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Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Hawai'i Volcanoes National Park

Natural Resource Report NPS/HAVO/NRR—2019/1967

ON THE COVER
Main: Kīlauea Crater, Hawai'i Volcanoes National Park
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Natural Resource Condition Assessment

Hawai‘i Volcanoes National Park

Natural Resource Report NPS/HAVO/NRR—2019/1967

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Executive Summary

Publisher's Note: Natural Resource Condition Assessments provide a snapshot-in-time evaluation of park resource conditions. For this report, most or all of the data discovery and analyses occurred during the period of 2013 to 2014. Thus, park conditions reported in this document pertain to that time period. Due to revised publishing requirements and/or scientific delays, this report was not published until 2019.

The purpose of this Natural Resource Condition Assessment (NRCA) is to evaluate current conditions for a subset of natural resources and resource indicators in Hawai'i Volcanoes National Park (HAVO) using existing data and information. The assessment is multi-disciplinary, and uses a hierarchical framework and reference conditions/values for comparison against current conditions. It also reports on trends in resource condition (when possible), identifies critical data gaps, and characterizes the general level of confidence for study findings. An important component of the report is the integration of geographical information system (GIS) products to spatially evaluate current resource conditions.

HAVO is located on the southeastern portion of Hawai'i Island, within the state of Hawai'i. The Park was incorporated into the National Park System in 1916. Currently, it encompasses roughly 134,760 ha. (333,000 ac.) and ranges from sea level to the summit of MaunaLoa at 4,169 meters (13,677 ft.) elevation. HAVO spans an extensive land area, is located in an extremely dynamic geological setting with two of the world's most active volcanoes, and contains considerable variations in substrate types, topography, elevation, and climate. These factors, combined with the unique evolutionary history of the Hawaiian archipelago, have resulted in abundant natural resources.

Although the Park was originally established to protect and study the significant volcanic processes and features within the Park (notably Kīlauea and MaunaLoa Volcano), it is now appreciated for its other important resources. A great diversity of ecosystems and vegetation types occur at HAVO ranging from wet forests to coastal anchialine pools and underground lava tubes. These varied environments harbor a unique and diverse assemblage of native wildlife and vegetation. Over 50 federally and state listed species and 26 Species of Concern (SOC) are known to occur within HAVO or historically occurred within the Park boundaries. The Park also serves as a popular tourist destination for domestic and international visitors, an education and research center, and a preserve for cultural resources.

Since its establishment, HAVO has identified protection of important natural resources as a fundamental part of the Park's purpose. However, past disturbances have modified the Park's landscape (e.g., introduction of nonnative ungulates, domestic grazing, ranching, logging, lava flows, and fires). The lasting effects of these past disturbances continue to influence the Park's natural resources, in addition to present-day threats and stressors. Current threats and stressors of significant concern to HAVO's natural resources include invasive plants and animals, diseases and pathogens, alternations in fire regimes, visitor use, and climate change.

To assess the current condition of HAVO's natural resources, this report evaluated 21 indicators. These indicators are largely derived from the Pacific Island Network's vital signs. Each indicator is associated with measures that evaluate and/or quantify the state or integrity of the indicator. The study framework provides a structure for grouping the diverse park indicators. This NRCA utilizes NPS' Ecological Monitoring Framework, which is a hierarchical, systems-based program developed to provide information on the status and trends of selected park resources. For each indicator in the framework, existing and available literature and data were reviewed. Data were analyzed, as appropriate, to synthesize information from diverse sources, provide summaries, or spatially depict conditions.

Each indicator was given an overall condition ranking based on a comparison of the current condition to established reference conditions or values. The four ranking categories are Good, Moderate, Of Concern, and Unknown. The extent of the knowledge base for each indicator was also ranked (represented by A-E). In general, more data means more confidence in the assessment of the indicator.

Nine of the indicators chosen for HAVO (~43%) are considered in "Moderate" condition, meaning that current conditions do not meet all or most of the reference conditions or values, but differences are not excessive. Eight of the indicators (~38%) are "Of Concern," defined as current conditions do not meet all or most of the reference conditions or values and the differences are excessive. One indicator (Cave and Lava Tube Communities) is considered in "Good" condition because currently all or most of the reference conditions are met or exceeded. For the remaining three indicators (Air Quality, Volcanic Features and Processes, and Soundscape), the condition is unknown because there was not enough evidence to determine the condition during the preparation of this report or reference conditions have not been defined.

Most conditions have unknown trends, which is a reflection of the fact that for most of the indicators (13 indicators) currently only status data (ranked "B") are available. Five of the indicators are supported by quantitative data collected over multiple years (ranked "A"). Long-term monitoring is currently being planned for several indicators, and it is expected that as monitoring programs develop, trend analysis will be possible for a larger suite of indicators.

While HAVO has a long history of repeated data collection for some resources in certain areas of the Park, additional data would be useful to determine overall resource conditions. For example, more studies in the newly acquired Kahuku Section would fill missing data gaps for this portion of HAVO. For most indicators, standardization of survey methods and search areas and more regular monitoring will allow for better trend analysis as longer-term data becomes available. Sporadic surveys with large time gaps often have different survey methodologies making comparisons difficult. Volcanic Features and Processes, Native Insects and Springtail Communities, Anchialine Pools, and Cave and Lava Tube Communities are particularly noted as having a paucity of publically available data.

Similar to other natural areas throughout the Hawaiian Islands, the physical environment and ecological communities at HAVO have been adversely impacted and risk further degradation by a myriad of threats and stressors. As a result, many of the indicators at HAVO do not meet the established reference conditions and values. Despite these findings, HAVO is an important refuge for many rare and unique Hawaiian species. Relatively intact examples of native Hawaiian ecosystems, as well as high biodiversity can be found in many areas of the Park. HAVO also protects and interprets the largest and most continuously active shield volcanoes in the United States, and is significant on a national level by serving as a living laboratory for scientific investigations.

Acknowledgments

SWCA Environmental Consultants and Fung Associates Inc. would like to acknowledge the staff at the Hawai'i Volcanoes National Park for sharing reports, plans, data, and their local knowledge of the Park. Specials thanks to Rhonda Loh for her coordination, collaboration, and advocacy throughout the preparation of this document. We gratefully acknowledge the technical and scientific expertise and local knowledge of David Benitez, Kelly Kozar, Sierra McDaniel, Danielle Foster, Darcy Hu, and Greg Kudray, as well as the assistance of additional staff in the Inventory & Monitoring program. Mahalo to scientists at the U.S. Geological Surveys' Pacific Island Ecosystems Research Center for their input, particularly Frank Bonaccorso, Linda Pratt, David Foote, and Paul Banko. We would like to thank Karl Magnacca for his insightful comments. Finally, thank you to the National Park Service for continuing to support and protect Hawai'i Volcanoes National Park.

Prologue

Publisher's Note: Changes in publishing requirements, and in some cases scientific delays, resulted in several NRCA reports not being published in a timely manner. These publications reported on studies initiated in the 2013–16 timeframe. Since Natural Resource Condition Assessments provide a snapshot-in-time evaluation of park resource conditions, it is important to note that data discovery and analyses for this study was conducted a few years prior to publication. Thus, park conditions reported in this document pertain to that time period. Please see the Publisher's Note at the beginning of the Executive Summary or Chapter 2 for dates specific to this report.

Chapter 1. NRCA Background Information

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

> ***NRCAs Strive to Provide…***
>
> - *Credible condition reporting for a subset of important park natural resources and indicators*
> - *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.

6An 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.

Chapter 2. Introduction and Resource Setting

Publisher's Note: Natural Resource Condition Assessments provide a snapshot-in-time evaluation of park resource conditions. For this report, most or all of the data discovery and analyses occurred during the period of 2013 to 2014. Thus, park conditions reported in this document pertain to that time period. Due to revised publishing requirements and/or scientific delays, this report was not published until 2019.

2.1. Introduction

2.1.1. History and Enabling Legislation

In the early 1900s missionaries, scientists, and other Euro-American visitors impressed by Kīlauea Volcano on Hawai'i Island began to lobby for federal management of the area and the creation of a national park in Hawai'i. Lorrin Thurston, an American businessman and publisher of the Honolulu Pacific Commercial Advertiser, spearheaded the public campaign to create a park and protect resources in the area. Support for a national park grew in 1912, when Dr. Thomas A. Jaggar became director of the Hawaiian Volcano Observatory (HVO) and the site was officially recognized as an important and accessible place to preserve and study geology. These two men continued to foster congressional support for the establishment of a park by writing editorials, providing tours, and running various public relations campaigns (Nakamura 2012).

On August 1, 1916, Hawai'i National Park was established as the 13th national park within the U.S. National Park System (NPS 2006a). Recognizing the geological research value of the active volcanic landscape on the Islands of Hawai'i and Maui, Congress declared in the enabling legislation (16 United States Code [USC] § 391) for Hawai'i National Park that:

> *The tracts of land on the island of Hawaii and the island of Maui, in the Territory of Hawaii … shall be perpetually dedicated and set apart as a public park or pleasuring ground for the benefit and enjoyment of the people of the United States … [and provide for] … the preservation from injury of all timber, birds, mineral deposits, and natural curiosities or wonders within said park, and their retention in their natural condition as nearly as possible.* (16 USC § 391)

At the time of its establishment, Hawai'i National Park included both the summits of Kīlauea and MaunaLoa on Hawai'i Island, as well as the summit of Haleakalā on Maui. It was not until 1961 that Hawai'i National Park was separated into what is currently known as Hawai'i Volcanoes National Park (HAVO) on Hawai'i Island and Haleakalā National Park (HALE) on Maui (NPS 2005a). In addition to the legislation that separated Hawai'i National Park into these distinct national parks, numerous acts have been passed to modify the Park's original enabling legislation and boundaries. These laws are listed and briefly summarized in Table 2.1-1.

Table 2.1-1. Federal legislation related to HAVO's enabling legislation (NPS 2011c).

Federal Law	Summary
Act of 1916	Established a Hawaiʻi National Park on Maui and Hawaiʻi Island
Act of 1920	Increased rights of the Governor of the Territory of Hawaiʻi to acquire privately owned lands and the right to pass over property within the boundaries of the Park.
Act of 1922	Added lands of the Kaʻū Desert and Kapāpala to the Park's boundaries.
Act of 1928	Extended the Park boundary to include additional lands.
Act of 1930	Granted the United States sole and exclusive jurisdiction of the Park, thereby prohibiting all hunting, killing, wounding, or capturing of any wild bird or animal (except dangerous animals) within the Park, and granting authority to manage and preserve from injury all timber, natural curiosities, or wonderful objects, and protect animals and birds from capture or destruction, and prevent their being frightened or driven from the Park.
Act of 1938	Added the Kalapana extension to the Park.
Act of 1959 (approved March 1959)	Transferred ownership and control of the Park from the Territory of Hawaiʻi to the United States.
Act of 1960 (approved September 1961)	Officially divided Hawaiʻi National Park into Haleakalā National Park on Maui and Hawaiʻi Volcanoes National Park on Hawaiʻi Island.
Act of 1978	Added 109 hectares (269 acres) to the Park and designated 49,817 hectares (123,100 acres) of the Park as wilderness, in accordance with the Wilderness Act of 1964.
Act of 2000	Eliminated restrictions on acquiring lands adjacent to the Park.

More recent legislation, regulations, and policies have provided additional guidance on HAVO's purpose. The most recent park purpose statement, which is currently being developed for the HAVO General Management Plan, states:

> *Hawaiʻi Volcanoes National Park protects, studies, and provides access to Kīlauea and MaunaLoa, two of the world's most active volcanoes; and perpetuates endemic Hawaiian ecosystems and the traditional Hawaiian culture connected to these landscapes*. (NPS 2011a)

The Park is now recognized on a national level for its wide-ranging values, as summarized in the Park's significance statements.

- Hawaiʻi Volcanoes National Park protects and interprets the largest and most continuously active shield volcanoes in the United States, and provides the best physical evidence of island building processes that continue to form the 2,000-mile-long Hawaiian Archipelago (NPS 2011a).
- Hawaiʻi Volcanoes National Park's active volcanoes serve as a living laboratory for scientific investigations that began over a century ago and continue to advance global understanding of volcanic processes (NPS 2011a).
- Hawaiʻi Volcanoes National Park protects, restores, and studies unique and diverse ecosystems and endemic species that are the result of over 30 million years of evolution on

an active volcanic landscape, wide climate variation, and the extreme isolation of the Hawaiian Islands (NPS 2011a).

- Hawaiʻi Volcanoes National Park encompasses the largest and most ecologically diverse wilderness in the Pacific islands (NPS 2011a).
- Hawaiʻi Volcanoes National Park embraces the Native Hawaiian spiritual significance of this landscape and interprets related cultural traditions (NPS 2011a).
- Hawaiʻi Volcanoes National Park encompasses sites, structures, objects, and landscapes that document over 600 years of human life and activities on an active volcanic landscape (NPS 2011a).
- Hawaiʻi Volcanoes National Park provides access to two of the most active volcanoes in the world and an opportunity to understand and appreciate the distinctive geology and natural and cultural adaptations to the land (NPS 2011a).

2.1.2. Geographic Setting

HAVO is located on the southeastern portion of Hawaiʻi Island, within the state of Hawaiʻi (Figure 2.1-1). Hawaiʻi Island is the youngest, largest, and southernmost island in the Hawaiian Archipelago. The island was formed when five volcanoes of varying ages—Kohala, MaunaKea, Hualālai, MaunaLoa, and Kīlauea—joined together (Juvik and Juvik 1998). HAVO covers approximately 10 percent of Hawaiʻi Island, encompassing roughly 134,760 hectares (ha) (333,000 acres [ac]). Most of HAVO falls within the Kaʻū District, which is the largest district on the island.

HAVO ranges from sea level to the summit of MaunaLoa at 4,169 meters (m) (13,677 ft) elevation (Figure 2.1-2). The makai (or seaward) extent of the Park ends at the mean high tide zone along the southern coast of the island. The 53 kilometers (km) (32 miles [mi]) of coastline within the Park extend from Kapāoʻo Point to Kupapau Point. However, the boundaries of HAVO continue to extend due to active lava flows within the Park (NPS 2011a, National Parks Conservation Association [NPCA] 2008). Since its ongoing eruption in 1983, Kīlauea has added over 200 ha (500 ac) of new land to the southwestern shore of Hawaiʻi Island (National Geographic 2009).

Significant features within HAVO include the Kīlauea summit and associated southwest and east rift zones, the MaunaLoa summit and the southwest rift zone, and a strip between the two summits of MaunaLoa and Kīlauea. Kīlauea lies in the eastern flank of MaunaLoa. In 2003, the NPS partnered with The Nature Conservancy (TNC) to acquire the 46,943-ha (116,000-ac) Kahuku Ranch from the estate of Samuel Mills Damon. (Acreage based on Tax Map Key descriptions; however, Global Positioning System (GPS)-based estimated acreage is 61, 053 ha [150,865 ac]). Kahuku Ranch, also known as the Kahuku district or Kahuku Unit, is located on the southwest rift zone of MaunaLoa Volcano. This addition to HAVO increased the size of the Park by 56 percent (Tsutsumi 2010).

HAVO is accessible by foot, bike, and vehicle. The two airports on Hawaiʻi Island, Kona International Airport and Hilo International Airport, are located roughly 201 km (125 mi) and 49 km (30 mi) from the Park Kīlauea Visitor Center, respectively.

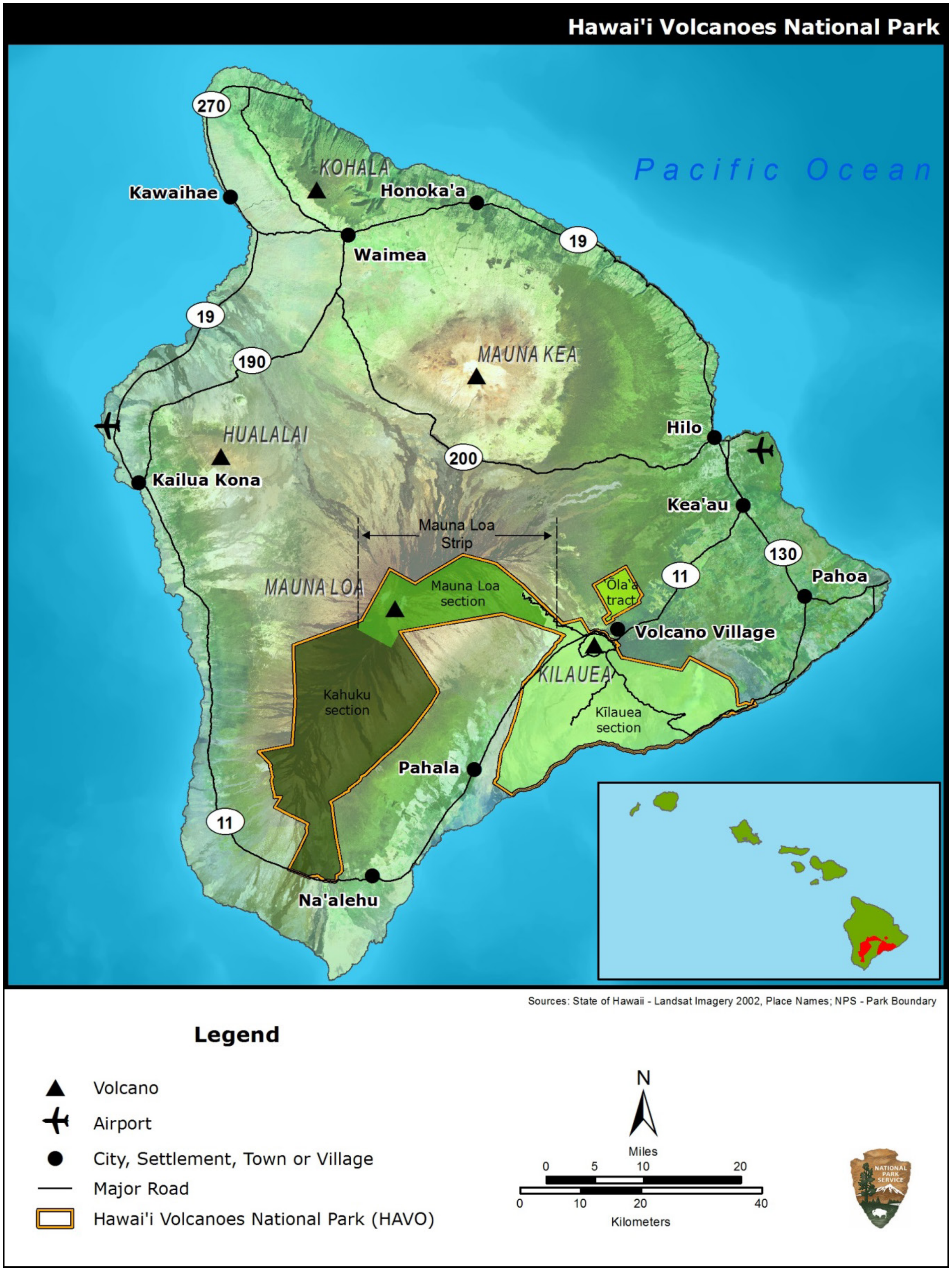

Figure 2.1-1. Location of Hawaiʻi Volcanoes National Park in the Hawaiian Islands (adapted from NPS 2011).

