^{-2} ± 95%CI), and c) mean species richness (# of species ± 95% CI) in Pu‘uhonua o Hōnaunau NHP assessment polygon (PHNHP, n=49 transects), the West Hawai‘i Reference Region (WHRR, n=1067 transects), and in Kalaupapa NHP (KNHP, n=173 transects) based on analysis of all available survey data collected within the West Hawai‘i reference region since 2005 (Table 4.4.3-1). Different letters above bars denote statistically different means (α=0.05). Statistical analyses were conducted using data transformed for normality (biomass$^{(1/3)}$, Numerical Density$^{(1/3)}$, Richness$^{(1/2)}$).

Consumer Group

There was a lower biomass in the area of interest adjacent to Pu‘uhonua o Hōnaunau NHP than in Kalaupapa NHP (Table 4.4.3-7). There is no significant difference in the percentage of biomass within each consumer group between the area of interest adjacent to Pu‘uhonua o Hōnaunau NHP and the West Hawai‘i reference region (PERMANOVA; R^2=0.0021, p-value = 0.127; Figure 4.4.3-3). There was a significant difference in the composition of consumer groups between the area of interest adjacent to Pu‘uhonua o Hōnaunau NHP and in Kalaupapa NHP on Moloka‘i (PERMANOVA; R^2=0.003, p-value = 0.003; Figure 4.4.3-3).

Table 4.4.3-7. Mean (± 95% CI) biomass (g m^{-2}) of fish by consumer group for all data collected within the area of interest adjacent to Pu‘uhonua o Hōnaunau National Historical Park (PHNHP), 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 since 2005 (Table 4.4.3-1). “n” refers to # of transects surveyed.

Consumer group	*PHNHP n=46*	*WHRR n=1050*	*KNHP n=173*
Top predator	1.6 ± 0.7	3.4 ± 0.4	13.7 ± 7.0
Secondary consumer	20.8 ± 7.1	20.1 ± 1.5	52.9 ± 10.4
Primary consumer	26.1 ± 4.2	26.5 ± 1.7	95.9 ± 14.7

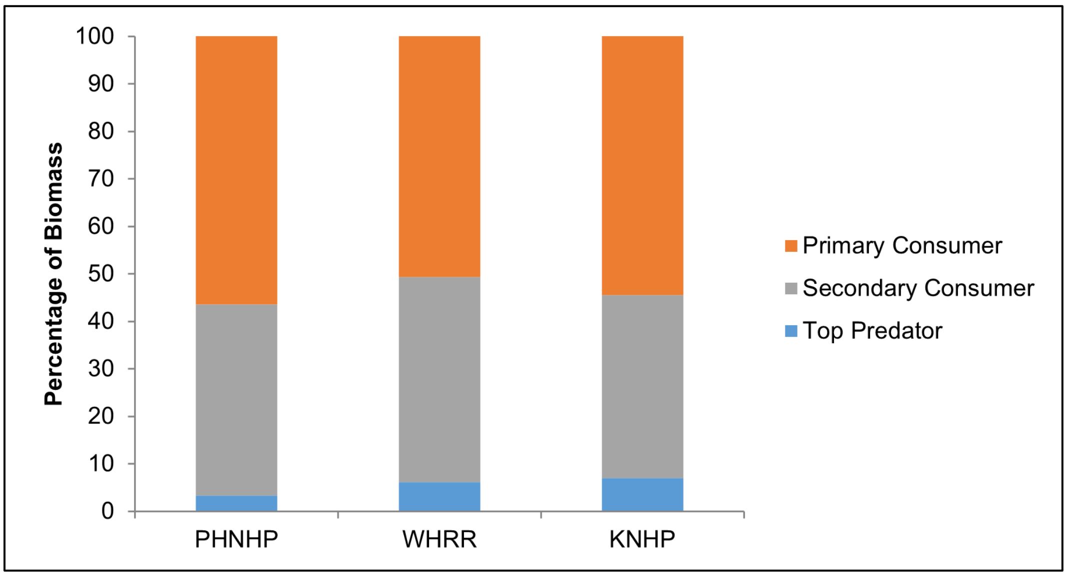


Figure 4.4.3-3. Mean percentage of biomass by consumer group in area of interest adjacent to Pu‘uhonua o Hōnaunau NHP (PHNHP, n=46 transects with non-zero values), within the West Hawai‘i Reference Region (WHRR, n=1050 transects), and in Kalaupapa NHP (KNHP, n=173 transects) based on analysis of all available survey data collected within the West Hawai‘i reference region since 2005 (Table 4.4.3-1).

Introduced Nearshore Marine Fish Species

Ta‘ape, to‘au (*Lutjanus fulvus*), and roi were the only introduced fish species recorded in the area of interest adjacent to Pu‘uhonua o Hōnaunau NHP, the West Hawai‘i reference region, and in Kalaupapa NHP (Rogers et al. 2004, Beets et al. 2010, Walsh et al. 2013). The majority of species within the area of interest adjacent to Pu‘uhonua o Hōnaunau NHP and the West Hawai‘i reference region outside of the area of interest adjacent to Pu‘uhonua o Hōnaunau NHP points are indigenous. There was no significant difference in the percentages of species in each grouping (i.e., endemic, indigenous, and introduced) between the area of interest adjacent to Puʻuhonua o Hōnaunau NHP and the West Hawaiʻi reference region (PERMANOVA; $R^2 = 0.003$, $p = 0.07$; Figure 4.4.3-4). There was a significant difference in the percentages of species in each grouping (i.e., endemic, indigenous, and introduced) between the area of interest adjacent to Puʻuhonua o Hōnaunau NHP and Kalaupapa NHP (PERMANOVA; $R^2 = 0.148$, $p = 0.001$; Figure 4.4.3-4). The West Hawaiʻi reference region and Kalaupapa NHP have a higher proportion of endemic species than the area of interest adjacent to Puʻuhonua o Hōnaunau NHP. Also, Kalaupapa NHP has a higher proportion of introduced species than the area of interest adjacent to Puʻuhonua o Hōnaunau NHP and the West Hawaiʻi reference region (Figure 4.4.3-4).

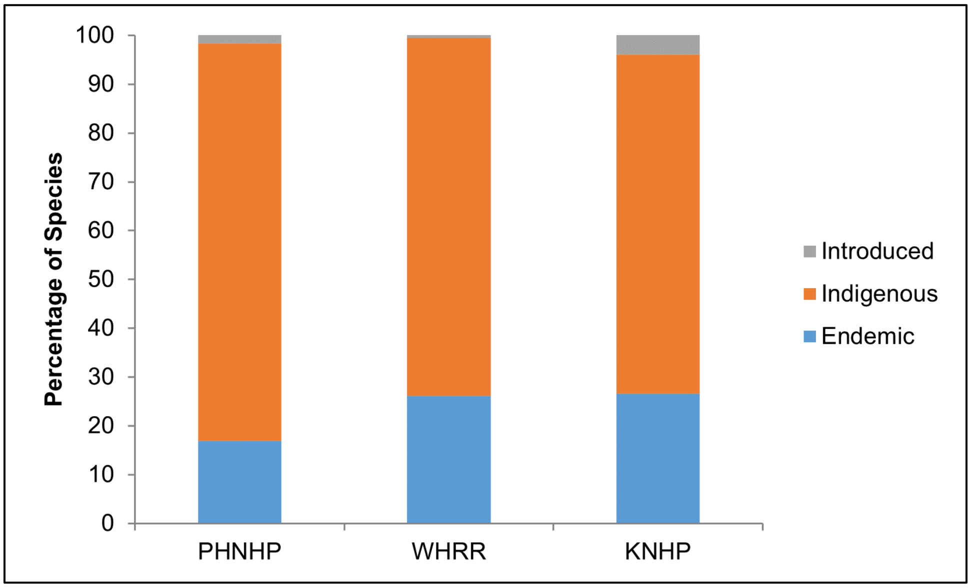


Figure 4.4.3-4. Percentage of introduced, indigenous and endemic species in the area of interest adjacent to Puʻuhonua o Hōnaunau National Historical Park (PHNHP, n=46 transects), the West Hawaiʻi Reference Region (WHRR, n=1043 transects), and in Kalaupapa National Historical Park (KNHP, n=170 transects) based on analysis of all available survey data collected within the West Hawaiʻi reference region since 2005 (Table 4.4.3-1).

It should be noted that the analyses presented above may be influenced by the schooling behavior of one of the more common non-native species taʻape. Several observations from the literature support suggest temporal variability associated with this schooling behavior. Beets et al. (2010) reported that taʻape were among the dominant species by biomass within the area of interest adjacent to Puʻuhonua o Hōnaunau NHP. Taʻape are a schooling species and often have a patchy distribution. The abundance of taʻape can be variable depending on the presence or absence of a school along a randomly placed transect (Walsh et al. 2013). For example, surveys conducted in the area of interest adjacent to Puʻuhonua o Hōnaunau NHP in 2004 found 18.0% of the fish counted and 2.4% of the biomass observed to be nonnative, primarily due to a single observation of a large school of taʻape (Rogers et al. 2004).

4.4.3.5 Data Gaps and Research Recommendations

While fisheries-independent data sets are readily available, data on fishing catch and effort are extremely limited. The reporting blocks used to summarize the commercial catch data for the area of interest adjacent to Puʻuhonua o Hōnaunau NHP are large (block 101 is 24,846 ha in area), data are summed over 10 years owing to confidentiality rules, and recreational/subsistence fishing is not included, so these data are likely not representative of fishing activity within the area of interest adjacent to Puʻuhonua o Hōnaunau NHP. To address the discrepancy in scale and availability of fisheries dependent data, the recommended research approach would be to establish fisheries-dependent monitoring within the area. Given the cultural value of Puʻuhonua o Hōnaunau NHP, the identification of species targeted by subsistence fishers and an understanding of the fishing effort and gear used within this area are of great importance.