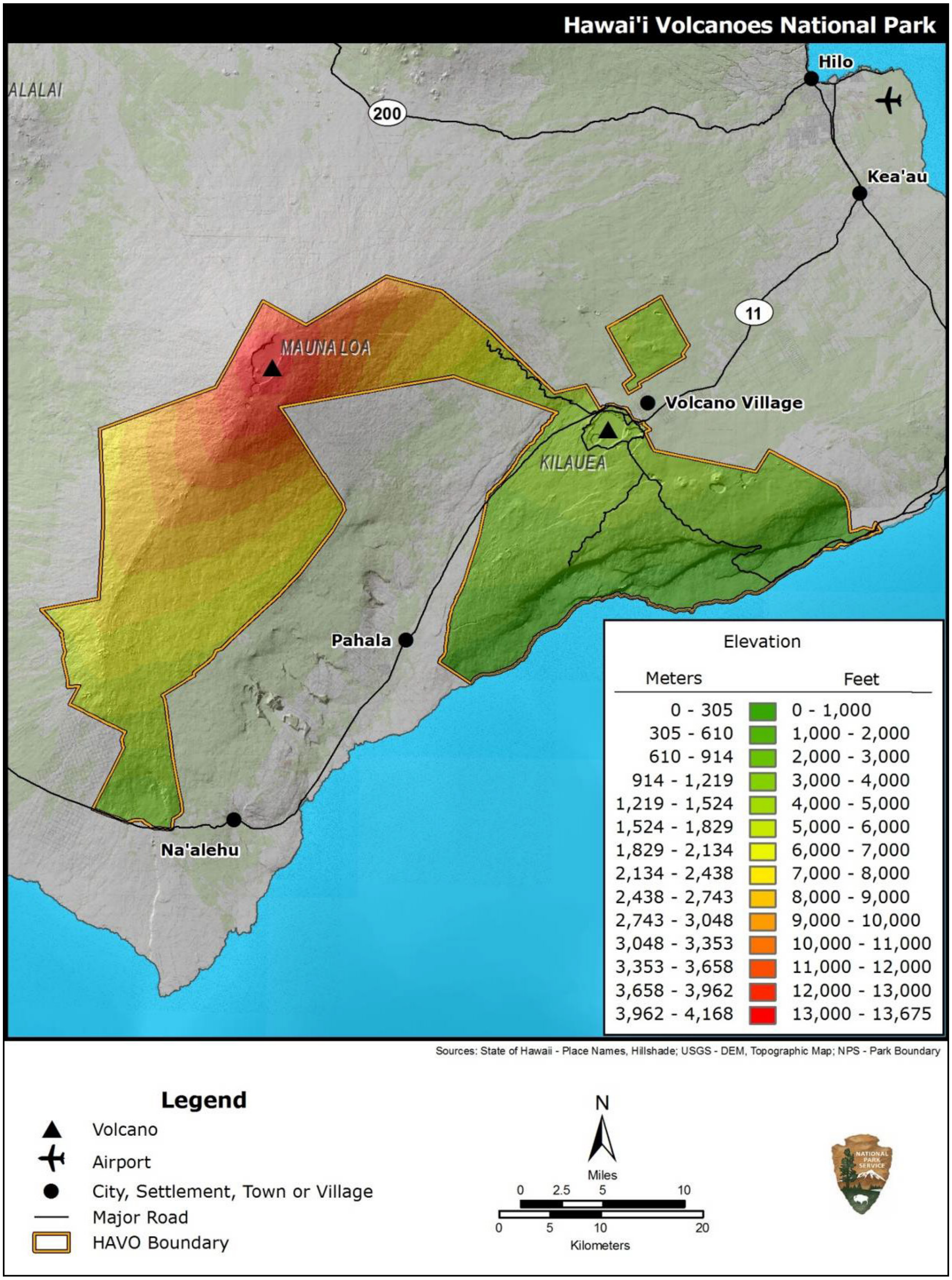

Figure 2.1-2. Elevation range within Hawai'i Volcanoes National Park (USGS, NPS).

Climate

Similar to the rest of the Hawaiian Islands, HAVO follows a two-season year with rainfall representing the major shift between seasons (NPS 2005b). In general, the summer season in Hawaiʻi is warm and dry, and trade winds originate from the northeast direction. The winter season (October through April) is typically characterized by cooler temperatures, higher precipitation, and less equable winds (Juvik and Juvik 1998).

However, climatic conditions (e.g., precipitation, humidity, temperature, wind, and solar radiation) within HAVO vary dramatically due to the Park's large land area, aspect and elevation range. This results in various microclimates throughout the Park.

Between 1949 and 2006, the mean annual temperature at the Kīlauea Visitor Center, at 1,219 m (4,000 ft) above sea level (asl), was approximately 16 degrees Celsius (ºC) (61 degrees Fahrenheit [ºF]). Mean monthly temperatures at the site ranged from 14ºC (58ºF) in January and February to 18ºC (64ºF) in August and September (Western Regional Climate Center [WRCC] 2006). Temperatures may be 12 to 15 degrees warmer in coastal lowlands within the Park compared to the Kīlauea Visitor Center (NPS 2011b). At the MaunaLoa Observatory (3,400 m or 11,150 ft asl), temperatures tend to be lower; the mean annual temperature was 7ºC (45ºF) between 1955 and 2012 (WRCC 2012).

One of the most variable conditions within the Park is the amount of rainfall different areas receive. According to rainfall estimates collected over a 30-year base period (1978–2007), mean annual rainfall can range from almost 6,000 millimeters (mm) (236 inches [in]) to less than 230 mm (9 in) per year throughout the Park (Giambelluca et al. 2011). Wet forests in areas, such as the detached ʻŌlaʻa tract, can receive more than 10 times more rainfall per year than sites in the coastal lowland region; high elevation alpine areas on MaunaLoa receive even lower rainfall amounts than lowland coastal areas. Near the Kīlauea Visitor Center, where rainfall data have been collected since 1913, mean annual rainfall is approximately 2,700 mm (106 in) per year. The majority of the rain falls during the winter season at this site (Giambelluca et al. 2011). Figure 2.1-3 depicts rainfall variability throughout the Park.

It is important to note that fog drip, an important component not accounted for in rainfall estimates, also influences the composition of vegetation and wildlife at HAVO. Fog drip is derived from the interception of cloud droplets by vegetation in high humidity conditions (Figure 2.1-4). It can be a major source of water in Hawaiʻi's middle-elevation zones (Giambelluca et al. 2011).

The rainfall patterns at HAVO are primarily the result of two phenomena: orographic rainfall and the trade wind temperature inversion layer. Orographic rainfall is rain generated when moisture-rich masses of air pushed to the island by northeasterly trade winds are forced up the side of mountains, causing adiabatic cooling and subsequently condensation and precipitation (Figure 2.1-4). As a result, areas on the windward side of high mountains receive more rainfall than the leeward portions of HAVO that are in the rain shadows of high mountains (Juvik and Juvik 1998, NPS 2005b).

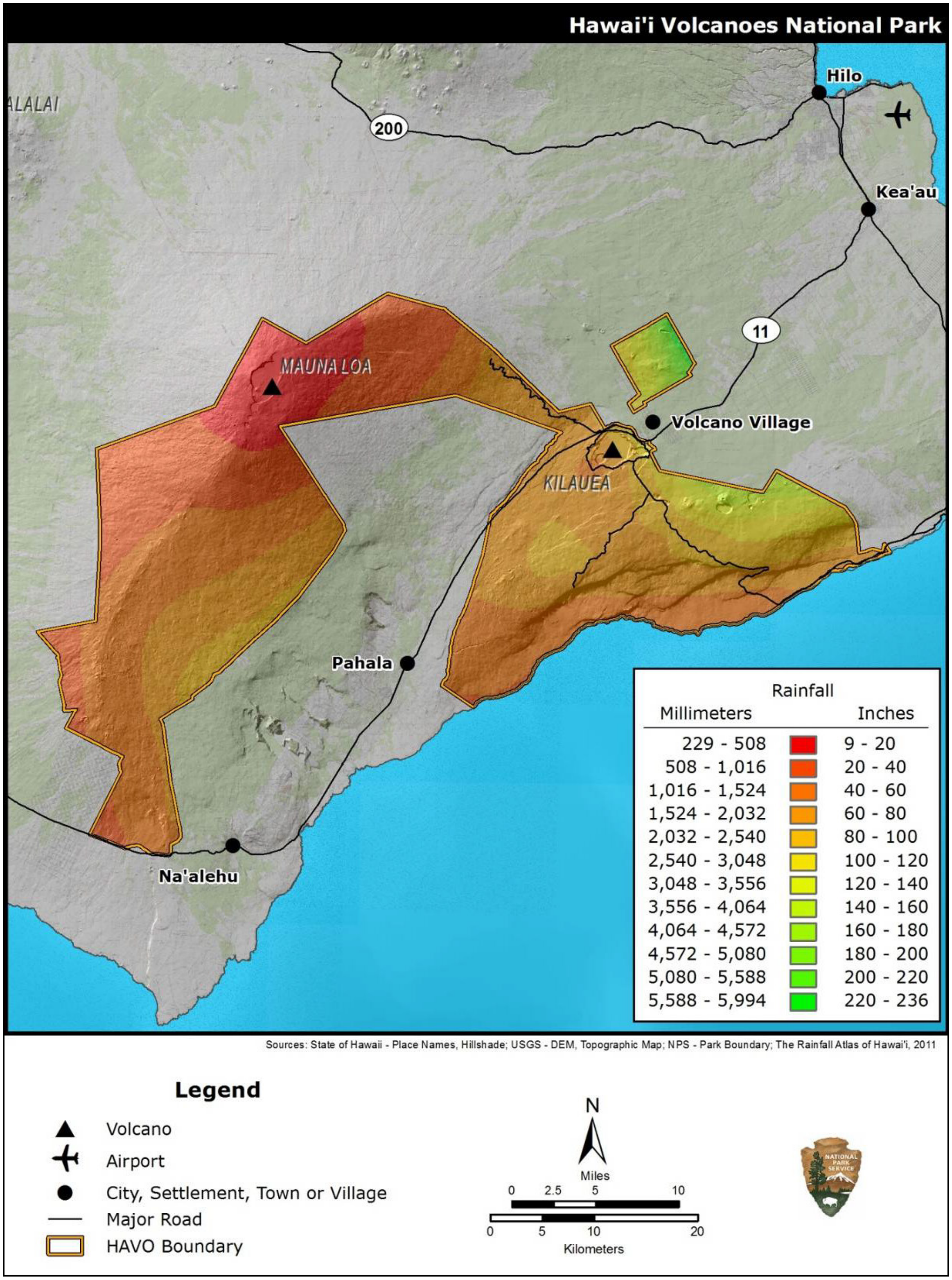

Figure 2.1-3. Mean annual rainfall throughout Hawai'i Volcanoes National Park, 1978–2007 (Giambelluca et al. 2011).

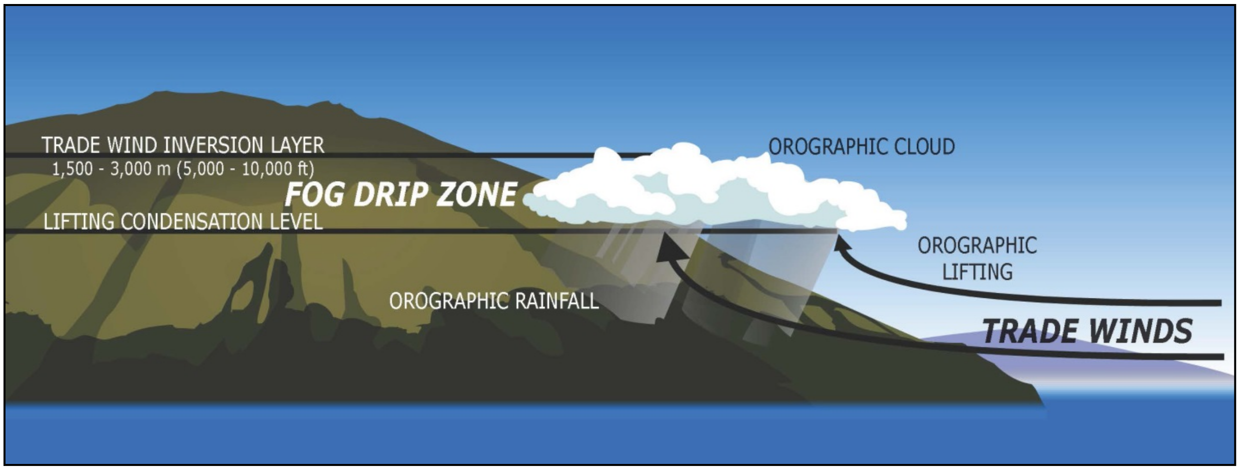

Figure 2.1-4. Orographic rainfall model and fog drip zone (Data for model Juvik and Juvik 1998).

The presence of the trade wind temperature inversion layer is another unique aspect that contributes to rainfall differences within the Park. Between 1,500 and 3,000 m (5,000–10,000 ft), rising air meets sinking air (moist convection) and moist surface air is prevented from rising to form rain clouds (NPS 2005b). This creates a cloud ceiling where the area above the layer is clearer, drier, and less humid than below the temperature inversion layer (Juvik and Juvik 1998). Such extremes of annual average precipitation produce dramatic climatic and biological gradients throughout HAVO.

Land Use and Ownership in the Park

Although the original intent of HAVO was to preserve geologic resources, the Park currently serves as a popular tourist destination for domestic and international visitors, an education and research center, a refuge for a vast array of plant and animal species, and a preserve for other significant natural and cultural resources.

Significant Visitor Establishments and Activities

The most visited areas of the Park are the Kīlauea Visitor Center and Jaggar Museum. The Kīlauea Visitor Center, located near the summit caldera, is commonly the first stop for Park visitors (Figure 2.1-5). Visitors can view interactive displays and videos, learn the most current news regarding volcanic activity, and speak to Park staff directly. Jaggar Museum, which overlooks the Halema‘uma‘u Crater at the summit of the Kīlauea Volcano, is a museum featuring the history, significance, and natural science behind volcanoes. It holds active seismographs and other equipment that scientists use today to monitor the daily activity of the volcanoes (NPS 2012a).

The Kīlauea Military Camp, which was established in 1916, is located 1 mile past the Kīlauea Visitor Center (Figure 2.1-5). The camp was historically used as a training facility, a Navy camp, and briefly as an internment camp and prisoner-of-war camp during World War II (U.S. Army MWR 2010). At present, the Kīlauea Military Camp is used as a recreation and vacation resort for all active and retired military, members of the Reserve and National Guard, and active and retired Department of Defense civilian employees (U.S. Army MWR 2010).

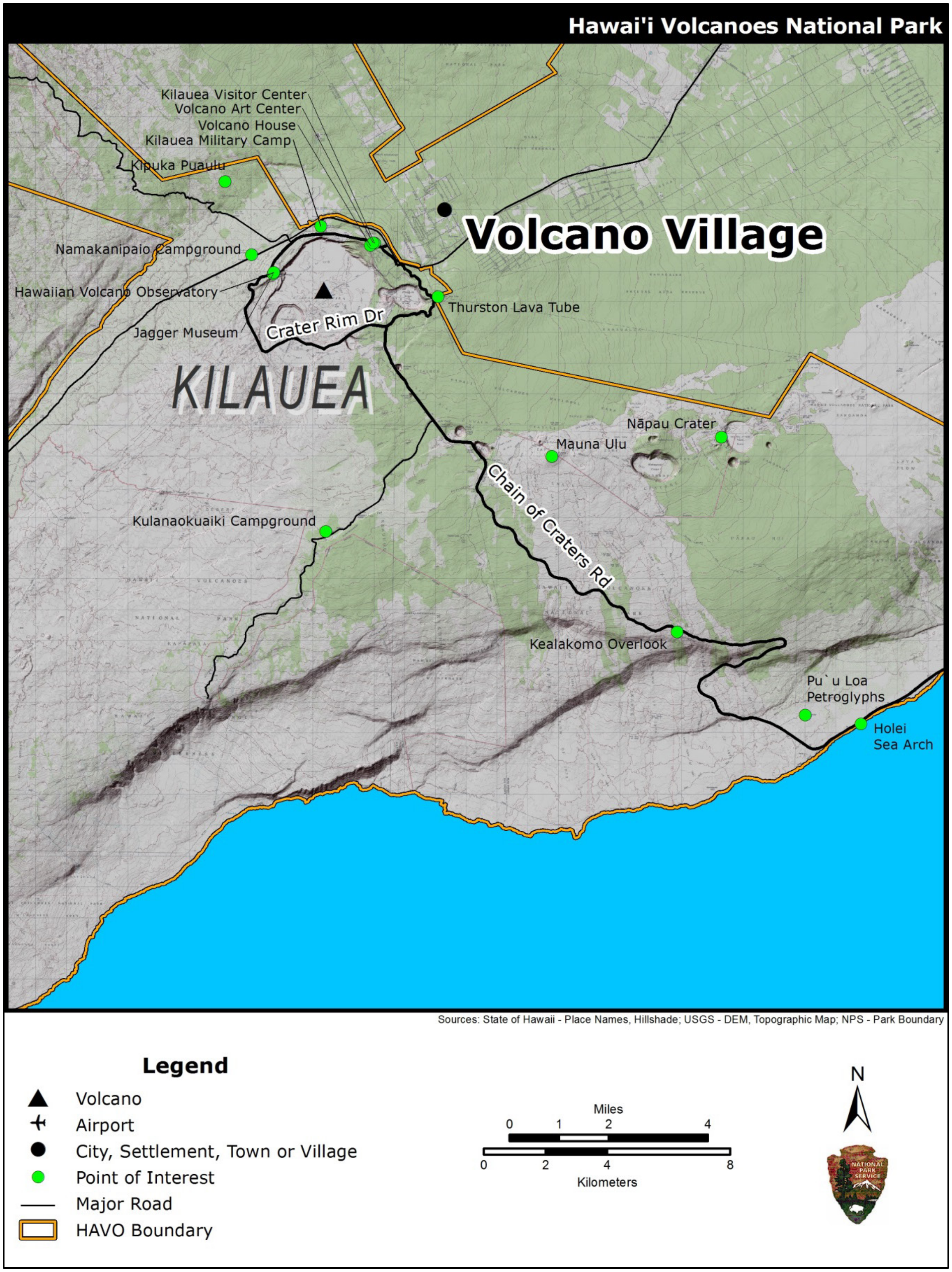

Figure 2.1-5. Significant visitor points of interest within Hawai‘i Volcanoes National Park (NPS 2012a).

The first Volcano House was constructed in 1846 by Benjamin Pitman, Senior. Successive structures evolved and were built in 1866, 1877, 1893, and 1941 (Volcano House 2012). The 1877 structure is now used as the Volcano Art Centre and the 1941 structure, rebuilt by George Lycurgus, was established as the only hotel within the Park. The Volcano House closed for seismic and fire safety improvements and re-opened in 2013 (NPS 2012a, Volcano House 2012).

HAVO contains approximately 80 km (50 mi) of paved roadways. The two main roads visitors travel are Crater Rim Drive and Chain of Craters Road (Figure 2.1-5). Crater Rim Drive is an 18-km (11-mi) roadway that circles Kīlauea's summit caldera and craters, passes through rainforest and desert, and provides access to scenic stops and short walks. Visitor highlights on this drive include Sulphur Banks, Steam Vents, Jaggar Museum, Halema‘uma‘u Crater, Devastation Trail, Kīlauea Iki Overlook, and Thurston Lava Tube (Figure 2.1-6). Chain of Craters Road offers a 64-km (40-mi) roundtrip drive that intersects with Crater Rim Drive.[1] It descends 1,128 m (3,700 ft) to the coast and dead ends at a lava flow that crossed the road in 2003 (NPS 2012a). Visitor attractions along Chain of Craters Road include Lua Manu and Pauahi craters, MaunaUlu Lava Shield, Kealakomverlook, and Hōlei Sea Arch (NPS 2012a).

Figure 2.1-6. Thurston Lava Tube, a popular visitor attraction along Crater Rim Drive (Photo: Natalie Lai 2011).

The Park also contains over 257 km (160 mi) of hiking trails, with a wide range of difficulty levels. There is a variety of scenery on these trails due to the Park's varying landscape, offering visitors opportunities to view lava flows or native rain forests (NPS 2012a). Other outdoor recreational opportunities include biking, picnicking, and camping. Two drive-in campgrounds, Nāmakanipaio

Half of Chain of Craters Road has been closed to visitors for the past five years due to eruptive activity in Halema‘uma‘u.

and Kulanaokuaiki (Figure 2.1-5), are available free of charge. These campgrounds operate on a first-come, first-serve basis and do not require a permit or reservations (NPS 2012a).

Portions of the Kahuku Unit (below 4,200 ft) are currently available to the public for day-use on weekends only. These areas contain hiking, picnicking, sightseeing, and interpretive programs (NPS 2012d). Additional visitor facilities and activities may also be developed in the Kahuku Unit as part of the new General Management Plan.