5. Discussion

By Brian Hudgens, Institute for Wildlife Science and Alan Friedlander, University of Hawai‘i at Mānoa

The overall condition of natural resources at Pu‘uhonua o Hōnaunau National Historical Park is mixed. Many resources benefit from the relative isolation of the park from urban developments. For example, there is little anthropogenic influence on the air quality in the park, night sky visibility, or water quality in groundwater, anchialine pools, or adjacent marine waters. There is also an appreciable native component to the flora and fauna found within the park. Some anchialine pools are in pristine condition, supporting a diversity of native species, and surrounded by native vegetation. Most waterbirds observed at Pu‘uhonua o Hōnaunau NHP are indigenous or migratory species. Bat detection rates at the park are substantially higher than elsewhere on the west coast of Hawai‘i Island and offshore waters adjacent to the park support a diverse and healthy benthic invertebrate community.

Other resources are negatively impacted by regional processes affecting the broader west coast of Hawai‘i Island. Large storms cause occasional flooding, and near shore natural and cultural resources are at risk due to sea level rise and island subsidence. Like most of the west coast of Hawai‘i Island, the vegetation and upland bird communities in the park are dominated by nonnative species. Nonnative ungulates in particular pose a threat to natural and cultural resources. Invasive fish inhabit some anchialine pools, severely impacting native invertebrate communities within those pools.

The mixed status of the natural resources at Pu‘uhonua o Hōnaunau NHP may reflect local mitigation of regional processes. The primary focus of these efforts is reduction or removal of invasive species populations within the park. Invasive species removal efforts have been conducted to restore anchialine pools invaded by nonnative fish, vegetation in nonnative dominated habitats throughout the park, and to protect waterbird populations threatened by nonnative predators.

In this regard, anchialine pools hold the most promise. Efforts are underway to remove tilapia and *Gambusia affinis* from anchialine pools where they occur. Fire has been used in the park to reduce cover of invasive plants on at least two occasions. In the 1960s nearly all of the park was burned in an effort to remove vegetation (Bishop museum maps; Apple 1962). Control burns were conducted in the 1980s with a follow-up burn in the 1990s associated with a pili grass restoration study in the parking area (F. Galieto, NPS, personal communication, 2017). There are limited efforts to manually and chemically remove weeds as well. Removal efforts of nonnative mammals have been sporadic. Goats, mongooses, cats, rats and mice have all been trapped at times since at least 2001. The park boundary fence does not fully enclose the park; monitoring and repairing the fence has been irregular. In addition, there have been efforts to protect specific locations within the park by using temporary barriers or fencing, sometimes strategically placed adjacent to historic walls, to exclude pigs and goats from an anchialine pool and loulu (*Pritchardia maideniana*) restoration areas, as well as installation of animal-proof trash cans to reduce interactions between Park visitors and feral cats and mongooses (M. Hayes, NPS, personal communication, 2017).

The key to successful invasive species management at Pu‘uhonua o Hōnaunau NHP will be strategies that allow for maintenance or control efforts to continue uninterrupted into the future. The least intensive follow up measures are needed for anchialine pools, which will need to be monitored regularly to ensure that all fish have been removed and to detect future reinvasions. The prevalence of both tilapia and *G. affinis* throughout Hawai‘i means that reintroductions are likely, either by dispersal through underground connections to water bodies outside the park or by human assisted introductions. On the other hand, the use of prescribed fire, chemical treatment and manual removal to reduce invasive plants requires intensive follow up. Reinvasion is likely to happen frequently as seeds disperse into Pu‘uhonua o Hōnaunau NHP from the existing seedbank and nearby source populations, requiring regular monitoring and repeated application of removal methods to prevent reestablishment of significant coverage within the park. For example, vegetation removal and burns in the 1960s cleared Pu‘uhonua o Hōnaunau NHP from vegetation, leaving unobstructed views of the ocean and historic walls (Figure 5-1; Apple 1962), but even with experimental burns in the 1980s and 1990s the vegetation at Pu‘uhonua o Hōnaunau NHP today is dominated by nonnative species. Complicating matters, many nonnative plants carry and recover from fire more readily than native species, leading to a cycle of increased fire frequency and invasive species dominance (Mueller-Dombois 1981). Seeding and outplanting of native plants has the additional benefit of leading to native-dominated seedbanks, reducing susceptibility to invasion by nonnative species.

Aerial view of Pu‘uhonua o Hōnaunau NHP following 1960s burning. NPS photo.

Effective recovery of the terrestrial plant community will require a holistic approach including robust plans for invasive plant removal, fuels mitigation, and native plant restoration in the context of the historic landscape, ethnographic resources and structures, in a changing environment. The NPS has an existing Vegetation Management Strategy (Pratt 1998) that serves as a foundation for such a strategy.

As with vegetation, control of invasive mammals will only be effective if intensive removal efforts are conducted with regularity. Populations of nonnative mammals on the west coast of Hawaiʻi Island are large and widespread. Given the mobility of these species, it is likely that any individuals removed will quickly be replaced by dispersal from neighboring lands. That does not mean that the impact of nonnative mammals on Puʻuhonua o Hōnaunau NHP natural and cultural resources cannot be significantly reduced. Regular, intensive predator trapping has been associated with increased numbers and reproductive success of the endangered ʻalae keʻokeʻo (Hawaiian coot, *Fulica alai*) and aeʻo (Hawaiian stilt, *Himantopus mexicanus knudseni*) at nearby Kaloko-Honokōhau NHP (Hudgens et al. Kaloko-Honokōhau National Historical Park NRCA). Trapping and targeted use of rodenticides have been used to eradicate mongooses from Kaʻena Point on Oʻahu (Young et al. 2013). Fencing has been used to prevent reinvasion by pigs, goats, and sheep at Hawaiian parks for decades. Goats have been excluded from large areas in West Hawaiʻi (Allen 2000). In places where goats have been excluded, native plants come back readily if present and nonnative species do not dominate the area, and restoration efforts to reduce invasive plant species are more effective (Mueller-Dombois and Spatz 1975, Mueller-Dombois 1981, Scowcroft and Hobdy 1987,). As is true with burning, goat removal will be most effective as a tool to restore native vegetation if combined with other treatments to reduce invasive grass cover and promote native species through outplanting and shading (Cabin et al. 2002, Leopold and Hess 2016).

Several species of nonnative terrestrial animals were omitted from this analysis during the early scoping phase of the project. Nonnative reptiles are abundant at Puʻuhonua o Hōnaunau NHP (Bazzano 2007). Over 3000 adventive terrestrial arthropod species have been recorded in the Hawaiian Archipelago, with nearly 400 new records since 2002 (Matsunaga et al. 2019). As with the nonnative mammals assessed in this report, there is little or no information for these species on their abundances within Puʻuhonua o Hōnaunau NHP or their impact on natural and cultural resources.

A big challenge in both assessing and managing natural resources at Puʻuhonua o Hōnaunau NHP is an overall lack of high quality data. For example, there are no data available on the occurrence or duration of streamflow in the Kiʻilae stream channel. Likewise, there are no data on groundwater levels, hydraulic gradients, or concentrations of nutrients, metals, pesticides or toxic substances. There is also no information on marine sediment layer depth or retention time, sand loss, or turbidity. Upstream changes in land use and coastal development have significantly impacted natural resources at NPS sites elsewhere on the west coast of Hawaiʻi Island (reviewed in Puʻukoholā Heiau NHS and Kaloko-Honokōhau NHP NRCAs), so it is important that good background measurements be established for hydrologic processes and conditions at Puʻuhonua o Hōnaunau NHP.

Although there have been multiple vegetation surveys conducted at Puʻuhonua o Hōnaunau NHP since the 1950s (Bryan and Emory 1957, Smith et al. 1986, Pratt and Abbott 1996, Cogan et al.

2011), differences in methods limit the value of comparisons between studies to understand how vegetation has changed through time or responded to restoration efforts. Repeated sampling at regular intervals using the same methods would allow better assessment of both the state of the community and overall responses to vegetation management.

Data are particularly sparse to assess the condition of native terrestrial fauna at Puʻuhonua o Hōnaunau NHP. Neither birds, monk seals nor bats have been surveyed in over a decade. Because most terrestrial vertebrates observed in Puʻuhonua o Hōnaunau NHP spend only a portion of their lives in the park, optimal park management on behalf of these species requires an understanding the influence of park lands on the fitness of individuals. Studies to determine what factors influence the amount of time individuals spend foraging in Puʻuhonua o Hōnaunau NHP would inform habitat restoration efforts aimed at maximizing the presence of native vertebrates in the park. Studies focused on those individuals using the park also have the potential to benefit populations contributing to the park's flora and fauna. For example, capture and release of bats to collect guano material, combined with adequate sampling of available insect prey, and genetic analysis of bat guano would confirm diet (identify prey resources) of bats using the park. Tracking (e.g., using radio telemetry) ʻōpeʻapeʻa and ʻīlio-holo-i-ka-uaua foraging in and around Puʻuhonua o Hōnaunau NHP to determine roosting and brooding sites, foraging areas, and habitat use would facilitate NPS partnerships with other landowners, ocean users, and members of the public to protect bats and monk seals that reside in and around the park throughout their lifecycles.