Scientific Research and Establishments

The Hawaiian Volcano Observatory (HVO), formerly known as Whitney Seismograph Vault No. 29, was constructed in 1912 as the first laboratory for seismology (NPS 2012a). The observatory, located at the rim of Kīlauea Caldera (Figure 2.1-5), is currently managed by the U.S. Geological Survey (USGS). HVO monitors and studies four volcanoes: Kīlauea, MaunaLoa, Hualālai, and Haleakalā (NPS 2012a, USGS 2012). Additionally, the Pacific Islands Ecosystem Research Center, USGS (PIERC-USGS), NPS Inventory and Monitoring Program, and U.S. Forest Service (USFS) quarantine laboratories are located in the Park. There are 12 weather stations and nine air quality monitoring stations located in the Park. Finally, HAVO attracts a number of research scientists from around the world who study the biological and physical processes occurring in the Park. In addition to geologic processes, these studies focus on the endemic invertebrates, birds, and plants; impacts of invasive introduced species; the influence of environment on species and community processes; and a handful of ethnographic studies (NPS 2012c).

Natural and Cultural Resource Management

Resource protection is a major operational function within the Park. This encompasses all activities related to the management, preservation, and protection of the Park's cultural and natural resources, including invasive species control, wildland fire management, ecosystem restoration, and cultural resource management (NPS 2005a). Various cultural resources, such as heiau (temples), graves, paved trails, canoe landings, petroglyphs, shelter caves, and agricultural areas, are preserved in the Park (NPCA 2008). Several features listed in the National Register of Historic Places occur within HAVO, including the 1790 Footprints, ʻĀinahou Ranch, ʻAinapō Trail, Kīlauea Crater, Puna-Kaʻū Historic District, Volcano House, Whitney Seismograph Vault No. 29, and Wilkes Campsite (NPS 2006b, 2012a).

In 1978, Congress designated 49,817 ha (123,100 ac) of wilderness within the Park. In 2012, an additional 48,973 ha (121,015 ac) were determined eligible wilderness in the Kahuku unit and are currently being studied for wilderness designation (NPS 2012d).

Adjacent Land Use

The Park is surrounded by various federal, state, and privately owned lands (Figure 2.1-7), most of which are managed for conservation and agriculture purposes. Several state forest reserves, natural area reserves, and game management areas are located close to the Park. State Route 11, also known as Māmalahoa Highway, is the primary roadway in the region and transverses the Park. Ownership and management of surrounding land uses have the potential to affect management and natural resource conditions within HAVO.

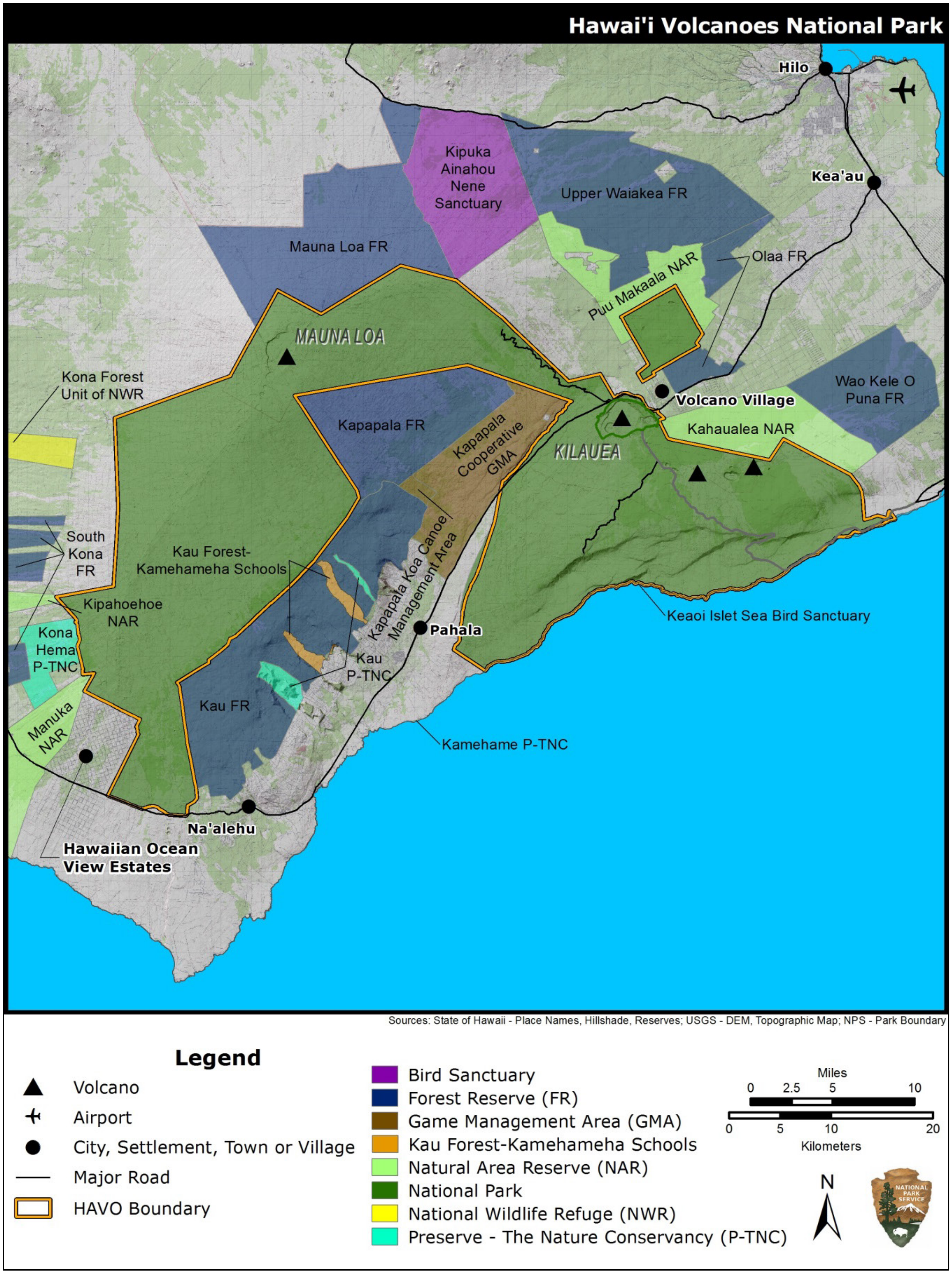

Figure 2.1-7. Land uses adjacent to the Park (NPS, State of Hawaii; TMK datasets available at http://geoportal.hawaii.gov/datasets/parcels-tmk).

Private lands surrounding the Park include lands owned by Kamehameha Schools (KS) and TNC. Both of these private landowners (TNC and KS), along with the Park, USFWS, State Department of Corrections, State Division of Forestry, USGS-Pacific Islands Ecosystem Research Center, and U.S. Forest Service are members of Three Mountain Alliance, the largest of the Hawaii Association of Watershed Partnerships.

KS is the largest private landowner in the state of Hawaiʻi. The organization owns several parcels adjacent to HAVO and is active in agricultural operations, as well as conservation management and stewardship of agricultural lands (including fencing and nonnative ungulate removal). TNC owns and manages three areas near HAVO: the Kona Hema Preserve (three contiguous units totaling 3,262 ha or 8,061 ac), the Kaʻū Preserve (four partially contiguous units totaling 1,435 ha or 3,548 ac), and Kamehame Preserve (10 ha or 24 ac) on the Kaʻū coast. TNC is also involved with fencing and nonnative ungulate removal on their lands adjacent to the Park (NPS 2011a).

The Natural Area Reserves System (NARS) was established by the State of Hawaiʻi in 1971 to "preserve and protect, in perpetuity, examples of Hawaii's unique terrestrial and aquatic natural resources, in order that present and future generations may be able to learn about and appreciate these natural assets" (NARSC 1997). The State Division of Forestry and Wildlife within the Department of Land and Natural Resources (DLNR) is mandated to manage and protect these lands so that the natural resources remain as unmodified as possible. There are four national area reserves (NARs) adjacent to HAVO: Kahaualeʻa NAR, Puʻu Makaʻala NAR, Kīpāhoehoe NAR, and Manukā NAR (Figure 2.1-7).

Forest reserves (FR) are also managed by the State Division of Forestry and Wildlife. These multi-use areas have several management goals that include providing public recreational opportunities, protecting forest watersheds, supporting sustainable forest industry, and maintaining biological integrity of native ecosystems (Hawaiʻi Administrative Rules, Chapter 104). FRs near HAVO include the Kapāpala FR, South Kona FR, Kaʻū FR, ʻŌlaʻa FR, MaunaLoa FR, Wai Kele O Puna FR, and Upper Waiakea FR (Figure 2.1-7).

Other state and federally managed conservation- or recreation-oriented lands in the vicinity of HAVO include Kapāpala (Cooperative) Game Management Area, Kapāpala Koa Canoe Management Area, Kīpuka ʻĀinahou Nēnē Sanctuary, and the Kona Forest Unit of the Hākalau Forest National Wildlife Refuge (NWR) Complex. The Keaoi Islet Seabird Sanctuary near Halapē was formerly managed by the Offshore Islet Restoration Committee, but has largely disappeared since the 1975 earthquake (Offshore Islet Restoration Committee 2012).

Several small communities exist near the Park, including Volcano Village, Pāhala, and Nāʻālehu (Figure 2.1-7). Volcano Village, located near the Kīlauea summit area, encompasses rural residential and agricultural lands and had an estimated population of 2,575 individuals in 2010 (Department of Business, Economic Development, and Tourism [DBEDT] 2011). Pāhala is a small community located outside of the Park between the Kahuku and Kīlauea sections, with a population of 1,356 individuals (DBEDT 2011).

Nāʻālehu is smaller than Volcano Village and Pāhala, with a total of 866 residents in 2010 (DBEDT 2011). Hawaiian Ocean View Estates is a large residential subdivision located immediately adjacent to the Kahuku Unit. Royal Gardens Subdivision, located on the eastern boundary of the Park, has been mainly uninhabited since lava flowed through the subdivision in the early 1980s (USGS 2012). Other nearby subdivisions include MaunaLoa Estates and Volcano Gold Course subdivision.

The sugar industry dominated the communities of Pāhala and Nāʻalehu until the 1990s. Today, the primary employment industries in Pāhala and Nāʻālehu are agriculture/forestry/fishing and construction. Retail trade and education/health/social services are the main industries in Hawaiian Ocean View (Kaʻū Community Development Plan Steering Committee in prep.). Diversified agriculture and tourists are important in the Puna areas (Puna Community Development Plan Steering Committee 2011).

2.1.3. Visitation Statistics and Economics

HAVO is open year round, 24 hours a day. Visitors come to the Park from all over the world, as well as locally from the other main Hawaiian Islands. HAVO is the single most visited tourist destination in the state and a major contributor to the local economy (Pacific Business News [PBN] 2012). High visitation has been attributed to resource accessibility. Although the Park itself covers a large area, HAVO offers convenient two-wheel drive roadways, whereas other natural areas in Hawaiʻi are commonly four-wheel drive. This is important since most rental car companies forbid taking their cars on unpaved roads (NPS 2012a).

According to HAVO staff, what makes the experience at the Park unlike any other is "the interplay of natural forces, including volcanism, weather, wildlife, vegetation, vistas, smells, color and shape of landform, air quality and varied light" (NPS 2011a). Visitors can also choose to visit the Park on their own using the various maps and materials offered by the Kīlauea Visitor Center or join an informative guided tour or program.

Since the Park first began recording visitation statistics in 1921, HAVO has received a cumulative total of 73,030,830 visitors (including residents and non-residents) (NPS 2012a). According to NPS' Public Use Statistics Office (PUSO) (2011), HAVO received an annual average of 1,321,314 visitors between 1990 and 2011 (Table 2.1-2).

Table 2.1-2. Visitor use statistics for Hawaiʻi Volcanoes National Park since 1990 (NPS PUSO 2012).

Year	# of Visitors	Change from Previous Year
1990	1,096,816	–
1991	1,238,653	12.93%
1992	1,151,661	-7.02%
1993	1,143,741	-0.69%
1994	1,174,289	2.67%
1995	1,175,028	0.06%
1997	1,832,087	48.76%

Table 2.1-2 (continued). Visitor use statistics for Hawai‘i Volcanoes National Park since 1990 (NPS PUSO 2012).

Year	# of Visitors	Change from Previous Year
1998	1,352,377	-26.18%
1999	1,502,855	11.13%
2000	1,514,636	0.78%
2001	1,343,286	-11.31%
2002	1,110,998	-17.29%
2003	991,875	-10.72%
2004	1,307,391	31.81%
2005	1,661,196	27.06%
2006	1,612,246	-2.95%
2007	1,467,779	-8.96%
2008	1,270,538	-13.44%
2009	1,233,105	-2.95%
2010	1,304,667	5.80%
2011	1,352,122	3.64%
Average	**1,321,314**	**2.28%**

However, visitation fluctuates seasonally and annually. Visitation is generally highest in July, August, and March as these months represent vacation periods for families with school children (NPS 2005a). The number of visitors to the Park also tends to mimic volcanic activity, which tends to attract higher visitor numbers. In addition, visitation levels at HAVO are closely related to trends in Hawai‘i Island visitation, indicating that the majority of visitors are not residents (NPS 2005a, Stynes 2009, 2011).

Visitor spending at HAVO represents one of the island’s leading economic contributors. The four economic sectors most directly affected by Park visitation are lodging, restaurants, retail trade, and recreation/amusement activities (NPS 2011a). In 2010, total spending of HAVO visitors was estimated at $88,258,000. The majority of this total was spent on lodging and food/beverage (52 percent) and retail (29 percent) (PBN 2012). This spending supported roughly 1,223 full- and part-time jobs in the Volcano area (NPS PUSO 2011). Table 2.1-3 summarizes 2010 data for spending and economic impacts of HAVO (NPS 2011a, NPS PUSO 2011).

According to analysis completed by Stynes (2009), most of the spending associated with Park visitation is from non-resident visitors, and visitation decreases during economic down turns. In Fiscal Year (FY) 2004, roughly 40 percent of paying visitors to the Park came as passengers of a commercial tour company, many of which originally arrived by large tour ships (NPS 2005a).

Table 2.1-3. Spending and economic impacts of Hawaiʻi Volcanoes National Park visitors in 2010 (NPS PUSO 2011).

Economic category	Metric	Total revenue
Visitors	Visits	1,304,667
	Overnight Stays	77,320
	Total Spending	$88,258,000
Direct Effects[1]	Jobs	835
	Labor Income	$29,176,000
Total Effects[2]	Value Added[3]	$45,580,000
	Jobs	1,223
	Labor Income	$42,179,000

[1] Changes in sales, income, and jobs that directly benefit from visitor spending.

[2] Sum of direct, indirect, and induced effects.

[3] Sum of employee compensation, income of sole proprietors, and indirect business taxes; value added by the region to the final good or service being produced.

Although the Park attracts many day-trip visitors, a challenge that exists for the Park and the Hawaiʻi Island community is to get those visitors to stay overnight and spend more money in the local economy. According to 2010 statistics, less than 6 percent of visitors stayed overnight. This is in part due to limited lodging options in the Park; the Volcano House has recently been closed for renovations and Kīlauea Military Camp is limited to active and retired military. There are, however, two campgrounds in the Park and numerous bed and breakfast establishments just outside the Park. The majority of HAVO's visitors are served by commercial tour companies that focus on one-day trips to the Park (NPS 2005a). These numbers may improve once the Volcano House re-opens.

The remainder of Hawaiʻi Island's economy relies heavily on tourism. The leisure/hospitality industry is the largest employer (County of Hawaiʻi 2007). Diversified agriculture (e.g., flowers, nursery products, coffee, macadamia nuts, tropical fruits, vegetable crops, orchards, aquaculture, forestry) and research are secondary components of the island's economy (Research Solutions, LLC and Gopalakrishnan 2002, County of Hawaiʻi 2007). Most of the state's livestock and aquaculture facilities are on Hawaiʻi Island. As the primary tourist destination on the island, HAVO represents a vital contributor to the island's economy (PBN 2012).

2.2. Natural Resources

2.2.1. Ecological Units and Watersheds

HAVO is physiographically divided into four main sections: Kīlauea, ʻŌlaʻa, MaunaLoa, and Kahuku (Figure 2.2-1). The Kīlauea section contains the summit of Kīlauea Volcano, Kīlauea's active southwest and east rift zones (areas associated with the rise and eruption of magma).

ʻŌlaʻa is comprised of the detached 4,047-ha (10,000-ac) ʻŌlaʻa Forest. The MaunaLoa section encompasses the summit of MaunaLoa Volcano and the MaunaLoa Strip, a narrow piece of land between MaunaLoa and Kīlauea. The newly acquired Kahuku section (also known as the Kahuku

Unit) encompasses 46,943 ha (116,000 ac) along the southwest rift zone of MaunaLoa from the summit to 762 m (2,500 ft) elevation (NPCA 2008).

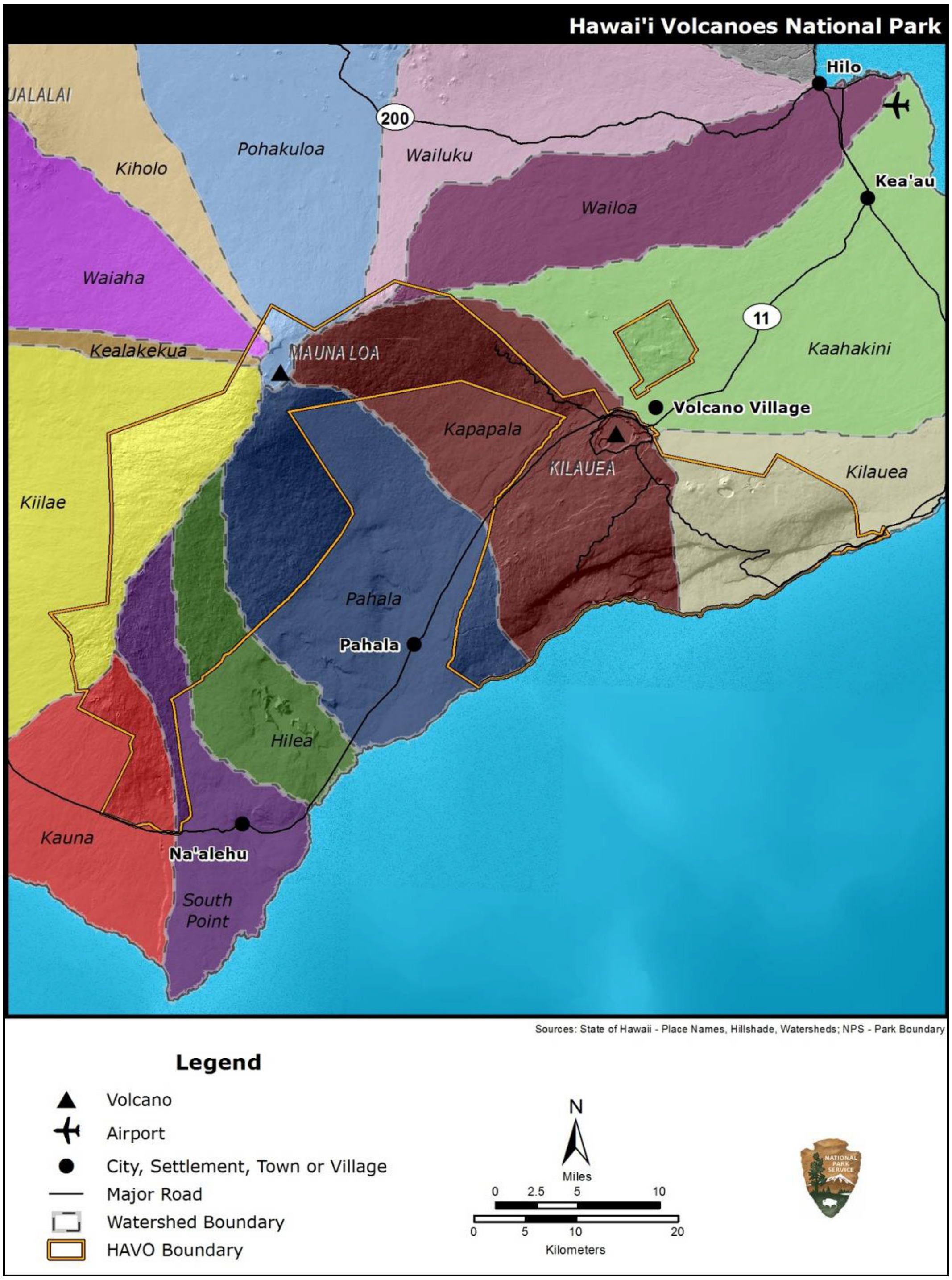

Figure 2.2-1. Watersheds within Hawai'i Volcanoes National Park and the vicinity (NPS, State of Hawaii watershed data made available at: http://geoportal.hawaii.gov/datasets/cfe1f5708d944a15ada695fc18f423a0_8/data).

The State of Hawai'i identifies 14 watersheds within the Park boundaries (Figure 2.2-1). The majority of the Park is located in the Kapapala and Pāhala watersheds. Although these watersheds periodically carry runoff to a common water body or outlet, there are no permanent surface streams in HAVO. Watersheds are often used to evaluate ecosystem structure, function, and composition; however, this approach is not used in this assessment since HAVO's boundaries encompasses only fragments of watersheds rather than extended units from the mountains to the oceans (Hay Smith et al. 2005).

There are seven ecological units in the Park (Table 2.2-1, Figure 2.2-2). These units were identified by park staff based on the vegetation communities defined by Mueller-Dombois and Fosberg (1974) and adapted from the current Fire Management Units (FMUs) established in the HAVO Fire Management Plan (NPS 2005b). The ecological units at HAVO are composed of different plant communities primarily created by sharp gradients of rainfall and elevation.

Table 2.2-1. Summary of ecological units.

Ecological Unit	Land Area	Elevation Range	Mean Annual Rainfall
Alpine and Aeolian	~37,948 ha (~93,771 ac)	2,590–4,169 m (8,500–13,677 ft)	508–711 mm (20–28 in)
Subalpine	~31,466 ha (~77,755 ac)	1,981–2,590 m (6,500–8,500 ft)	762–1,016 mm (30–40 in)
Montane Seasonal	~10,705 ha (~26,454 ac)	1,219–2,042 m (4,000–6,700 ft)	1,016–1,524 mm (40–60 in)
Mesic/Wet Forest	~22,084 ha (~54,571 ac)	760–1,340 m (2,500–4,400 ft)	1,524–3,556 mm (60–140 in)
Mid-elevation Seasonal	~29,854 ha (~73,771 ac)	305–1,219 m (1,000–4,000 ft)	508–1,524 mm (20–60 in)
Coastal Lowland	16,684 ha (~41,228 ac)	0–709 m (0–2,325 ft)	990–2,134 mm (39–84 in)
Coastal Habitat	224 ha (~554 ac)	0–40 m (0–130 ft)	970–1,955 mm (38–77 in)

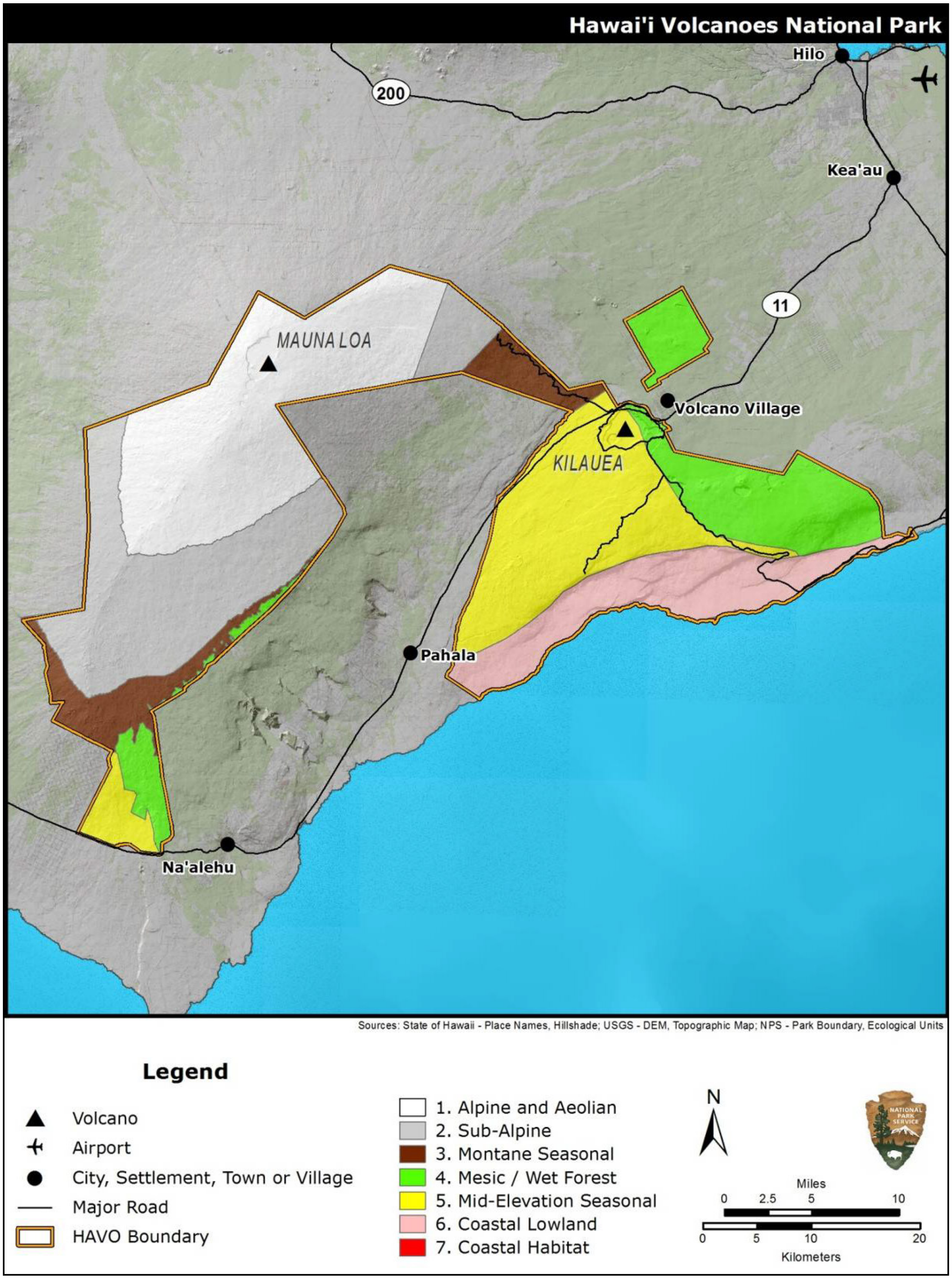

Figure 2.2-2. Ecological units within Hawaiʻi Volcanoes National Park (NPS 2005b). Note: Difficult to see coastal habitat unit due to scale; see Figure 4.12-1.

Alpine and Aeolian

The alpine and aeolian unit is the highest elevation unit within HAVO, stretching from 2,590 m (8,500 ft) elevation to the summit of MaunaLoa at 4,169 m (13,677 ft). This unit is unique because it is located above the trade wind inversion layer, which prevents warm, moist surface air from rising. As a result, the climate in the alpine and aeolian environment is clearer, cooler, and less humid than below the inversion layer (Juvik and Juvik 1998, NPS 2005b). There are extreme variations in daily temperatures in this unit, with occasional freezing during winter nights. Average annual temperatures range from 6°C to 9°C (43°F–48°F). Mean annual rainfall in the alpine and aeolian unit is between 508 and 711 mm (20–28 in) (NPS 2005b, 2011a, Giambelluca et al. 2011).

Large portions of the alpine and aeolian unit are unvegetated, particularly near the summit of MaunaLoa, because aeolian ecosystems depend on windblown food and nutrients from lower elevations. In lower elevations of the unit, vegetation is dominated by a few hardy native plants including low-growing shrubs and grasses (Stone and Pratt 2002). Scattered kīpuka, or islands of older vegetation surrounded by nearly barren lava flows, often have distinct biotic communities. The endemic Hawaiian Petrel, or ʻUaʻu (*Pterodromo sandwichensis*), wekiu bug (*Nysius wekiuicola*), and a wolf spider (Lycosidae) comprise some of the wildlife in the alpine and aeolian unit (Stone and Pratt 2002, NPS 2005b, 2011a).

Subalpine

The subalpine unit is located immediately downslope of the alpine and aeolian unit between 1,981 and 2,590 m (6,500–8,500 ft) elevation. This unit is not contiguous, occurring in portions of both the Kahuku and MaunaLoa sections. In the MaunaLoa subalpine section, annual precipitation averages between 762 and 1,016 mm (30–40 in), with most falling in the winter months. The Kahuku subalpine is wetter due to more frequent clouds and fog drip (i.e., condensation of moisture on vegetation). The average annual temperature in this unit is between 9.44°C and 12.22°C (49°F–54°F) (NPS 2005b, 2011a).

In the MaunaLoa section of the subalpine unit, vegetation is sparse and occurs mainly in two kīpuka: Kīpuka Kulalio and Kīpuka Maunaʻiu. These kīpuka lie on older pāhoehoe lava flows dated between 1,500 and 4,000 years old (Stone and Pratt 2002). ʻŌhiʻa (*Metrosideros polymorpha*) scrub is the most widespread plant community in the subalpine unit and is characterized by scattered, low-growing ʻōhiʻa, with an understory of native shrubs and grasses. On the younger or ʻaʻā flows, ʻōhiʻa trees are even more scattered. Native plants dominate the vegetation in the MaunaLoa's subalpine unit and rare species, such as māmane (*Sophora chrysophylla*) and the outplanted MaunaLoa silversword (*Argyroxiphium kauense*), occur here. Similar vegetation is found in the Kahuku subalpine, although native species abundance and diversity is reduced in the Kahuku section due to centuries of browsing and trampling by mouflon sheep and other ungulates (Stone and Pratt 2002, NPS 2005b, 2011a). However, the Kahuku subalpine contains the largest natural population of the MaunaLoa silversword remaining on the island.

Montane Seasonal

The montane seasonal unit at HAVO occurs between 1,219 and 2,042 m (4,000–6,700 ft). It is located on the lower slopes of the MaunaLoa section and on the southwest facing slope of the

Kahuku section between 1,524 and 1,829 m (5,000–6,000 ft) elevation. The MaunaLoa montane seasonal has a summer-dry climate, with drier conditions during summer. Rainfall increases with decreasing elevation. In contrast, the montane seasonal unit in the Kahuku section is summer-wet, with the majority of the rainfall occurring in the summer. Kahuku's montane seasonal unit is characterized by afternoon cloud build-up and low-lying fog. Mean annual temperatures are 10°C to 15°C (50°F–60°F), with occasional winter frost at higher elevations (NPS 2005b, 2011a). Mean annual rainfall in the entire montane seasonal unit ranges from 1,016 to 1,524 mm (40–60 in) (Giambelluca et al. 2011).

The vegetation of the montane seasonal unit varies with substrate age and soil depth. Several small but significantly diverse and well-developed mesic forests (Kīpuka Kī, Kīpuka Puaulu, and three Kīpuka located along the shared boundary with Keauhou Ranch) occur on the lower eastern portion of MaunaLoa's montane seasonal unit. A unique mānele (*Sapindus saponaria*)/koa (*Acacia koa*)/ʻōhiʻa forest containing many threatened, endangered, and rare species occurs in these kīpuka (NPS 2005b, 2011a). Upslope of the kīpuka, on weathered pāhoehoe, koa is the primary canopy tree. Decades of herbivory by nonnative cattle and goats have removed much of the native vegetation. The subsequent removal of these animals resulted in limited recovery of native plants. In the understory, nonnative pasture grasses dominate in lower elevation areas, while native shrubs, sedges, and grasses are more common in higher elevation areas of MaunaLoa's montane seasonal unit. Younger ʻaʻā flows support much less vegetation than areas with older pāhoehoe flows, containing open to sparse ʻōhiʻa woodlands, with sparse or scattered native shrubs (Figure 2.2-3) (NPS 2005b, 2011a).

Figure 2.2-3. Montane seasonal unit in the MaunaLoa section (Photo: Tiffany Agostini 2012).

In the Kahuku section, vegetation predominantly consists of open to closed stands of ʻōhiʻa. The ground cover is composed of a variety of native shrubs and ferns, as well as native and nonnative grasses. Small stands of koa with invasive grass understory also occur, particularly on the western portion of Kahuku. Similar to the MaunaLoa section, younger ʻaʻā flows support more open to sparse ʻōhiʻa woodlands in the Kahuku montane seasonal (NPS 2005b, 2011a).

Mesic/Wet Forest

The mesic and wet forest communities at HAVO grade into each other such that delineating the boundary between the two is difficult. They share many of the same species and fire issues. For these reasons, these two communities were put into a single FMU (NPS 2005b). In this assessment, however, the mesic and wet forests are discussed separately due to differences in resources, weeds, and management issues (Linda Pratt, Botanist, USGS, pers. comm. 2014). Mesic and wet forests are also present in a distinct component of the Park known as Kahuku Pasture.

Wet Forests

Wet forests in HAVO receive between 2,286 and 3,556 mm (90–140 in) of rainfall annually (NPS 2005b). Nearly all of HAVO's wet forest is found in the eastern region of the Park where trade wind rains fall almost daily. Wet forests cover about 12,140 ha (30,000 ac) of the Park and are found in five locations: on the eastern rim of the summit caldera of Kīlauea Volcano; along the East Rift zone of Kīlauea above approximately 700 m (2,300 ft) elevation; in the ʻŌlaʻa tract east of the community of Volcano; in Kahuku above the Kaʻū Forest Reserve; and on the eastern edge of the pastures in Kahuku between 914 and 1,524 m (3,000–5,000 ft) elevation. Wet forests are much more extensive in HAVO than mesic forests.

The wet forests in HAVO are characterized by two major plant associations: tree fern or hāpuʻu (*Cibotium glaucum*) forests and uluhe fern (*Dicranopteris linearis*) forests. Tree fern forests are multi-layered and dominated by ʻōhiʻa and a diversity of tree ferns (Figure 2.2-4). On the older, deep ash soils (such as the ʻŌlaʻa forest and some areas of the east rift zone of Kīlauea), tree ferns form a dense canopy with open stands of other native trees. On younger substrates in tree fern forests (such as Kīlauea summit and volcanically active areas), the canopy is composed of closed stands of ʻōhiʻa, with a subcanopy of other native trees and tree ferns (NPS 2011a).

Uluhe fern forests are common in early successional communities on younger lava flows. These forests are also present in secondary successional communities that experienced ʻōhiʻa dieback, a natural successional phenomenon in which large stands of ʻōhiʻa lose crown foliage (Mueller-Dombois 1983). Uluhe forms a dense mat-like cover climbing over trees and shrubs, suppressing the growth of other species. As a result, species diversity is lower in the uluhe fern forests than tree fern forests at HAVO (NPS 2011a).

Figure 2.2-4. Tree fern or hāpuʻu (*Cibotium glaucum*) wet forest (Photo: Tiffany Agostini 2012).

Mesic Forests

Mesic forests in HAVO receive less annual rainfall than wet forests, with between 1,524 and 2,286 mm (60–90 in) per year. In HAVO, mesic forests are primarily found in the following locations: east of Chain of Craters Road and west of wet forests; makai (seaward) of wet forest in the southeastern section of the Park; and in the lower and eastern portions of the Kahuku Unit (NPS 2005b).

Mesic forests are characterized by closed to open stands of ʻōhiʻa and koa. The understory vegetation in HAVO's mesic forests is highly variable. In Kahuku, the mesic forest understory is composed of native trees, shrubs, and tree ferns. The understory vegetation is similar east of Chain of Craters Road, but there it also contains dense stands of the introduced faya tree (*Morella faya*) or the native uluhe fern. In the lower east rift of Kīlauea, the understory is covered by the introduced swordfern fern (*Nephrolepis* spp.) (NPS 2005b).

Kahuku Pasture (Former Mesic and Wet Forest)

In the lower eastern portion of the Kahuku Unit, between 762 and 1,524 m (2,500–5,000 ft) elevation, there is an approximately 2,914-ha (7,200-ac) area that was extensively cleared for cattle grazing by the previous landowner. Most of the area has an open canopy of ʻōhiʻa or ʻōhiʻa/koa. Nonnative pasture grasses, particularly kikuyu grass (*Cenchrus clandestinus*), dominate the understory. Small, isolated patches of diverse mesic and wet forest are scattered and increasingly abundant on the eastern boundary of the pasture adjacent to the Kaʻū Forest Reserve. This area is considered more mesic than wet. Domestic cattle were removed in 2010, and the Park is developing plans to facilitate forest recovery (NPS 2005b, 2011a).

Mid-elevation Seasonal

The mid-elevation seasonal unit is typically sheltered from daily trade-wind rains and, therefore, receives low rainfall compared to most regions of the Park. Precipitation ranges from 508 to 1,524 mm (20–60 in) per year, with the western portion receiving less rainfall (Giambelluca et al. 2011). There is typically a distinct dry, warm period during summer (NPS 2005b, 2011a). Temperatures in the mid-elevation seasonal unit vary from 15°C to 19°C (60°F–72°F) (Stone and Pratt 2002). The zone is made up of two units, one on Kīlauea and the other in Kahuku.

The Kīlauea unit extends from Kīlauea Caldera at approximately 1,219 m (4,000 ft) to the Hīlina, Poliokeawe, and Hōlei Pali at roughly 305 m (1,000 ft) elevation. The Ka‘ū Desert makes up a large portion of this unit. The collapsed summit of Kīlauea, the southwest Rift zone, and the upper Chain of Craters region are also included in this unit (Stone and Pratt 2002).

Fire has been most prevalent in the mid-elevation seasonal Kīlauea unit compared to other areas of the Park. Past herbivory by nonnative cattle and goats followed by wildfires have reduced native vegetation cover and promoted rapid re-establishment of nonnative grasses (NPS 2005b, 2011a). The vegetation in the mid-elevation seasonal unit is also dependent on substrate and rainfall. Younger flows or areas with little ash-soil development or water-holding capacity are composed of sparse native shrubs, mostly pūkiawe (*Leptecophylla tameiameiae*) and ‘a‘ali‘i (*Dodonaea viscosa*) and scattered, low-growing ‘ōhi‘a. On older lava flows with deeper ash development, dry ‘ōhi‘a woodlands are common. These woodlands are often invaded by nonnative grasses and sedges including bush beardgrass (*Schizachyrium condensatum*), broomsedge (*Andropogon virginicus*), and molasses grass (*Melinis minutiflora*). In other areas of the mid-elevation seasonal unit, native species have been displaced by faya trees and savannas of nonnative grasses.

The Ka‘ū Desert lies in Kīlauea’s rain shadow and receives less than 1,200 mm (47 in) of moisture annually (U.S. Fish and Wildlife Service [USFWS] 2002). This area is particularly dry and barren. The substrate is mostly young, unweathered lavas and drought-tolerant plants are sparsely distributed. Strong winds and sulfur dioxide fumes contribute to reduced plant growth in the Ka‘ū Desert (Stone and Pratt 2002).

In Kahuku’s mid-elevation seasonal unit, there is an open to sparse dry woodland with small to moderate sized ‘ōhi‘a. The sparse ground cover is dominated by nonnative grasses (Benitez et al. 2008). Nonnative Christmas berry (*Schinus terebinthifolius*) is also an important component of the Kahuku mid-elevational seasonal unit (NPS 2005b, 2011a).

Coastal Lowland

The coastal lowland unit lies below the mid-elevation seasonal and wet/mesic forest units on the lower slopes of Kīlauea. The unit is bounded by Kīlauea’s Great Crack on the west and Waha‘ula in the east. It includes prominent cliffs and scarps in the Hīlina fault system, such as Hōlei Pali and Poliokeawe Pali, as well as the coastal plain upland of the Park’s coastal cliffs and beaches (Stone and Pratt 2002). A mosaic of different aged lava flows is present, with more recent flows on the eastern side of the unit. The elevation ranges from sea level to the tops of the pali at 709 m (2,325 ft) asl.