Although the NPS does not have management authority for marine waters, the ecological and physical qualities of nearshore marine waters are relevant to the park's cultural and natural resources and values and to visitor experience and understanding. Marine resources have significant cultural value in Hawaiʻi and 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 stimulated the development of complex management systems within ahupuaʻa, district (moku), and island. Subsistence fishing and gathering of marine organisms continues to be culturally and economically important in many communities throughout Hawaiʻi (Poepoe et al. 2007, Friedlander et al. 2013, 2014).

The heavy influence of regional environmental and anthropogenic processes on the natural resources found within Puʻuhonua o Hōnaunau NHP and on the marine resources adjacent the park, means that effective management of those resources depends on cooperation with surrounding community and regional stakeholders. The integration of traditional ecological knowledge and customary Hawaiian practices in collaborative partnerships with community and stakeholders aligns with the fundamental resource values (NPS 2017) at Puʻuhonua o Hōnaunau NHP.

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Appendix A. Vertebrate Species list for Puʻuhonua o Hōnaunau National Historical Park

This list represents the NPS reported species list as of 2018. Nomenclature and nativeness reported follow that reported by the NPS. For the full species list and updated reported abundances see: https://irma.nps.gov/NPSpecies/Search/SpeciesList/PUHO.

Table A-1. NPS reported species list as of 2018.

Category	Order	Family	Scientific name	Common names	Nativeness
Mammal	Artiodactyla	Bovidae	*Capra hircus*	feral goat	Nonnative
Mammal	Artiodactyla	Suidae	*Sus scrofa*	feral pig, puaʻa	Nonnative
Mammal	Carnivora	Canidae	*Canis familiaris*	domestic dog	Nonnative
Mammal	Carnivora	Felidae	*Felis catus*	domestic cat, house cat	Nonnative
Mammal	Carnivora	Herpestidae	*Herpestes javanicus*	Indian mongoose	Nonnative
Mammal	Carnivora	Phocidae	*Neomonachus schauinslandi*	Hawaiian monk seal	Native
Mammal	Chiroptera	Vespertilionidae	*Lasiurus cinereus semotus*	Hawaiian hoary bat	Native
Mammal	Rodentia	Muridae	*Mus musculus*	house mouse	Nonnative
Mammal	Rodentia	Muridae	*Rattus exulans*	Polynesian rat	Nonnative
Mammal	Rodentia	Muridae	*Rattus norvegicus*	Norway rat	Nonnative
Mammal	Rodentia	Muridae	*Rattus rattus*	black rat, ʻiole, roof rat	Nonnative
Bird	Accipitriformes	Accipitridae	*Buteo solitarius*	Hawaiian hawk, ʻIo	Native
Bird	Charadriiformes	Charadriidae	*Pluvialis fulva*	Kolea, Pacific Golden Plover	Native
Bird	Charadriiformes	Recurvirostridae	*Himantopus mexicanus knudseni*	aeʻo, Hawaiian stilt	Native
Bird	Charadriiformes	Scolopacidae	*Arenaria interpres*	ʻAkekeke, ruddy turnstone	Native
Bird	Charadriiformes	Scolopacidae	*Heteroscelus incanus*	ʻulili, Wandering Tattler	Native
Bird	Charadriiformes	Scolopacidae	*Numenius tahitiensis*	bristle-thighed curlew, Kioea	Native
Bird	Columbiformes	Columbidae	*Columba livia*	rock dove	Nonnative

Table A-1 (continued). NPS reported species list as of 2018.

Category	Order	Family	Scientific name	Common names	Nativeness
Bird	Columbiformes	Columbidae	*Geopelia striata*	barred dove, zebra dove	Nonnative
Bird	Columbiformes	Columbidae	*Streptopelia chinensis*	Chinese dove, Lace-necked dove, spotted dove	Nonnative
Bird	Galliformes	Phasianidae	*Francolinus erckelii*	erkel's francolin	Nonnative
Bird	Galliformes	Phasianidae	*Francolinus pondicerianus*	gray francolin	Nonnative
Bird	Galliformes	Phasianidae	*Phasianus colchicus*	ring-necked pheasant	Nonnative
Bird	Passeriformes	Cardinalidae	*Cardinalis cardinalis*	northern cardinal	Nonnative
Bird	Passeriformes	Emberizidae	*Paroaria capitata*	yellow-billed cardinal	Nonnative
Bird	Passeriformes	Emberizidae	*Sicalis flaveola*	saffron finch	Nonnative
Bird	Passeriformes	Estrildidae	*Estrilda caerulescens*	Lavender Fire-Finch, lavender waxbill	Nonnative
Bird	Passeriformes	Estrildidae	*Lonchura malabarica*	warbling silverbill	Nonnative
Bird	Passeriformes	Estrildidae	*Lonchura punctulata*	nutmeg mannikin, Ricebird, Spotted Munia	Nonnative
Bird	Passeriformes	Fringillidae	*Carpodacus mexicanus*	house finch, linnet, papayabird	Nonnative
Bird	Passeriformes	Fringillidae	*Serinus mozambicus*	yellow-fronted canary	Nonnative
Bird	Passeriformes	Passeridae	*Passer domesticus*	English sparrow, house sparrow	Nonnative
Bird	Passeriformes	Sturnidae	*Acridotheres tristis*	Common Myna	Nonnative
Bird	Passeriformes	Zosteropidae	*Zosterops japonicus*	Japanese white-eye, mejiro	Nonnative
Bird	Pelecaniformes	Ardeidae	*Nycticorax nycticorax*	‘Auku‘u, Black-crowned Night Heron	Native
Bird	Psittaciformes	Psittacidae	*Cyanoliseus patagonus*	Patagonian conure	Nonnative
Bird	Strigiformes	Strigidae	*Asio flammeus sandwichensis*	Hawaiian short-eared owl, Pueo	Native
Bird	Strigiformes	Tytonidae	*Tyto alba*	Barn Owl	Nonnative
Bird	Suliformes	Fregatidae	*Fregata minor*	great frigatebird, ‘iwa	Native
Bird	Suliformes	Sulidae	*Sula leucogaster*	‘a, brown booby	Native

Table A-1 (continued). NPS reported species list as of 2018.

Category	Order	Family	Scientific name	Common names	Nativeness
Reptile	Squamata	Chamaeleonidae	*Chamaeleo jacksonii*	Jackson’s chameleon	Nonnative
Reptile	Squamata	Gekkonidae	*Gehyra mutilata*	stump-toes gecko	Nonnative
Reptile	Squamata	Gekkonidae	*Hemidactylus frenatus*	common house gecko	Nonnative
Reptile	Squamata	Gekkonidae	*Hemiphyllodactylus typus*	tree gecko	Nonnative
Reptile	Squamata	Gekkonidae	*Lepidodactylus lugubris*	mourning gecko	Nonnative
Reptile	Squamata	Gekkonidae	*Phelsuma laticauda*	gold dust day gecko	Nonnative
Reptile	Squamata	Iguanidae	*Anolis carolinensis*	green anole	Nonnative
Reptile	Squamata	Scincidae	*Lampropholis delicata*	metallic skink	Nonnative
Reptile	Squamata	Typhlopidae	*Ramphotyphlops braminus*	Brahminy blind snake	Nonnative
Reptile	Testudines	Cheloniidae	*Chelonia mydas*	green sea turtle, honu	Native

Appendix B. Fish taxa listed as primary, secondary, and apex consumer groups

Table B-1. Fish taxa listed as primary, secondary, and apex consumer groups (Hawaii Cooperative Fishery Research Unit, unpublished data; Friedlander et al. 2017).

Primary	Secondary	Secondary	Secondary	Apex
Abudefduf sordidus	*Spratelloides delicatulus*	*Diodon hystrix*	*Ostracion whitleyi*	*Aprion virescens*
Acanthurus achilles	*Abudefduf abdominalis*	*Doryrhamphus excisus*	*Oxycheilinus bimaculatus*	*Carangoides orthogrammus*
Acanthurus blochii	*Abudefduf vaigiensis*	*Echeneis naucrates*	*Oxycheilinus unifasciatus*	*Caranx ignobilis*
Acanthurus dussumieri	*Acanthurus thompsoni*	*Echidna nebulosa*	*Oxycirrhites typus*	*Caranx lugubris*
Acanthurus guttatus	*Aetobatus narinari*	*Enchelycore pardalis*	*Paracirrhites arcatus*	*Caranx melampygus*
Acanthurus leucopareius	*Albula glossodonta*	*Enchelynassa canina*	*Paracirrhites forsteri*	*Caranx sexfasciatus*
Acanthurus lineatus	*Amblycirrhitus bimacula*	*Encrasicholina purpurea*	*Parapercis schauinslandi*	*Caranx species*
Acanthurus maculiceps	*Ammodytoides pylei*	*Epibulus insidiator*	*Parapercis species*	*Carcharhinus amblyrhynchos*
Acanthurus nigricans	*Anampses chrysocephalus*	*Evistias acutirostris*	*Parupeneus chrysonemus*	*Carcharhinus galapagensis*
Acanthurus nigrofuscus	*Anampses cuvier*	*Exallias brevis*	*Parupeneus cyclostomus*	*Cephalopholis argus*
Acanthurus nigroris	*Anampses species*	*Fistularia commersonii*	*Parupeneus insularis*	*Elagatis bipinnulata*
Acanthurus olivaceus	*Antennarius commersoni*	*Foa brachygramma*	*Parupeneus multifasciatus*	*Epinephelus quernus*
Acanthurus species	*Anthias species*	*Forcipiger flavissimus*	*Parupeneus pleurostigma*	*Euthynnus affinis*
Acanthurus triostegus	*Aphareus furca*	*Forcipiger longirostris*	*Parupeneus porphyreus*	*Katsuwonus pelamis*
Acanthurus xanthopterus	*Apogon erythrinus*	*Genicanthus personatus*	*Plagiotremus ewaensis*	*Pseudocaranx cheilio*
Alectis ciliaris	*Apogon kallopterus*	*Gnathanodon speciosus*	*Plagiotremus goslinei*	*Scomberoides lysan*
Aluterus scriptus	*Apogon maculiferus*	*Gobiidae species*	*Platybelone argalus*	*Seriola dumerili*
Blenniella gibbifrons	*Apogon species*	*Gomphosus varius*	*Plectroglyphidodon imparipennis*	*Seriola rivoliana*
Blenniidae species	*Apolemichthys arcuatus*	*Goniistius vittatus*	*Plectroglyphidodon johnstonianus*	*Sphyraena barracuda*
Calotomus carolinus	*Arothron hispidus*	*Gunnellichthys curiosus*	*Pleurosicya micheli*	*Sphyraena helleri*
Calotomus zonarchus	*Arothron meleagris*	*Gymnomuraena zebra*	*Polydactylus sexfilis*	*Triaenodon obesus*
Cantherhines sandwichiensis	*Asterropteryx semipunctatus*	*Gymnothorax eurostus*	*Priacanthus meeki*	*Tylosurus crocodilus*
Cantherhines verecundus	*Atherinomorus insularum*	*Gymnothorax flavimarginatus*	*Priacanthus species*	–