The mean annual rainfall in this unit is between 990 and 2,134 mm (39–84 in), with drier conditions during the summer months (Abbott and Pratt 1996, Giambelluca et al. 2011). Rainfall declines from east to west because prevailing trade winds are blocked by the volcano, creating orographic rainfall on the windward slope of Kīlauea (Belfield et al. 2011). Temperatures are typically warm in the lowland region of the Park. The mean annual temperature is greater than 22°C (72°F) (Stone and Pratt 2002).

Due to dry conditions and the relatively young age of the substrate, vegetation growth is limited in the coastal lowland unit. The unit is largely dominated by nonnative grasses (NPS 2011a). The drier, western portion of the unit is primarily nonnative grassland comprised of natal redtop (*Melinis repens*), thatching grass (*Hyparrhenia rufa*), molasses grass, bush beardgrass, and broomsedge. Patches of the native pili grass (*Heteropogon contortus*), as well as nonnative shrubs also occur in this area. On the wetter, eastern side of the coastal lowlands, pili is more abundant.

The native forests that formerly existed in this unit have been dramatically altered by past grazing by nonnative goats and cattle, historic fires and lava flows. Much of the vegetation that remained following lava flows and removal of ungulates has been converted by wildfires to a low, open shrubland with scattered native shrubs, mostly ‘a‘ali‘i and ‘ūlei (*Osteomeles anthyllidifolia*), and interspersed grasses (NPS 2011a). Today, only a remnant coastal ‘ākia (*Wikstroemia sandwicensis*) shrubland remains in the eastern coastal lowlands. The diverse dry and mesic forests that were once distributed on the pali faces (Abbott and Pratt 1996) now exist only as small stands. These remnant forests include those such as the Nāulu Forest. Open stands of ‘ōhi‘a occur on younger flows, while older flows support stands of native lama tree (*Diospyros sandwicensis*) with an understory of the native shrub alahe‘e (*Psydrax odorata*) (NPS 2011a).

Coastal Habitat

The coastal habitat unit at HAVO stretches along the entire 53-km (33-mi) shoreline of the Kīlauea section of the Park from Kapāo‘o Point to Kupapau Point. The unit was formerly classified within the coastal lowland unit; however, it was delineated as a separate unit by NPS in 2012 to recognize/differentiate areas most influenced by the marine environment. The coastal habitat unit encompasses a 30-m (98-ft) band of land parallel to the coastline, as well as nine areas that extend farther inland that contain significant or potentially significant coastal strand vegetation or wildlife habitat. These more inland areas include (from west to east) Ka‘aha, Kaluē, Halapē, Keauhou, unnamed area between Keauhou and ‘Āpua, ‘Āpua Point, unnamed area between ‘Āpua and Kahue, Kahue Point, and unnamed area near Kahue.

Mean annual rainfall is slightly less than the coastal lowland unit, ranging from 970 to 1,955 mm (38–77 in) (Giambelluca et al. 2011). Similar to the coastal lowland unit, the amount of rainfall declines from east to west. The coastal habitat unit is warmer than other areas in the Park. Elevation ranges from sea level to roughly 40 m (130 ft) asl.

Most of HAVO’s shoreline is characterized by high lava cliffs. However, a wide array of other habitat types are scattered throughout the unit including low bluffs, isolated white sand beaches, extensive black sand beaches, tide pools, anchialine pools, lava benches, sea arches, beach berms comprised of cobble or pebble, and periodically inundated areas (Figure 2.2-5). Some of these areas provide unique, high-quality habitat for native seabirds and shorebirds (Stone and Pratt 2002, Kozar et al. 2007). The coastal bluffs provide nesting and brooding habitat for several Hawaiian geese or nēnē (*Branta sandvicensis*). Several sandy beaches in the unit are also used as nesting beaches for hawksbill sea turtles (*Eretmochelys imbricata*) (Seitz et al. 2012) and basking areas for Hawaiian monk seals (*Monachus schauinslandi*) and green sea turtles (*Chelonia mydas*). Both ʻaʻā and pāhoehoe lava types are present (Smith 1980), dating from very recent flows to flows roughly 70,000 years old (Sherrod et al. 2007).

Figure 2.2-5. Sea arch in the coastal habitat unit (Photo: Noe Abejon 2010).

The varied habitats and substrates support different plant assemblages. The coastal habitat supports both native and nonnative stand vegetation, defined as salt-tolerant plants generally limited to areas under the influence of salt spray (Gagne and Cuddihy 1990). Common strand vegetation at HAVO includes the low-growing native mauʻu ʻakiʻaki sedge (*Fimbristylis cymosa*), the native pōhuehue vine (*Ipomoea pes-caprae*), the native naupaka shrub (*Scaevola taccada*)*,* nonnative shrub sourbush (*Pluchea caroliensis*)*,* and the nonnative shrub lantana (*Lantana camara*). These species co-occur with nonnative grasses. Other areas support nonnative coconut trees (coconut), native milo trees (*Thespesia populnea*), and the endangered ʻōhai (*Sesbania tomentosa*).

Historically, the vegetation and topography of this unit has been dramatically influenced by subsidence and tsunamis. It is considered one of the most degraded native ecosystems in HAVO (Belfield et al. 2011). In addition to the nine extended areas mentioned above, other notable areas within the narrow coastal band that contain significant coastal vegetation are Papalehau Point and Ku‘e‘e.

2.2.2. Resource Descriptions

HAVO spans an extensive land area, is located in an extremely dynamic geological setting, and contains considerable variations in substrate types, topography, elevation, and climate. These factors, combined with the unique evolutionary history of the Hawaiian archipelago, have resulted in abundant natural resources. HAVO's natural resources are so valuable that the Park was designated an International Biosphere Reserve in 1980 and was recognized as a World Heritage Site in 1987.

The Park was originally established to protect and study the significant volcanic processes and features within the Park. It is one of only 22 U.S. national parks that hold volcanic resources (Heggie and Heggie 2004). HAVO contains craters, calderas, lava tubes, spatter and cinder cones, steam vents, sea arches, cracks, caves, and other features as a result of active volcanism and frequent seismic activity (NPS 2008a, Thornberry-Ehrlich 2009). Mauna Loa and Kīlauea volcanoes are the primary geological features of the Park.

MaunaLoa is considered the largest free-standing mountain in the world, measuring more than 79,195 km^3 (19,000 mi^3) from its base at 5,486 m (18,000 ft) below sea level (bsl) to 4,169 m (13,677 ft) asl. It is also one of the world's most active volcanoes; it has erupted 33 times since the first historical eruption in 1843 until the last eruption in 1984 (NPS 2008a, 2011a, Thornberry-Ehrlich 2009). Kīlauea, although smaller in size than Mauna Loa, is the most active volcano in the world. It has been erupting almost daily since January 1983 and, as of January 2011, Kīlauea has added roughly 206 ha (510 ac) to the southern shore of Hawai‘i Island (USGS 2009). These two active volcanoes continue to shape the Park. This geological dynamism renders all descriptions of Park features subject to change at any time.

Although the volcanic landscape was the principal reason for establishing HAVO, the Park is now appreciated for its other important resources. A great diversity of ecosystems and vegetation types occur at HAVO including coastal strand, remnant lowland wet and dry forest, anchialine pools, dry grasslands, dry open woodlands, early successional lava flows and kīpuka mosaics, montane mesic and rain forests, subalpine forests and shrublands, and a sparsely vegetated alpine zone. The tropical rainforest at HAVO is the largest federally managed tract of tropical rainforest in the National Park System (NPS 2008a). These varied environments harbor a unique and diverse assemblage of native wildlife and vegetation. Many of the native species at HAVO are endemic to the Hawaiian Islands, or found nowhere else in the world.

More than 400 native species of vascular plants and another 600 nonnative vascular plant species have been documented within the Park (NPS 2011a). The diverse group of native plants at HAVO includes the beautiful Lobelioids and exceptional silverswords (Perry 2006). Vegetation supports a wide array of native avifauna such as Hawaiian honeycreepers, flycatchers, thrushes, seabirds, hawks, and geese (Figure 2.2-6). Of the 87 bird species recorded in HAVO, 46 are native to the Hawaiian Islands (NPS 2011a). HAVO is known to have a high abundance and diversity of native invertebrates (Magnacca and Foote 2006). Over 1,000 native invertebrate species are present in the

Park including butterflies and moths (~200 native species), beetles (~150 native taxa), bees and wasps (~150 species), and picture wing flies (~20 native species). More than 100 endemic species of moths have been documented in the Kahuku Unit alone (Giffin and Rowe 2007). Appendix A lists all taxa recorded in the Park according to NPS' Integrated Resource Management Applications (IRMA).

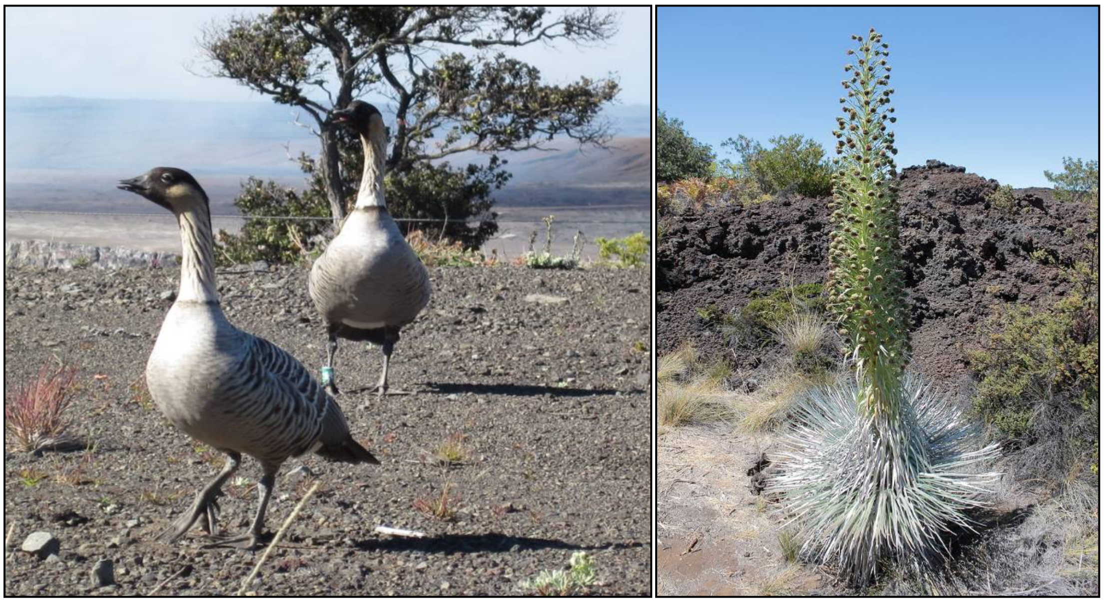

Figure 2.2-6. The endangered Hawaiian Goose or Nēnē (*Branta sandvicensis*) and endangered MaunaLoa Silversword (*Argyroxiphium kauense*) occur at HAVO (Photo: Mark Chynoweth 2010 [left] and Karl Magnacca 2011 [right]).

An overwhelming majority of the federally endangered and threatened species in the United States are found in the state of Hawaiʻi. HAVO has among the highest number of threatened and endangered species within the National Park System, in addition to many rare plants and animals. Over 50 federally and state listed species are known to occur within HAVO or historically occurred within the Park boundaries (Table 2.2-2).

Table 2.2-2. Number of federally and state listed species known to occur within HAVO (Pratt et al. 2011).

Special Status	Plants[1]	Birds[2]	Mammals	Invertebrates	Reptiles
Federally/State-Listed Species	36	9	2	5	2
Endangered	34	8	2	3	1
Threatened	2	1	0	1	1
Proposed Endangered	0	0	0	1	0
Candidate	4	1	0	2	0
Species of Concern[3]	24	2	0	0	0

[1] Includes planted species and species that were historically known, but not seen in recent years.

[2] Does not include species recognized as extinct.

[3] Modified from unpublished info provided by R. Loh.

Currently, 36 native plant species located within HAVO or historically known to occur within HAVO are listed as federally endangered, threatened, or proposed listed species (NPS 2011a, Pratt et al. 2011). These plants encompass a wide range of growth forms from trees and palms to herbs and ferns. Additionally, several endangered species occur adjacent to, but not within the Park (e.g., kīponapona or (*Phyllostegia racemosa*), and others contain critical habitat within HAVO, although natural populations of the species are not currently known to occur within the Park boundaries (e.g., hāhā or (*Cyanea hamatiflora* ssp. *carlsonii*) (NPS 2011a).

The endangered Hawaiian hoary bat or ‘ope‘ape‘a (*Lasiurus cinereus semotus*), the only native land mammal in the Hawaiian Islands, has been documented in the Park. HAVO also provides habitat for nine federally and state listed bird species and one candidate endangered bird species. Five insect species at HAVO are listed as threatened or endangered and the orange-black damselfly (*Megalagrion xanthomelas*) is a candidate for listing (Pratt et al. 2011). The native scavenging anchialine pool shrimp (*Metabetaeus lohena*), which is a candidate for listing, has also been recorded in HAVO (Russ et al. 2010). The endangered Hawksbill sea turtle, threatened green sea turtle, and endangered Hawaiian monk seal are known to nest or bask on several beaches in HAVO (Pratt et al. 2011, Seitz et al. 2012). Federally and state-listed endangered, threatened, proposed endangered, and candidate species known at HAVO are listed in Appendix B.

HAVO is also home to rare or sensitive species of special concern. These species do not receive legal protection, but may be in need of concentrated conservation actions. Species of concern (SOC) is an informal list of species of management concern that was adopted from the USFWS Honolulu Office's. Often not enough is known about these species to prepare a formal listing package or some were formerly candidate species. According to NPS policy, all species identified as species of management concern by the Park are to be managed in a manner similar to those that are federally or state listed (NPS 2011a). Currently, 24 plant species and two bird species are given this designation at HAVO (Loh 2010, Pratt et al. 2011).

Vast networks of underground lava tubes or caves occur within the Park boundaries. Roughly 1,000 cave entrances and 320 km (200 mi) of cave passages have been surveyed by the Hawai‘i Speleological Society (Thornberry-Ehrlich 2009). The full extent of HAVO's lava tubes and caves and the resources within these features (i.e., animals, plants, paleontological deposits, sediments, minerals, and relief features) are largely unknown (Perry 2006). However, these habitats have the potential to contain interesting geological features, provide refuge for rare and endemic cave-adapted invertebrates and native plants (Howarth et al. 2007), and preserve archaeological and paleontological resources (James et al. 1987).

At least 20 anchialine pools are known to exist along HAVO's coast (Chai et al. 1989). The Park displays a range of pool types, from excavated or otherwise modified well sites to deep fissure-pools in pāhoehoe lava flows. All pools share a common feature of tidal fluctuations, yet lack surface connections to the ocean (David Foote, Wildlife Biologist, PIERC-USGS, pers. comm. ~2013). Anchialine pools provide a rare opportunity to view a mixohaline habitat where seawater and groundwater meet. Pools at HAVO support populations of a candidate endangered brackish-water shrimp, as well as a diverse assemblage of cyanobacterial crusts, algal mats, molluscs, other crustaceans, and an undescribed subterranean eel (Maciolek 1983, Russ et al. 2010, David Foote, Wildlife Biologist, PIERC-USGS, pers. comm. 2014). Some of the Park's pools are densely vegetated and provide foraging and roosting habitat for shorebirds and other wildlife.

Special Ecological Areas

In 1985, the NPS began designating areas of the Park that contain valuable natural resources as Special Ecological Areas (SEAs). These special management and research units were developed to prioritize management of invasive species in areas determined to be the most intact, diverse, unique, and manageable sites in the Park, in which nonnative plant populations are localized or at low densities; therefore, control of invasive species is considered more feasible in SEAs than other areas (Tunison and Stone 1992).

At HAVO, SEAs are more intensively managed for rare plant recovery and invasive plants than other areas of the Park. SEAs are selected and prioritized based on four main criteria: 1) representativeness of a particular ecological zone or rarity of vegetation type; 2) manageability (i.e., accessibility), and high potential for native species recovery; 3) species diversity and rare species; and 4) value for research and interpretation (Tunison and Stone 1992, Loh and Tunison 2009). When the SEA approach was adopted in 1985, there were six SEAs covering 4,856 ha (12,000 ac) (Loh and Tunison 2009). Today, there are almost 30 active SEAs covering roughly 31,339 ha (77,440 ac) of the Park (Figure 2.2-7).

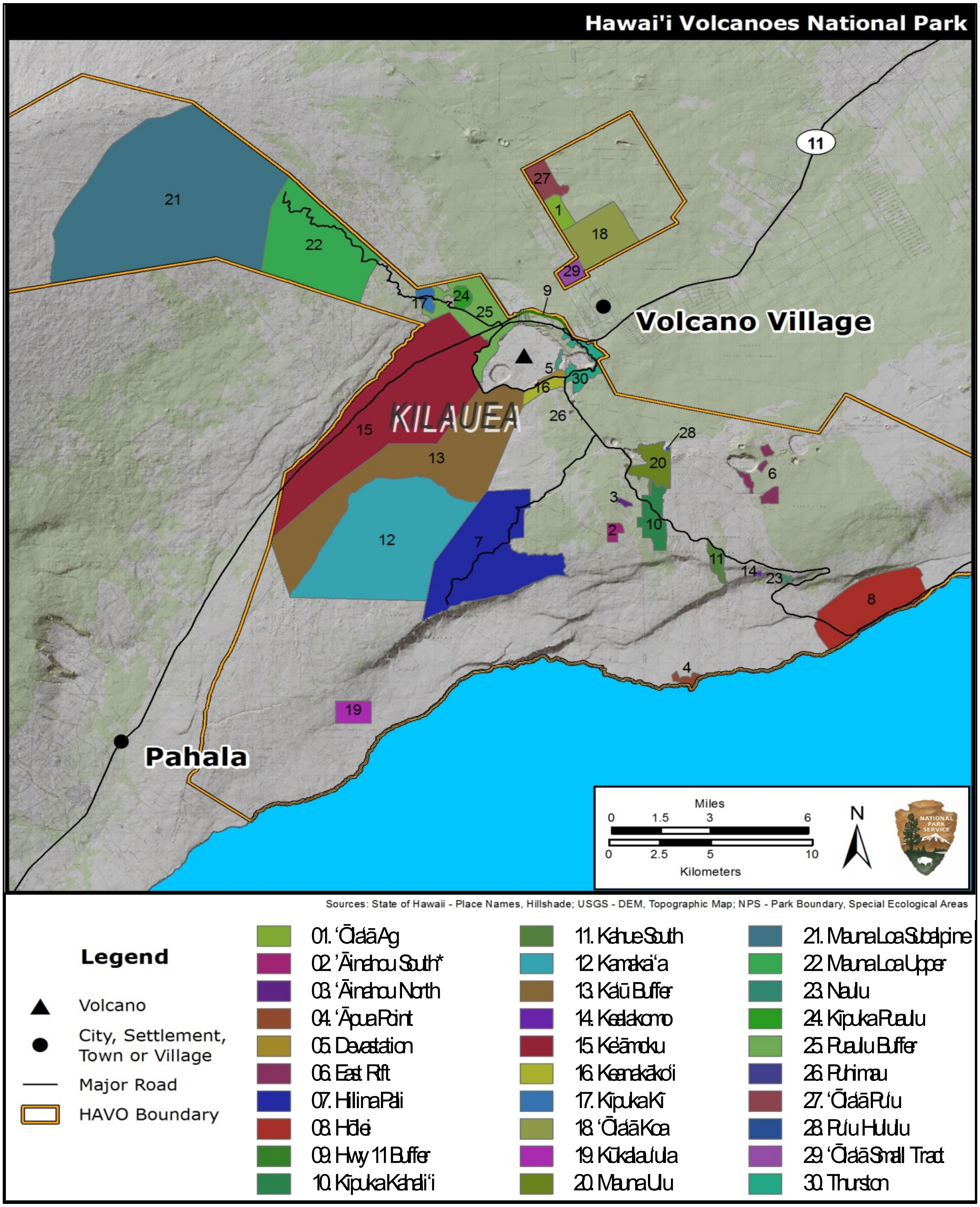

Figure 2.2-7. Special Ecological Areas (SEAs) within Hawaiʻi Volcanoes National Park (*denotes work suspended) (NPS, Loh et al. 2014).