Table B-1 (continued). Fish taxa listed as primary, secondary, and apex consumer groups (Hawaii Cooperative Fishery Research Unit, unpublished data; Friedlander et al. 2017).

Primary	Secondary	Secondary	Secondary	Apex
Canthigaster amboinensis	*Aulostomus chinensis*	*Gymnothorax javanicus*	*Priolepis eugenius*	–
Canthigaster jactator	*Balistes polylepis*	*Gymnothorax melatremus*	*Pristiapogon kallopterus*	–
Canthigaster solandri	*Balistes species*	*Gymnothorax meleagris*	*Pristiapogon taeniopterus*	–
Canthigaster species	*Belonidae species*	*Gymnothorax nudivomer*	*Pristilepis oligolepis*	–
Centropyge fisheri	*Bodianus albotaeniatus*	*Gymnothorax pictus*	*Pseudanthias bicolor*	–
Centropyge flavissima	*Bothus mancus*	*Gymnothorax rueppelliae*	*Pseudanthias hawaiiensis*	–
Centropyge interrupta	*Bothus pantherinus*	*Gymnothorax species*	*Pseudanthias thompsoni*	–
Centropyge loriculus	*Bothus species*	*Gymnothorax steindachneri*	*Pseudocheilinus evanidus*	–
Centropyge potteri	*Brotula multibarbata*	*Gymnothorax undulatus*	*Pseudocheilinus octotaenia*	–
Chanos chanos	*Callionymus comptus*	*Halichoeres ornatissimus*	*Pseudocheilinus tetrataenia*	–
Chlorurus perspicillatus	*Calotomus species*	*Hemitaurichthys polylepis*	*Pseudojuloides cerasinus*	–
Chlorurus species	*Cantherhines dumerilii*	*Hemitaurichthys thompsoni*	*Psilogobius mainlandi*	–
Chlorurus spilurus	*Canthidermis maculatus*	*Heniochus diphreutes*	*Ptereleotris heteroptera*	–
Cirripectes obscurus	*Canthigaster coronata*	*Heteropriacanthus cruentatus*	*Pterois sphex*	–
Cirripectes species	*Canthigaster epilampra*	*Hippocampus fisheri*	*Rhinecanthus aculeatus*	–
Cirripectes vanderbilti	*Caracanthus typicus*	*Hippocampus kuda*	*Rhinecanthus rectangulus*	–
Coryphopterus duospilus	*Carangoides ferdau*	*Holocentridae species*	*Sargocentron diadema*	–
Coryphopterus species	*Chaetodon auriga*	*Iniistius aneitensis*	*Sargocentron ensifer*	–
Enneapterygius atriceps	*Chaetodon citrinellus*	*Iniistius pavo*	*Sargocentron punctatissimum*	–
Entomacrodus marmoratus	*Chaetodon ephippium*	*Iniistius species*	*Sargocentron species*	–
Eviota epiphanes	*Chaetodon fremblii*	*Iniistius umbrilatus*	*Sargocentron spiniferum*	–
Gnatholepis anjerensis	*Chaetodon kleinii*	*Kuhlia sandvicensis*	*Sargocentron tiere*	–
Gnatholepis caurensis hawaiiensis	*Chaetodon lineolatus*	*Labridae species*	*Sargocentron xantherythrum*	–
Hemiramphus depauperatus	*Chaetodon lunula*	*Labroides phthirophagus*	*Saurida flamma*	–
Hemiramphus species	*Chaetodon lunulatus*	*Lactoria fornasini*	*Saurida gracilis*	–

Table B-1 (continued). Fish taxa listed as primary, secondary, and apex consumer groups (Hawaii Cooperative Fishery Research Unit, unpublished data; Friedlander et al. 2017).

Primary	Secondary	Secondary	Secondary	Apex
Istiblennius zebra	*Chaetodon miliaris*	*Lutjanus fulvus*	*Saurida species*	–
Kyphosus bigibbus	*Chaetodon multicinctus*	*Lutjanus kasmira*	*Scorpaenodes kelloggi*	–
Kyphosus cinerascens	*Chaetodon ornatissimus*	*Macropharyngodon geoffroy*	*Scorpaenodes parvipinnis*	–
Kyphosus hawaiiensis	*Chaetodon quadrimaculatus*	*Malacanthus brevirostris*	*Scorpaenopsis brevifrons*	–
Kyphosus species	*Chaetodon reticulatus*	*Microcanthus strigatus*	*Scorpaenopsis cacopsis*	–
Kyphosus vaigiensis	*Chaetodon tinkeri*	*Monotaxis grandoculis*	*Scorpaenopsis diabolus*	–
Melichthys niger	*Chaetodon trifascialis*	*Mugil cephalus*	*Scorpaenopsis species*	–
Melichthys vidua	*Chaetodon unimaculatus*	*Mullidae species*	*Scuticaria okinawae*	–
Monacanthidae species	*Cheilio inermis*	*Mulloidichthys flavolineatus*	*Scuticaria tigrinus*	–
Naso lituratus	*Chromis acares*	*Mulloidichthys mimicus*	*Sebastapistes ballieui*	–
Naso species	*Chromis agilis*	*Mulloidichthys pflugeri*	*Sebastapistes coniorta*	–
Naso unicornis	*Chromis hanui*	*Mulloidichthys vanicolensis*	*Sebastapistes species*	–
Omobranchus rotundiceps	*Chromis leucura*	*Muraenidae species*	*Selar crumenophthalmus*	–
Opua nephodes	*Chromis ovalis*	*Myrichthys magnificus*	*Stethojulis balteata*	–
Parablennius thysanius	*Chromis vanderbilti*	*Myripristis amaena*	*Sufflamen bursa*	–
Pervagor aspricaudus	*Chromis verater*	*Myripristis berndti*	*Sufflamen fraenatus*	–
Pervagor spilosoma	*Cirrhilabrus jordani*	*Myripristis chryseres*	*Synodontidae species*	–
Plectroglyphidodon sindonis	*Cirrhitops fasciatus*	*Myripristis kuntee*	*Synodus binotatus*	–
Priolepis aureoviridis	*Cirrhitus pinnulatus*	*Myripristis species*	*Synodus dermatogenys*	–
Scarus dubius	*Conger cinereus marginatus*	*Myripristis vittata*	*Synodus species*	–
Scarus psittacus	*Conger species*	*Naso annulatus*	*Synodus ulae*	–
Scarus rubroviolaceus	*Coris ballieui*	*Naso brevirostris*	*Synodus variegatus*	–
Scarus species	*Coris flavovittata*	*Naso caesius*	*Taenianotus triacanthus*	–
Stegastes marginatus	*Coris gaimard*	*Naso hexacanthus*	*Thalassoma ballieui*	–
Tetraodontidae species	*Coris venusta*	*Naso maculatus*	*Thalassoma duperrey*	–

Table B-1 (continued). Fish taxa listed as primary, secondary, and apex consumer groups (Hawaii Cooperative Fishery Research Unit, unpublished data; Friedlander et al. 2017).

Primary	Secondary	Secondary	Secondary	Apex
Zebrasoma flavescens	*Ctenochaetus hawaiiensis*	*Nemateleotris magnifica*	*Thalassoma lutescens*	–
Zebrasoma veliferum	*Ctenochaetus strigosus*	*Neomyxus leuciscus*	*Thalassoma purpureum*	–
–	*Cymolutes lecluse*	*Neoniphon aurolineatus*	*Thalassoma quinquevittatum*	–
–	*Cymolutes praetextatus*	*Neoniphon sammara*	*Thalassoma species*	–
–	*Dascyllus albisella*	*Neoniphon species*	*Thalassoma trilobatum*	–
–	*Dasyatis lata*	*Novaculichthys taeniourus*	*Trimma taylori*	–
–	*Decapterus macarellus*	*Oplegnathus fasciatus*	*Upeneus arge*	–
–	*Decapterus species*	*Oplegnathus punctatus*	*Wetmorella albofasciata*	–
–	*Dendrochirus barberi*	*Ostorhinchus maculiferus*	*Xanthichthys auromarginatus*	–
–	*Diodon holocanthus*	*Ostracion meleagris*	*Xanthichthys mento*	–
–	–	–	*Zanclus cornutus*	–

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