A summary of the Park's profile is provided in Table 2.2-3.

Table 2.2-3. Summary of HAVO profile. Per NPS guidelines, common and Hawaiian species names are used in this report, initially followed by scientific names parenthetically. However, some native plants lack unique Hawaiian or common names or the same names are used for different species, and therefore scientific names are used throughout the report for those species.

Park Aspect	Metric	Measurement
Geographic	Total Park area	134,760 ha (333,000 ac)
	Elevation range	4,169 m (13,677 ft)
	Length of shoreline within park	53 km (33 mi)
Visitation	Average total park visitors/year	1,358,782
	Visitor centers	2
	Campgrounds	2
	Education centers	1
Roads and Trails	Total length of road network	106 km (66 mi)
	Total length of hiking trails	257 km (160 mi)
Aquatic Natural Resources	Perennial streams	0
	Anchialine pools	>20
Terrestrial Natural Resources	Active volcanoes	2
	Total area designated as wilderness	49,817 ha (123,100 ac)
	Special Ecological Areas	30
	No. of native terrestrial vascular plant species*	>400
	No. of native terrestrial animals species	>1,147
Cultural Resources	Historic Structures	205
	National Register Properties	8
	Archaeological Sites	286
	Museum Objects	391,880

2.2.3. Resource Issues Overviews

Historic and Prehistoric Activities Influencing Resources

The current condition of the Park is in part due to the human and natural influences that occurred prior to the Park's establishment. Past disturbances that modified the landscape include the introduction of nonnative ungulates and plants, domestic grazing, ranching, logging, lava flows, and fires (both natural and human-caused).

Feral and Domestic Ungulates

Nonnative ungulates, or mammals with hooves, have extensively modified resources at HAVO and at many other natural areas throughout the Hawaiian Islands. Domestic pigs (*Sus scrofa*) were first brought to the Hawaiian Islands when Polynesians arrived to the archipelago over 1,000 years ago. European pigs (which eventually replaced the Polynesian pigs), goats (*Capra hircus*), sheep (*Ovis aries*), and cattle (*Bos taurus*) were also introduced after European contact in the late eighteenth century (Spatz and Mueller-Dombois 1973, Tomich 1986, Katahira et al. 1993). Mouflon sheep (*Ovis* *musimon*) were introduced to the Island of Hawai‘i in 1957 and were brought to Kahuku Ranch in 1968 and again in 1974, before the Kahuku Unit was incorporated into the Park (Hess, Jeffrey, et al. 2006, Stephens et al. 2008). Many of these animals became feral after introduction. As herds spread widely across the island, grazing and browsing became uncontrolled (Cuddihy and Stone 1990).

Many forested areas of HAVO were cleared and converted to pasture before becoming a part of the National Park System. Cattle grazing occurred in the MaunaLoa Strip before the area was added to the Park (Belfield and Pratt 2002). Goat and cattle ranching occurred in portions of Kīleaua’s East Rift zone and surrounding areas since the late 1900s (Pratt et al. 1999). ‘Āinahou Ranch functioned as a commercial cattle ranch before it was purchased by NPS in the 1970s (NPS 2004). Several ranching and livestock endeavors operated within the Kahuku Unit from 1911 until 2010 (Benitez et al. 2008, Avery 2009).

Ungulates browse, trample, and modify or destroy native vegetation and ecosystems. These animals can also inhibit native plant reproduction (Scowcroft and Hobdy 1987), increase erosion by exposing soil (Ford and Grace 1998, Tep and Gaines 2003), and facilitate dispersal of invasive species (Stone et al. 1992). Pasture development at HAVO and the vicinity was also accompanied with the intentional introduction of nonnative plant species for forage. Although ungulate management measures were first implemented at HAVO in 1927, the lasting effects of these animals continue to influence the Park’s natural resources (NPS 2011a).

<u>Logging and Harvesting</u>
Certain areas of the Park have been extensively modified by logging, or the cutting and removal of native trees (Benitez et al. 2008). Large-scale logging of sandalwood (*Santalum paniculatum*) began in the early 1800s in the Kahuku Unit within the Park. Koa and ‘ōhi‘a continued to be logged in Kahuku up until the area became part of the Park (Avery 2009, Benitez et al. 2008). Skid roads were also created to haul trees from the area, resulting in further impacts to native areas. Pulu, a silky material obtained from the fibers of native tree ferns, was also harvested from tree fern fronds in Kahuku and on Kīlauea’s East Rift forest along the trail to Nāpau Crater during the late nineteenth century. It was collected, dried, packaged, and exported to California for pillow and mattress stuffing (NPS 2005a, Benitez et al. 2008). Evidence of the historic East Rift pulu factory are still present (Rhonda Loh, Chief of Natural Resources Management, NPS HAVO, pers. comm. 2014).

<u>Lava Flows</u>
Numerous eruptions of the Mauna Loa and Kīlauea Volcanoes occurred prior to the 1916 establishment of the Park. Kīlauea, in particularly, was extremely active between the late 1700s and 1920 (Tilling et al. 2010). Significant eruptive events continued throughout the last century including the MaunaUlu flow series (1969–1974) and the present day Pu‘u ‘Ō‘ō-Kipuaianaha that began in 1983 (USGS 2009). These eruptions resulted in extensive lava flows covering large areas of the Park and the vicinity, which greatly influenced natural resources. Many of these flows destroyed vegetation on contact. Barren lava surfaces created by these flows are extremely harsh environments for new plants and animals to establish and survive; pioneer vegetation can take a long time to establish on these substrates (Walker 1999, Stone and Pratt 2002). These

disturbance events can drastically change the landscape, creating distinct habitat for flora and fauna. Lava flows also ignite fires and few native Hawaiian plant species are able to survive and regenerate after fire compared to fire-adapted nonnative plants (LaRosa et al. 2008).

Current Threats and Stressors to Resources

The physical environment and ecological communities within the Park risk further degradation by a myriad of current threats and stressors. Threats are defined as "environmental trends with potentially negative impacts" (Bruckner et al. 2005), and stressors are physical, chemical, or biological perturbations to a system that cause significant changes in the ecological components, patterns, and processes in natural systems (NPS 2006c). Threats and stressors that are specifically of concern at HAVO include invasive plants and animals; diseases and pathogens; alternations in fire regimes; visitor use; and climate change.

Invasive Species

An invasive species is defined as "an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health" (Executive Order 13112). Oceanic islands are particularly vulnerable to invasive species due to a variety of factors (Denslow 2003, Clements and Daehler 2007, Junker et al. 2011). Invasive species are known to have adverse impacts on native species and ecosystems throughout the Hawaiian Islands (NPS 2008a). Due to the prevalence of invasive biota at HAVO, invasive species are separated into several categories to better characterize impacts.

Invasive ungulates

Authorized grazing has been discontinued within HAVO. Beginning in the early 1970s, a systematic program of fencing and hunting effectively eliminated animals from many parts of the Park. In the Kīlauea, MaunaLoa, and ‘Ōla‘a sections of HAVO, feral goats, sheep, mouflon sheep, and cattle are excluded from all Park habitats from sea level to 2,895 m (9,500 ft) elevation. Within these protected areas, feral pigs are excluded from interior fence units that contain various plant communities where critical sensitive resources occur.

Despite these efforts, the presence of nonnative ungulates remains a major management concern today (NPS 2011a). The risk to Park resources if even small numbers of animals are allowed to breach barrier fences is high because of 1) the high risk of extirpating small populations of rare and endangered species; and 2) abundant food and favorable environmental conditions that allow ungulate populations to rebuild very quickly from only a few individuals (Tunison et al. 1995, Perry 2006, NPS 2011a). Also, impacts to resources remain high in areas where all ungulates are not excluded. These include the Kahuku section and areas where pigs remain in the Kīlauea, MaunaLoa, and ‘Ōla‘a sections of the Park (Hess, Kawakami, et al. 2006, Perry 2006, NPS 2011a). Additionally, the recent establishment of axis deer (*Axis axis*) on the island poses an imminent threat to natural resources in the Park and on the Island of Hawai‘i because current fences are not designed to keep out these high jumping animals.

The presence of nonnative ungulates represents a major stressor for Hawaiian ecosystems and biota. The browsing, grazing, trampling, and rooting activities of these animals can destroy native plant species and degrade wildlife habitat. Ungulates consume large amounts of native vegetation such as bark, leaves, and seeds (Courchamp et al. 2003) and inhibit reproduction and suppress regeneration (Scowcroft and Hobdy 1987). They also facilitate the dispersal and establishment of nonnative plants by transporting propagules (Stone et al. 1992). Indirectly, their activities have been shown to accelerate erosion and alter soil properties (Ford and Grace 1998, Tep and Gaines 2003, Van Driesche and Van Driesche 2004, Browning 2008). Pigs in particular augment the prevalence of avian diseases by creating wallows with standing water, thereby increasing breeding sites for vector mosquitoes (Atkinson et al. 2005). This is particularly significant in the Park where there are few natural sources of standing water.

Invasive flora

Many of the over 10,000 plant species and cultivars introduced to the Hawaiian Islands have become invasive (Staples and Herbst 2005, Zouhar et al. 2008). Invasive plants in the Hawaiian Islands compete with and displace native plants, alter nutrient cycling patterns, change hydrologic regimes, remove wildlife habitats, and alter a variety of other ecosystem processes (Smith 1985, Vitousek 1990, Seitz et al. 2012). Many invasive plants at HAVO modify fire regimes, facilitating the spread of fire and recovering rapidly after fire.

Of the roughly 600 nonnative vascular plant species recorded in HAVO, over 130 species are managed or monitored for their invasive potential (Benitez et al. 2012). While the impact of some incipient invaders is not known, other nonnative plants have been documented to significantly alter native communities in HAVO and throughout the Hawaiian Islands (Tunison et al. 1992). Particularly widespread and/or disruptive invasive plant species in HAVO are discussed in Section 4.3. Mapping efforts for many potentially invasive plants in Kahuku have not been as intensive relative to original sections of the Park; therefore, distribution and control strategies for several species remain in development. Invasive plant taxa have been documented in all of the ecological units of HAVO. Higher proportions of nonnative plants (including invasive species) are found in high traffic areas, such as visitor centers, administrative and residential areas, roadsides and trails, as well as at lower elevations (Benitez et al. 2012).

Invasive small mammals

Introduced small mammals present at HAVO include black rats (*Rattus rattus*), Norway rats (*Rattus norvegicus*), Polynesian rats (*Rattus exulans*), house mice (*Mus musculus*), small Indian mongooses (*Herpestes javanicus*), dogs (*Canis familiaris*), and feral cats (*Felis catus*). These small, nonnative mammals are omnivorous and are known to consume a variety of native birds, invertebrates, and plants that occur within the Park. Population estimates of these species at HAVO are not currently available.

Rats are extremely ubiquitous and have been credited with causing a high number of plant and animal extinctions on islands (Towns et al. 2006). In Hawai‘i, they feed on a variety of plant material including seeds, fruits, bark, and vegetative material (Scowcroft and Sakai 1984, Hess et al. 2004, Shiels 2011, Shiels and Drake 2011). They also consume native insects, snails, and other invertebrates (Hadfield et al. 1993). All three rat species are predators of eggs, nestlings, young, and occasionally adults of native burrowing seabirds and tree nesting birds (VanderWerf 2001, Mitchell et al. 2005, Kozar et al. 2007, Swift and Burt-Toland 2009). Black rats are also known to prey on nēnē eggs (Banko et al. 1999).

Mongooses are also omnivorous. At HAVO, they have been noted to prey on native Hawaiian birds, including the endangered Hawaiian goose or nēnē (Stone and Anderson 1988, Perry 2006, Hays and Conant 2007). Within the coastal habitat unit of the Park, there has been evidence of mongoose predation on hawksbill sea turtle nests (Seitz et al. 2012).

Feral cats occur in a wide range of elevations and vegetation types in the Park. Studies within HAVO have documented cats consuming small mammals, invertebrates, and birds, including the endangered nēnē and the endangered Hawaiian petrel (*Pterodroma sandwichensis*) (Natividad-Hodges and Nagata 2001, Hess et al. 2008). Hawksbill sea turtle nests at HAVO show signs of cat predation (Seitz et al. 2012). Cats also host toxoplasmosis, a disease which kills both endangered Hawaiian birds and marine mammals (Hess et al. 2008). It is also transmissible to humans via cat feces. Feral dogs occur in Kahuku, and have been observed to chase and kill mouflon sheep. These individuals could pose a threat to nēnē where they co-ocurr.

<u>Invasive insects</u>

Throughout the Hawaiian Islands, invasive nonnative insects have been documented to adversely affect native biodiversity through herbivory, predation, parasitism, pollination disruption, and hybridization and competition with native species (Haines and Foote 2005, Krushelnycky, Joe, et al. 2005, Lach 2008, Junker et al. 2011). Insects have the greatest rate of yearly establishment of all animal or plant groups in the Hawaiian Islands (Staples and Cowie 2001). More than 2,500 nonnative insects are known to have established in the state of Hawaiʻi (Kenis et al. 2009). HAVO is especially vulnerable to invasive insects because the Park contains an abundant and diverse group of native invertebrates; it is located in close proximity to urban and agricultural centers that harbor many nonnative species; and the large amount of off-island visitors have the potential to inadvertently transport insect pests (Magnacca and Foote 2006).

Three species of invasive ants have been documented at HAVO—the big-headed ant (*Pheidole megacephala*), long-legged ant (*Anoplolepis longipes*), and Argentine ant (*Linepithema humile*) (Stone and Pratt 2002). These species can have devastating effects on native species. Ants prey upon native insects or compete with insects for food resources, nesting areas, and shelter sites (Zimmerman 1978, Krushelnycky et al. 2004, Krushelnycky, Loope, et al. 2005, Krushelnycky and Gillespie 2008). This may indirectly impact native plants by reducing essential pollinator populations and available nectar resources, thereby decreasing reproductive success of native plants (Krushelnycky, Joe, et al. 2005, Lach 2008, Junker et al. 2011). They also have the potential to reduce hatching success, growth rates, and overall reproductive success of ground-nesting birds (Plentovich et al. 2009).

Other invasive insects considered to threaten and stress the natural resources at HAVO include the two-spotted leafhopper (*Sophonia rufofascia*), western yellowjacket wasps (*Vespula pensylvanica*), and southern house mosquito (*Culex quinquefasciatus*). Numerous species of parasitoid wasps have also been documented in the Park (Peck et al. 2008). Several projects have been implemented at

HAVO to monitor the extent and impacts of these organisms and test control measures (Gambino and Loope 1992, Magnacca and Foote 2006, Foote et al. 2011).

Invasive reptiles and amphibians (herpetofauna)

There are no native terrestrial reptiles or amphibians in the Hawaiian Islands. Compared to other groups of nonnative species (i.e., plants, ungulates), relatively little is known about the impacts of these species in Hawaiʻi and other island ecosystems (Sin et al. 2008). However, the predatory nature of these species, as well as their ability to reach high densities, suggests some impacts to native ecosystems (Staples and Cowie 2001, Kraus 2005, Perry 2006). The house gecko (*Hemidactylus frenatus*) and bullfrog (*Ranacatesbeiana*) were reported by Kraus (2005) and the coqui frog (*Eleutherodactylus coqui*) by Tavares (2008). Several Jackson's chameleons (*Chamaeleo jacksonii*) have been sighted in the Thurston area over the last 10 years (Rhonda Loh, Chief of Natural Resources Management, NPS HAVO, pers. comm.). The brown anole (*Anolis sagrei*) has not established within the Park, but has the potential to threaten native species (Kraus 2005).

Diseases and Pathogens

Endemic island species are particularly susceptible to introduced pathogens and diseases (Bataille et al. 2009). Two mosquito-borne avian diseases, avian malaria (*Plasmodium relictum*) and avian pox (*Avipoxvirus* sp.), have been implicated as the main reason for mortality of the native Hawaiian forest birds in low-elevation areas (Van Riper et al. 2002, Atkinson et al. 2005, LaPointe et al. 2005, Reiter and LaPointe 2007). The introduced southern house mosquito (*Culex quinquefasciatus*) is the primary vector of these diseases. It occurs from sea level to 1,800 m (5,900 ft) (LaPointe 2008) and, thus, impacts native birds in most ecological units of the Park.

Alternations in Fire Regimes

Evidence suggests that fire was infrequent in the Hawaiian Islands prior to human habitation, but increased during Polynesian and European contact. The coastal lowlands at HAVO were intentionally burned by Polynesians for agriculture and to promote desirable plants (Tunison et al. 2001). Numerous fires have occurred at HAVO, particularly in the coastal lowlands and mid-elevation seasonal units (Figure 2.2-8, Section 4.20). The recent history of fires at HAVO indicates that fire size and frequency increased dramatically in the latter part of the twentieth century. These dramatic increases are largely due to invasion by fire-adapted, nonnative C4 grasses and other fast-growing invasive plants, as well as goat removal in the Coastal Lowlands (Tunison et al. 2001). Lava flows ignited about half of the fires in the Park (NPS 2005b).

Fire is a significant threat to the resources at HAVO, transforming native ecosystems by destroying native species and causing further spread of nonnative, fire-promoting grasses (Hughes et al. 1991, D'Antonio and Vitousek 1992, Ainsworth and Kauffman 2009, D'Antonio et al. 2011). The mid-elevation seasonal unit has been particularly impacted by fires. During the last 25 years, over half of the seasonally dry woodlands have been converted to nonnative grasslands on Kīlauea (Tunison et al. 2001, NPS 2005b, LaRosa et al. 2008, Loh et al. 2007).

Figure 2.2-8. A prescribed research burn conducted by Park staff to evaluate impacts of wildfire on vegetation at HAVO (Photo: NPS).

Visitor Use

HAVO is the most popular tourist attraction in the state, typically drawing more than one million visitors per year (NPS 2011a, NPS PUSO 2011). The Park is also open 24 hours a day, 365 days a year. The impact of these visitors on HAVO's natural resources has not been studied. The most likely visitor impacts at HAVO include loss or disruption of vegetation due to trampling and collection; soil erosion and compaction; and disturbance of sensitive native avifauna or mammals (Park et al. 2008). High visitation rates, particularly from off-island tourists, also make the Park more vulnerable to inadvertent introduction and invasion by nonnative species.

Despite HAVO's large geographic size and high visitor rate, visitor activity is concentrated along the Chain of Craters Road and Crater Rim Drive. As a result, visitor impacts are heavily concentrated on these roads and immediately adjacent areas (NPS 2008a). Visitors are not authorized to enter more environmentally sensitive areas of the Park, including most caves and lava tubes that are easily affected by human activity (Stephens 2006). Informational signs along trails and near high-use recreational areas direct visitors to keep on maintained trails. However, the percentages of visitors that adhere to these signs are unknown.

Climate Change

The Intergovernmental Panel on Climate Change (IPCC) defines "climate change" as a change in the mean or variability of one or more measures of climate that persists for an extended period, typically decades or longer, whether the change is due to natural variability, human activity, or both (IPCC 2007). Various climatic changes have already been observed in the Pacific islands and scientists predict further changes are likely or possible (Schramm and Loehman 2011).

In Hawaiʻi, average air temperatures have risen by 0.17ºC (0.3ºF) per decade over the past 30 years (Fletcher 2010). Stronger warming is occurring at higher elevations (0.27ºC or 0.48ºF per decade), which is faster than the global rate (Giambelluca 2008, Fletcher 2010). Air temperature warming has the potential to lower the trade wind inversion, reducing critical precipitation inputs from mist and fog drip (Benning et al. 2002, Miller 2008). Average annual sea surface temperatures and deep ocean temperatures are also increasing (Schramm and Loehman 2011). Rainfall has declined throughout the Hawaiian Islands over the past two decades. Although the number of heavy rainfall events has decreased, the amount of rain falling in heavy storms has increased by 12% (Fletcher 2010). Sea level changes vary throughout the islands due to geologic uplift. On Hawaiʻi Island, sea levels have risen by 3.6 cm (1.5 in) per decade (Fletcher et al. 2002).

As a result of these changes, the Hawaiian Islands face a variety of impacts to their natural resources. Individual species and populations may respond to climatic changes by altering 1) range and distribution, 2) phenology and physiology, 3) community composition and interaction, and 4) ecosystem structure and dynamics (Walther et al. 2002, Parmesan and Matthews 2006). Furthermore, higher sea levels may inundate coastal areas, decreasing habitat for both marine and terrestrial species, and increasing coastal erosion.

One of the most important potential impacts at HAVO is the migration of invasive species to new areas. For example, mosquito vectors are currently limited to certain areas within HAVO due to specific rainfall, temperature, and elevation restrictions. This has caused some native bird species to seek refuge in higher elevation, lower temperature areas where the mosquito and disease are not able to survive. Climatic shifts have the potential to expand the habitat of disease-carrying insects, increasing transmission potential of vector-borne diseases in Hawaiian forest birds (Woodworth et al. 2005, Atkinson and LaPointe 2009). Similarly, herpetofauna not currently present in the Park may also be able to establish due to changing temperatures (Kraus 2005). Invasive species are often better adapted to warmer night temperatures than native species and, therefore, may out-compete vulnerable native species (Giambelluca et al. 2008).

2.3. Resource Stewardship

2.3.1. Management Directives and Planning Guidance

Since its establishment in 1916, HAVO has identified protection of important natural resources as a fundamental part of the Park's purpose. Resource protection, defined as "all activities related to the management, preservation and protection of the Park's cultural and natural resources," represents the largest functional operation in the Park (compared to Visitor Experience & Enjoyment, Facility Operations, Maintenance, and Management & Administration) (NPS 2005a). In 2004, resource protection comprised 36% of the Park's total expenditures. Excluding cultural resource management, the total operational expenditures for natural resource management in 2004 were over $2.8 million (NPS 2005a). Resource protection initiatives include research, restoration efforts, species-specific management, wildland fire management, predator control, water quality monitoring, and information integration activities (NPS 2005a). Figure 2.3-1 displays the resource protection expenditures by program in 2004.

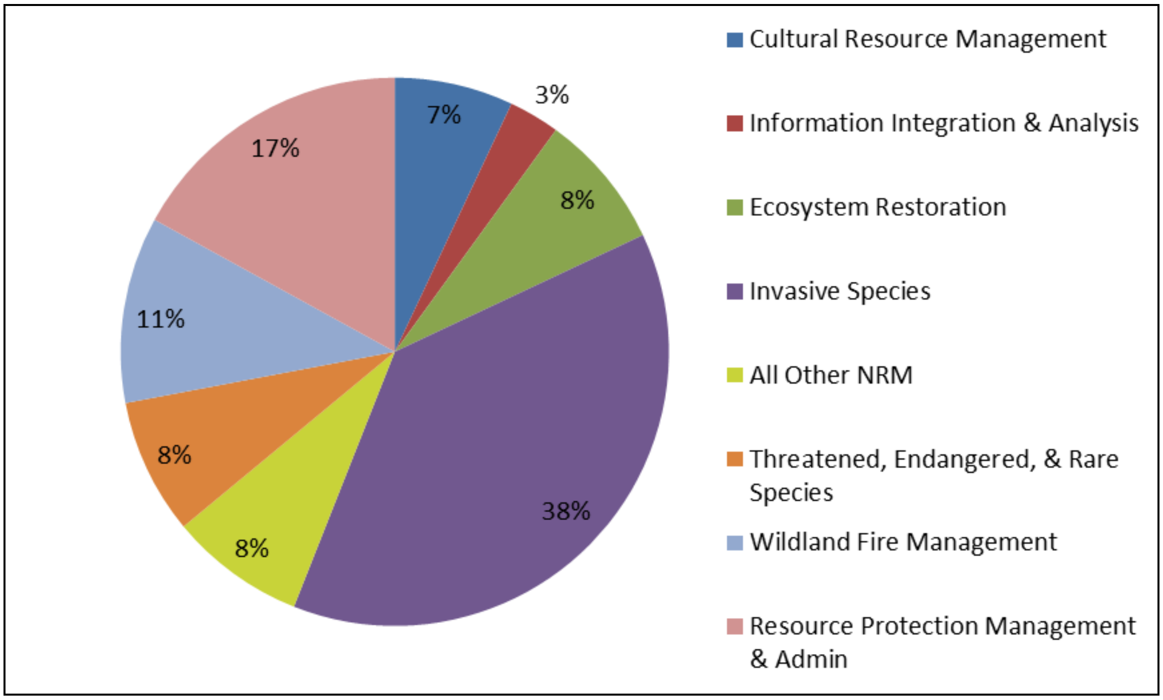

Figure 2.3-1. Resource protection expenditures by program in Fiscal Year 2004 (NPS 2005a).

HAVO's natural resource stewardship directives and planning are primarily guided by the Park's management plans, as well as legislation and policies. They are also informed by the most current resource studies and research.

Various management plans have been developed for HAVO that influence natural resource management (Table 2.3-1). Many of these plans are outdated due to changing Park boundaries and geological conditions. The Park's Master Plan (1975) and the Resource Management Plan (1999) provide long-term guidance for the stewardship of HAVO's natural resources.

Table 2.3-1. Hawai'i Volcanoes National Park's management plans.

Management Plan	Source	Status
Air Tour Management Plan	In development; Loh, pers. comm. 2014	Currently reviewing public comments on preliminary alternatives.
General Management Plan/ Wilderness Study/ EIS	NPS in prep.	Public comment period ended 1/2/2012. Draft document in progress.
Kahuku Interim Operating Plan	NPS 2006	Approved 8/28/2006.
Land Acquisition Plan	NPS 1980	Approved in 1980.
Land Protection Plan	NPS 1986	Original plan published in 1986 with addendums in 1998 and 2011.
Master Plan	NPS 1975	Published in 1975. Revised General Management Plan/ Wilderness Study in progress.

Table 2.3-1 (continued). Hawai'i Volcanoes National Park's management plans.

Management Plan	Source	Status
Natural Resources Management Plan	NPS 1974	Published in 1974, updated in 1984 and 1999.
Protecting & Restoring Native Ecosystems by Managing Non-native Ungulates Plan/ EIS	NPS 2013	Final Plan/EIS published in January 2013.
Proposed Wilderness Areas EIS	NPS 1975	Published in 1975.
Wildland Fire Management Plan	NPS 2007	Published in 2005, updated in 2007.

The following resource management goals were identified in the HAVO Resource Management Plan (NPS 1999):

- Restore Park ecosystems recently invaded by alien species through removal of key alien species followed by natural recovery; restore highly altered Park ecosystems through a program of active rehabilitation to conditions as natural as practicable. Expand restoration efforts focused on localized model areas to a Park-wide scale.
- Restore lost biodiversity in Park ecosystems by recovering endangered, threatened, and rare plant and animal species, and by reintroducing locally extirpated species.
- Inventory cave resources in a systematic interdisciplinary way to insure an integrated approach for the stewardship of both natural and cultural resources.
- Develop and maintain an understanding of populations, communities, ecosystems, threats, stressors, and ecosystem health through a systematic, science-based program of inventory and monitoring.
- Maintain and expand Park partnerships for natural resource management, particularly those involving neighboring lands and control of invasive species threatening parklands.
- Reduce the negative impacts of wildfire but use fire as a restoration tool when possible.
- Monitor air quality and composition to protect employee health and understand ecosystem change.

At present, the Park is in the process of developing a General Management Plan and a Wilderness Study and Environmental Impact Statement (GMP/Wilderness Study/EIS) (NPS in prep). This document will replace the outdated 1975 Master Plan, developing a strategic vision for the entire Park. It will also determine if any lands should be recommended for inclusion in the National Wilderness Preservation System. Four preliminary alternatives for managing HAVO have been developed for the GMP/Wilderness Study/EIS and were described in the Park's summer 2011 newsletter (NPS 2011b) as follows:

- Alternative A would continue current management and provide a baseline for evaluating changes and impacts in other alternatives. Existing programming, facilities, staffing, and funding would generally continue at their current levels.

- Alternative B would strengthen and broaden opportunities to connect people with the volcanic world treasure, Hawai‘i Volcanoes National Park.
- Alternative C would integrate concepts, perspectives, and values from traditional Native Hawaiian land management (such as the ahupua‘a land management system) and ecological knowledge into current Park management thinking and decisions.
- Alternative D emphasizes the Park’s role as a refuge and haven for native biota, people, and cultures in a world constantly adapting to volcanic activity and island building processes.

One of the four alternatives or an assimilation of separate parts of the four alternatives will be designated in the Draft GMP/Wilderness Study/EIS, which is expected to be published in 2013 (NPS 2011b).

2.3.2. Status of Supporting Science

NPS’ Inventory & Monitoring (I&M) program was established to “collect, organize, and make available natural resource data” to “improve park management through greater reliance on scientific knowledge” (NPS 2011d). The program is organized into 32 networks based on geography and shared natural resource characteristics. The I&M program helps each Park complete a set of basic natural resource inventories. These inventories function as the baseline for establishing long-term monitoring of vital signs (NPS 2011d). Vital signs are defined as “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” (Fancy et al. 2009). By monitoring these vital signs, the I&M program provides scientifically sound information to make informed decisions about natural resource management.

HAVO is part of the Pacific Island Network (PACN). The PACN represents the most extensive network in the NPS I&M program spanning across the tropical Pacific (HaySmith et al. 2005). The network encompasses the following 11 NPS units: War in the Pacific National Historic Park (Guam), American Memorial Park (Northern Mariana Islands), National Park of American Samoa (American Samoa), USS Arizona Memorial (Hawai‘i), Kalaupapa National Historical Park (Hawai‘i), Haleakalā National Park (Hawai‘i), Ala Kahakai National Historic Trail (Hawai‘i), Pu‘ukoholā Heiau National Historic Site (Hawai‘i), Kaloko-Honokōhau National Historical Park (Hawai‘i), Pu‘uhonua o Hōnaunau National Historical Park (Hawai‘i), and Hawai‘i Volcanoes National Park (Hawai‘i). The PACN I&M program maintains offices within HAVO to facilitate data sharing between Park and PACN staff (HaySmith et al. 2005).

At HAVO, the PACN’s I&M program has played a key role in inventorying natural resources within the Park and compiling and evaluating existing natural resource data. The program has helped in identifying and prioritizing vital signs for the Park. Additionally, the PACN’s I&M program has been integral in implementing vital sign monitoring and developing detailed monitoring protocols intended to provide high-quality, long-term information on the status and trends of the vital signs. Compared to other Parks in the network, HAVO has a long history of repeated data collection (HaySmith et al.

2005). Inventory and vital sign monitoring are important activities that provide scientific information needed to protect and manage park resources for present and future years (NPS 2006a).

Several basic natural resource inventories have been completed within HAVO (Table 2.3-2). At least 90 percent of the vascular plant and faunal species present within the Park have been documented. This includes rare plants within the remote ʻŌlaʻa tract and seabirds on MaunaLoa. Mammal surveys have also been conducted in select areas of the Park. HAVO has the largest invertebrate specimen base of any park in the PACN network (NPS 2006a).

Table 2.3-2. Status of National Park Service inventory reports for HAVO (NPS 2012b).

Inventory Report	Status	Year
Air Quality	Complete	2006
Air Quality Related Values	Complete	2010
Base Cartography Data	Complete	2009
Baseline Water Quality Data	Complete	2007; 2010
Climate Inventory	Complete	2007
Geologic Resources Inventory	Complete	2010
Natural Resources Bibliography	Complete	2001; 2007
Soil Resources Inventory	Complete	2005; 2008
Species Lists	Complete	2006; 2008
Species Occurrence and Distribution	Complete	2007
Vegetation (Mapping) Inventory	In Progress	Estimated complete September 2014
Water Body Location and Classification	Complete	2008

The PACN's list of vital signs was chosen following comprehensive discussions by various subject matter experts in the region (Haysmith et al. 2005, Stephens 2006). Thirty-one vital signs were selected for the PACN; however, not all vital signs are applicable to each park within the network (Haysmith et al. 2005). Figure 2.3-2 depicts vital signs generally considered important in a Hawaiian watershed. Monitoring protocols were developed or are in the process of being developed for the majority of the PACN vital signs to ensure consistent and accurate long-term monitoring.

Thirteen PACN vital signs were initially planned to be monitored at HAVO, as shown in Table 2.3-3 (HaySmith et al. 2005). Due to lack of funding and Park personnel available to support the vital sign monitoring program, the list of vital signs monitored at HAVO was reduced (Rhonda Loh, Chief of Natural Resources Management, NPS HAVO, pers. comm.). Currently, only nine vital signs are monitored or planned to be monitored at HAVO. Although cave community, terrestrial invertebrate communities, insectivorous bats, and water quality were identified as important ecological indicators, monitoring protocols are not planned to be developed at this time due to limited resources.

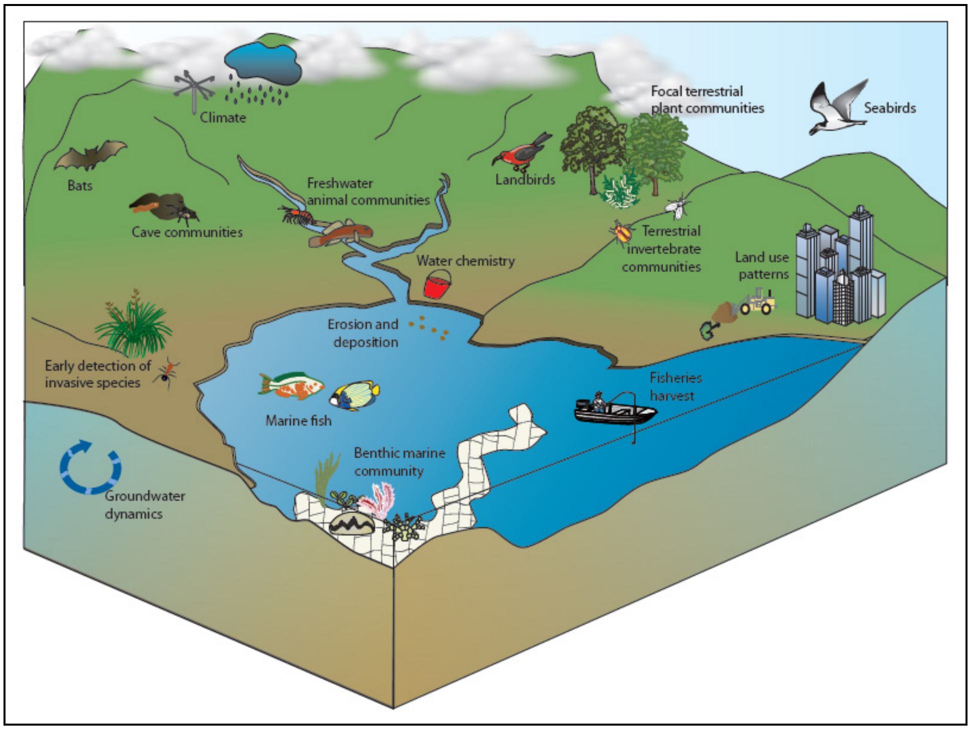

Figure 2.3-2. Conceptual illustration of vital signs important in the PACN (HaySmith et al. 2005).

Table 2.3-3. Hawaii Volcanoes National Park vital signs and monitoring protocol status.

PACN Vital Sign	Protocol Status
Weather/climate	Completed 2011
Early detection of invasive plants	Protocol in development
Established invasive plant species	Completed 2012
Focal terrestrial plant species	Protocol in development
Focal terrestrial plant communities	Completed 2011
Landbirds	Completed 2011
Seabirds	Protocol in development
Landscape dynamics	Protocol in development
Anchialine pools/freshwater animal communities	Protocol in peer review
Insectivorous bats	Monitoring not implemented by PACN; pilot project data available for 2007–2009
Cave community	Monitoring not implemented by PACN
Terrestrial invertebrate communities	Monitoring not implemented by PACN
Water quality	Monitoring not implemented by PACN

The PACN I&M program has selected a set of key measures for each vital sign to convey the condition of the resource. The current condition of these measures at HAVO, as well as the data sources supporting these condition determinations, is provided in Table 2.3-4. I&M data are not available for all measures at this time.

Table 2.3-4. PACN vital signs summary table, Hawai'i Volcanoes National Park (updated 11/2/2011) (NPS 2011e). Data Sources: 1) Western Regional Climate Center (WRCC); 2) PACN Climate Monitoring Protocol and Annual Reports; 3) PACN Early Detection of Invasive Plant Species Monitoring; 4) PACN Established Invasive Plant Species Monitoring; 5) PACN Focal Terrestrial Plant Species Monitoring; 6) PACN Focal Terrestrial Plant Communities Monitoring; 7) PACN Landbird Monitoring Protocol; 8) PACN Landbird Monitoring Annual Report (2010); 9) HAVO Monitoring; 10) PACN Landscape Dynamic.

Vital Sign	Measure	Current Condition	Data Sources
Weather/climate	Hawai'i Vol NP HQ 54 Annual Precipitation/ Long-term means	49.55 in / 51.77 in	1, 2
	Hawai'i Vol NP HQ 54 Avg. Annual Min Temp/ Long-term Means	48.1ºF / 52.8ºF	1, 2
	Hawai'i Vol NP HQ 54 Avg. Annual Max Temp/Long-term Means	65.2ºF / 67.6ºF	1, 2
	Kealakomo 38.8 Annual Precipitation/ Long-term Means	N/A/ 59.1 in	1, 2
	MaunaLoa Slope Obs Annual Precipitation/ Long-term Means	3.25 in / 18.77 in	1, 2
	MaunaLoa Slope Obs Avg. Annual Min Temp/ Long-term Means	25.1ºF / 37ºF	1, 2
	MaunaLoa Slope Obs Avg. Annual Min Temp/ Long-term Means	38.4ºF / 53.5ºF	1, 2
	Keaumo Annual Precipitation/ Long-term Means	16.29 in / 47.89 in	1, 2
	Keaumo Avg. Annual Min Temp/ Long-term Means	44.3ºF / 45.8ºF	1, 2
	Keaumo Avg. Annual Max Temp/ Long-term Means	72.2ºF / 71.5ºF	1, 2
	Pali 2 Annual Precipitation/ Long-term Means	16.3 in / 55 in	1, 2
	Pali 2 Avg. Annual Min Temp/ Long-term Means	58.6ºF / 59.6ºF	1, 2
	Pali 2 Avg. Annual Max Temp/ Long-term Means	75.5ºF / 74.9ºF	1, 2
Early detection of invasive plants	Incipient invasions (# new species)	TBD	3
Established invasive plant species	Target invasive species richness (# per plot)	TBD	4
	Target invasive species frequency (proportion of plots with species)	TBD	4
	Target invasive species cover (percent class)	TBD	4

Table 2.3-4 (continued). PACN vital signs summary table, Hawai‘i Volcanoes National Park (updated 11/2/2011) (NPS 2011e). Data Sources: 1) Western Regional Climate Center (WRCC); 2) PACN Climate Monitoring Protocol and Annual Reports; 3) PACN Early Detection of Invasive Plant Species Monitoring; 4) PACN Established Invasive Plant Species Monitoring; 5) PACN Focal Terrestrial Plant Species Monitoring; 6) PACN Focal Terrestrial Plant Communities Monitoring; 7) PACN Landbird Monitoring Protocol; 8) PACN Landbird Monitoring Annual Report (2010); 9) HAVO Monitoring; 10) PACN Landscape Dynamic.

Vital Sign	Measure	Current Condition	Data Sources
Focal plant species	Frequency (% of occupied plots)	TBD	5
	Cover (percent)	TBD	5
	Recruitment (# of seedlings)	TBD	5
Focal terrestrial plant communities	Native species richness (# native species)	TBD	6
	Trees density (# live native trees per ha)	TBD	6
	Shrub density (# native per ha)	TBD	6
	Tree recruitment (# of native seedlings per ha)	TBD	6
	Ratio of native to nonnative understory cover	TBD	6
	Coarse woody debris (# large downed wood per hectare)	TBD	6
Landbirds	Number of native species detected	10	7, 8
	Number of endangered species detected	5	7, 8
	Number of nonnative species detected	19	7, 8
	‘Apapane abundance	523,140 ± 44,362 (451,080–627,840)	7, 8
	‘Apapane distribution (# tracts occupied)	8/8	7, 8
	Hawai‘i amakihi abundance	195,070 ± 23,545 (156,870–248,360)	7, 8
	Hawai‘i amakihi distribution (# tracts occupied)	8/8	7, 8
	Hawai‘i ‘elepaio abundance	7,901 ± 1,774 (5,009–11,828)	7, 8
	Hawai‘i ‘elepaio distribution (# tracts occupied)	5/8	7, 8
	‘Ōma‘o abundance	21,160 ± 1,911 (17,419–24,786)	7, 8
	‘Ōma‘o distribution (# tracts occupied)	7/8	7, 8

Table 2.3-4 (continued). PACN vital signs summary table, Hawai'i Volcanoes National Park (updated 11/2/2011) (NPS 2011e). Data Sources: 1) Western Regional Climate Center (WRCC); 2) PACN Climate Monitoring Protocol and Annual Reports; 3) PACN Early Detection of Invasive Plant Species Monitoring; 4) PACN Established Invasive Plant Species Monitoring; 5) PACN Focal Terrestrial Plant Species Monitoring; 6) PACN Focal Terrestrial Plant Communities Monitoring; 7) PACN Landbird Monitoring Protocol; 8) PACN Landbird Monitoring Annual Report (2010); 9) HAVO Monitoring; 10) PACN Landscape Dynamic.

Vital Sign	Measure	Current Condition	Data Sources
Landbirds (continued)	ʻIʻiwi abundance	18,804 ± 3,676 (12,230–27,197)	7,8
	ʻIʻiwi distribution (# tracts occupied)	6/8	–
Seabirds	Hawaiian petrel colony distribution	TBD	9
	Hawaiian petrel colony density	TBD	9
	Active nest density	TBD	9
Landscape dynamics	% of land use/land cover change	TBD	10

Chapter 3. Study Scoping and Design

3.1. Preliminary Scoping

Input from Park staff at HAVO was solicited throughout the preparation of this assessment. An initial kick-off meeting was held on November 8, 2011. Seven NPS staff members, two individuals from organizations affiliated with the Park, and two biologists from SWCA Environmental Consultants (SWCA) attended the meeting. Three additional SWCA staff members participated via conference call. During this meeting, the group confirmed the purpose, scope, and report outline for the HAVO NRCA. Due to budgetary constraints, SWCA was only tasked to complete Chapters 1 through 3 of the NRCA during FY 2012. Additional funds for the completion of the NRCA was awarded to SWCA in September 2012.

During the initial kick-off meeting, individuals were asked to identify ecological units within the Park, types of threats and stressors of greatest concern, significant natural resources within HAVO, and potential indicators of natural resource conditions. NPS staff delineated a new ecological unit (Coastal Habitat) as a result of this meeting. This effort involved internal discussions about appropriate parameters for inclusion within the unit, as well as a field mapping effort. Final determinations about the ecological units and significant natural resources were confirmed during follow-up emails and telephone conversations with staff. NPS also provided SWCA with various electronic and hard copy files including management reports, I&M reports and protocols, and geospatial data during the meeting. Additional reports and datasets were obtained from the Pacific Cooperative Studies Unit, USGS, and NPS' IRMA, a web portal for natural resource information.

Following the kick-off meeting, SWCA had on-going correspondence with HAVO staff to confirm details of the Park and its resources. A follow up meeting for Chapters 4 and 5 was held via conference call on December 6, 2012, and site visits to key locations within the Park were conducted on December 13 and 14, 2012. Key NPS staff members were also consulted throughout the drafting of the NRCA to identify an appropriate framework, indicators, measures, and reference conditions/values. An effort was made to integrate metrics from the I&M Vital Signs monitoring program.

3.2. Study Design

3.2.1. Indicator Framework, Focal Study Indicators

All NRCAs use a hierarchical study framework that provides a structure for grouping diverse park resources and resource indicators. These frameworks include the following components:

- Natural resource indicators.
- Reference conditions/values.
- Current condition reporting by indicators.
- Current condition summaries by broader resource categories or topics, and by park areas.

This NRCA utilizes NPS' Ecological Monitoring Framework developed by Fancy et al. (2009), which is a hierarchical, systems-based monitoring program developed to provide information on the status and trends of selected park resources. The framework was adapted by the NRCA team to reflect the unique natural resources of the Park. NPS' Ecological Monitoring Framework (Fancy et al. 2009) was chosen for this NRCA because it builds on the past and current investments by NPS and other partners.

The top tier of the framework (Level 1) is composed of four categories: 1) Air and Climate, 2) Geology and Soils, 3) Biological Integrity, and 4) Landscapes (Table 3.2-1). These categories are used to report on the broader condition of the Park's resources (HaySmith et al. 2005). The more specific Level 2 and Level 3 categories within the framework were also developed from the NPS' Ecological Monitoring Framework. Level 2 categories are not as broad as the Level 1 categories, and not as specific as the Level 3 categories. For HAVO, the most important Level 2 categories are Invasive Species and Focal Species or Communities due to the high number of indicators within these categories (Table 3.2-1).

The Level 3 categories are the focal study indicators for the HAVO NRCA (Table 3.2-1). These indicators are used to report on the current condition of the Park's most important natural resources and were largely derived from the PACN's I&M program vital signs. Vital signs are defined as "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" (Fancy et al. 2009). The PACN's list of vital signs was chosen following comprehensive discussions by various subject matter experts in the region. Additional indicators evaluated in this assessment include those resources that have been identified as important in the Park's planning or management documents, as well as relevant indicators currently being monitored by other agencies. The majority of the indicators (over 80%) fall within the Biological Integrity category.

The indicators in this report can be considered resources (e.g., landbirds), ecological processes (e.g., fire regime), or threats/stressors on resources (e.g., invasive ungulates). Twenty-one indicators are assessed in this report. Each indicator has measures that evaluate and/or quantify the state or integrity of the indicator (Table 3.2-1). Although the framework covers large spatial and ecological scales, the list of indicators is limited to a subset of important resource indicators due to funding constraints and data availability. For example, the Lightscape & Night Sky and Landscape Dynamics indicators were not addressed due to budget constraints, limited data and higher priority concerns. However, the importance of understanding and managing these indicators should be noted.

Table 3.2-1. HAVO NRCA study framework, indicators, and measures.

Level 1	Level 2	Indicator (Level 3)	Measures
Air & Climate	Air Quality	Air Quality	Ozone concentration
			Atmospheric wet deposition of sulfur & nitrogen
			Visibility
			Sulfur dioxide concentrations
Geology & Soils	Subsurface Geologic Processes	Volcanic Features & Processes	Volcanic eruptions
			Lava flows
			Mass wasting
Biological Integrity	Invasive Species	Invasive Terrestrial Plants	Range within Park
			Abundance within SEAs
			Number of incipient species that become established
		Invasive Ungulates	Ungulate fencing
			Ungulate-free areas
			Abundance
			Breaches/ingress into ungulate-free areas
		Invasive Small Mammals	Abundance of invasive small mammals in sampled areas
			Observed predation events & impacts to sensitive, rare, & listed species
		Invasive Terrestrial Insects	Number, distribution, & abundance of ant species
			Distribution & abundance of western yellowjacket wasps
			Abundance of two spotted leafhopper
		Coqui Frogs	Number of frogs reported & removed
			Extent of invasion
			Evidence of reproduction
	Focal Species or Communities	Focal Native Plant Taxa	Number of extirpated taxa
			Number of extant taxa

Table 3.2-1 (continued). HAVO NRCA study framework, indicators, and measures.

Level 1	Level 2	Indicator (Level 3)	Measures
Biological Integrity (continued)	Focal Species or Communities (continued)	Focal Native Plant Taxa (continued)	Number of individuals/extant taxa
			Number of taxa protected from ungulates
			Natural recruitment of plants
		Wet Forest Plant Communities	Native species richness
			Percent cover of native species
			Percent of area protected from ungulates
		Subalpine Plant Communities	Native species richness
			Presence & abundance of listed species/SOC
			Number & distribution of invasive target plant species
			Percent of area protected from ungulates
	Focal Species or Communities (cont'd	Anchialine Pools	Abundance & surface area of pools
			Native species richness
			Abundance of native species
			Number of listed species/SOC
			Presence of Invasive pool fauna
			Presence of pool vegetation
			Water quality
Landscapes	Fire & Fuel Dynamics	Fire Regime	Number of wildfires/year
			Area burned by wildfire/year
			Causes of wildfire
			Persistence of native plants post-fire
	Soundscape	Soundscape	Levels of ambient sound & noise.

3.2.2. Reporting Areas

In the initial meeting for the NRCA, HAVO staff was asked to identify ecosystem or habitat units within the Park. After several weeks, meeting participants came to a consensus that seven ecological units occur in the Park: alpine and aeolian, subalpine, montane seasonal, mesic/wet forest, mid-elevation seasonal, lowland coastal, and coastal habitat (see Figure 2.2-2, Section 2.2.2). Dividing the Park into these units is consistent with the vegetation communities defined by Mueller-Dombois and Fosberg (1974) and the current FMUs established in the HAVO Fire Management Plan (NPS 2005b).

Most of the NRCA focal study indicators (Level 3 categories) are present in multiple ecological units; thus, dividing the assessment by ecological unit would cause significant overlap and complications in determining the condition of indicators (Kilkus et al. 2011). As a result, the study findings of this report are not summarized by reporting areas (i.e., ecological units), although the units may be discussed in each resource indicator condition assessment.

3.2.3. General Approach and Methods

To evaluate and report on the current condition of each indicator in the framework, existing and available literature and data were reviewed. Data were analyzed, as appropriate, to synthesize information from diverse sources, provide summaries, or spatially depict conditions. The following information is included for each indicator assessment in Chapter 4.

<u>Background</u>

This section provides context for the reader by describing characteristics of the indicator, the distribution or extent of the indicator at HAVO, and why the indicator is important at HAVO.

<u>Measures</u>

This section lists the measure(s) for each indicator. Measures are defined as those values or characterizations that evaluate and quantify the state of ecological health or integrity of an indicator.

<u>Reference Conditions/Values</u>

This section defines the reference condition(s) or value(s) for the measures of the indicator and discusses how the condition/value was developed. These benchmarks can be based on historical reference sites, management targets, desired conditions, or ecological and regulatory thresholds.

<u>Existing Data</u>

This section describes the available literature and datasets (from multiple and diverse sources) that were reviewed and used to evaluate the measures for the indicator. Methods used for processing or evaluating the data may also be discussed.

<u>Current Condition</u>

In this section, available literature is analyzed to summarize the current condition of the indicator within HAVO. It may also identify trends in resource condition (if possible). The current condition is compared with the established reference condition(s) or value(s). Past or current threats and stressors on the resource are identified. Maps and graphs are provided to illustrate conditions or threats/stressors to the indicators.

This section also contains an overall condition summary to provide a quick representation of the assessed condition. The four ranking categories are Good, Moderate, Of Concern, and Unknown. If available and reliable evidence exists to report on a trend in the resource condition, an up arrow is included for improving conditions, a down arrow is included for declining conditions, and a right arrow is included for stable conditions. If a reliable trend cannot be determined, no arrow is included. Descriptions of the condition rankings and graphics are shown in Table 3.2-1.

Table 3.2-1. Description of condition ranking and graphics.

Ranking		Description
	Good	Current condition meets or exceeds all or most of the reference conditions or values.
	Moderate	Current condition does not meet all or most of the reference conditions or value(s); however, the differences are not excessive.
	Of Concern	Current condition does not meet all or most of the reference conditions or values and the differences are excessive.
	Unknown	Not enough evidence to determine condition during the drafting of this report.

Table 3.2-1. Description of condition ranking and graphics.

Ranking		Description
	Improving Trend	Reliable evidence shows that the condition is improving.
	Stable Trend	Reliable evidence shows that the condition is stable.
	Degrading Trend	Reliable evidence shows that the condition is degrading.

Information Gaps/Level of Confidence

This section describes the extent of the knowledge base (i.e., qualitative and quantitative data) available for each indicator and identifies information gaps that would help to determine the condition of a given indicator. In general, more data means more confidence in the assessment of the indicator. A determination of the extent of the knowledge base available for each indicator is also shown in Table 3.2-2. This categorization is designed to identify both the quality and quantity of the information present.

Table 3.2.2. Description of the extent of the knowledge base ranking.

Ranking		Description
A	Data w/ trends	Quantitative data collected over multiple years for all measures.
B	Status Data	Quantitative data collected only once for all or most measures; unable to determine trend(s).
C	Limited Data	Data limited to qualitative data, anecdotal evidence, observations for the majority of measures.
D	Raw Data	Qualitative data collected, but not analyzed.
E	No Available Data	Lacking data for all measures.

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Chapter 4. Natural Resource Conditions

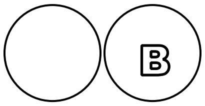
This chapter provides a detailed assessment of current conditions for the 21 indicators emphasized in this study. Each indicator includes the following components, as described in Section 3.2.3:

- Background
- Measures
- Reference Conditions/Values
- Existing Data
- Current Condition
- Information Gaps/Level of Confidence
- Literature Cited/Other Resources

The indicators are presented according to the project framework (Table 3.2-1), with the Air and Climate indicator first, followed by the Geology and Soils indicator, the Biological Integrity indicators (including Invasive Species and Focal Species or Communities), and finally the Landscape indicators (including Fire & Fuel Dynamics and Soundscape).

It is important to note that conditions and trends are based on the measures and reference conditions/values developed for each indicator. Establishing reference conditions or values was challenging for many indicators. While there is value in providing useful comparisons in order to place condition assessments within a larger context, it is difficult to quantify reference conditions in the Hawaiian Islands because historic data is often limited, few undisturbed sites remain, and high habitat diversity on a small spatial scale results in a wide range of acceptable resource conditions.

4.1. Air Quality



Background

HAVO is classified as a Class I air quality area, receiving the highest protection of air quality under the Clean Air Act (NPS Air Resources Division [ARD] 2007). Air quality at HAVO is primarily affected by Kīlauea and MaunaLoa, two of the world's most active volcanoes. Kīlauea has maintained a continuous eruption since 1983, and is the primary source of emissions impacting air quality in the Park, particularly at Halemaʻumaʻu and Puʻu ʻŌʻō (Michaud et al. 2006, NPS ARD 2007, Nelson and Sewake 2008, Environmental Protection Agency (EPA) 2012b, NPS 2013). Kīlauea volcano currently releases an average of 1,000 to 2,000 tonnes of sulfur dioxide (SO_2) per day (Elias and Sutton 2012, EPA 2012c). The SO_2 gas can impact human health by causing breathing difficulties (e.g., bronchoconstriction and increased asthma symptoms), respiratory illness, and can aggravate existing heart and lung conditions. Concentrations of SO_2 in HAVO vary depending primarily on the intensity of volcanic activity, wind speed, and wind direction. Elevated SO_2 levels can lead to restrictions and closures of certain areas in the Park (NPS ARD 2012b).

In addition to SO_2, Kīlauea releases the volcanic gasses hydrogen sulfide, hydrogen chloride, hydrogen fluoride, carbon dioxide, and some trace metals including mercury. These volcanic emissions mix with sunlight, oxygen, atmospheric moisture, and dust, creating volcanic smog, or "vog" (NPS ARD 2007, EPA 2012c) (Figure 4-1-1). Vog impacts air quality on a regional scale by creating haze, reducing visibility, causing rain acidification, modifying soil composition, and affecting vegetation and cultural resources (Sutton et al. 2000, Nelson and Sewake 2008, EPA 2012c, Elias and Sutton 2012).

While naturally occurring volcanic emissions dominate the overall air quality in the park, anthropogenic sources of air pollutants are also present. These include vehicle exhaust, fossil fuel combustion, and fugitive dust from roads. Some of these emissions occur within the Island of Hawaiʻi, while others are believed to originate from outside of the state (EPA 2012c).

NPS' Air Resources Division (ARD) identifies ozone (O_3), visibility, and atmospheric wet deposition of nitrogen and sulfur as key indicators of air quality in national parks. Ground-level O_3 is the main component of smog and can become harmful to humans and plants at high concentrations (EPA 2012b, NPS ARD 2013a). Visibility is monitored through the Interagency Monitoring of Protected Visual Environments (IMPROVE) network. As part of the Regional Haze program, the Environmental Protection Agency (EPA) has a goal to reduce human-caused visibility impairment at all Class I air quality areas and restore natural visibility conditions by 2064 (NPS ARD 2010, 2013, EPA 2012c). Atmospheric deposition of nitrogen and sulfur can acidify lakes, streams, and soil, and can affect biodiversity (NPS ARD 2013a).

Figure 4.1-1. Sulfur dioxide monitoring station at HAVO (Photo: Tiffany Agostini 2012).

In addition to the three NPS' ARD defined air quality indicators (ozone, visibility and wet deposition of sulfur and nitrogen), sulfur dioxide (SO_2) concentrations are used as an additional measure for the Park. Monitoring for volcanic SO_2 emissions is vital to the safety of HAVO visitors and staff. This indicator is important in HAVO given its potential to adversely impact natural resources and human health in the Park.

Measures

- Ozone concentrations
- Atmospheric wet deposition of sulfur and nitrogen
- Visibility
- Sulfur dioxide concentrations

Reference Condition/Value

Overall Air Quality Condition

NPS' ARD uses the criteria listed in Table 4.1-1 to determine the condition of air quality in national parks. Ozone condition is based on the National Ambient Air Quality Standard (NAAQS) and attainment/nonattainment status; deposition condition is based on wet deposition levels and ecosystem sensitivity; and visibility condition is based on human-caused haze (average current visibility minus estimated average natural visibility) (NPS ARD 2013a).

Table 4.1-1. NPS Air Resources Division air quality index values (NPS ARD 2010, 2013a).

Condition	Ozone Concentration[1] (ppb)	Wet Deposition of Nitrogen or Sulfur[2] (kg/ha/yr)	Visibility Condition[3] (dV)
Significant Concern	≥76	>3	>8
Moderate Concern	61—75	1—3	2—8
Good Condition	≤60	<1	<2

[1] Five-year average of the 4th highest daily maximum 8-hour concentration.

[2] The overall wet deposition condition is based on the more concerning condition of either Nitrogen or Sulfur.

[3] The visibility condition is the difference between the five-year average current visibility (between the 40th and 60th percentiles) and the estimated average natural visibility.

The reference condition for ozone, wet deposition, and visibility at HAVO is rated at good according to Table 4.1-1.

Good conditions are defined as 5-year averages of the 4th highest daily maximum 8-hour ozone concentrations less than or equal to 60 parts per billion (ppb); wet deposition amounts less than 1 kilogram per hectare per year (kg/ha/yr); and the 5-year average current visibility (between the 40th and 60th percentiles) is less than 2 deciviews (dv) above estimated average natural visibility (NPS ARD 2010, 2013). Per NPS guidelines (NPS ARD 2013a), each of the measures listed in Table 4.1-1 (i.e., ozone, atmospheric wet deposition, and visibility) is assigned a score based on its condition; measures designated as Warrants Significant Concern are assigned nine points, measures designated as Warrants Moderate Concern are assigned five points, and measures determined in the Good Condition category are assigned one point. These points are then averaged to determine the overall air quality condition in the Park.

HAVO is a unique national park because naturally occurring volcanic emissions greatly influence air quality in the Park. Because volcanic emissions are uncontrollable natural phenomenon, poor air quality incidents resulting from volcanic input are recognized by the EPA as exceptional events. For exceptional events, the normal regulatory process established by the Clean Air Act is not appropriate and air quality monitoring data associated with such events are subject to exclusion to avoid violations and nonattainment designations (EPA 2007, 2013). Due to the temporal nature of volcanic activity at HAVO, differentiating natural and anthropogenic impacts on visibility and wet deposition of sulfur cannot be accurately measured.

In addition to the three NPS' ARD defined air quality indicators (ozone, visibility and wet deposition of sulfur and nitrogen), sulfur dioxide (SO_2) concentrations are used as an additional measure for the Park. Monitoring for volcanic SO_2 emissions is vital to the safety of HAVO visitors and staff. This indicator is important in HAVO given its potential to adversely impact natural resources and human health in the Park.

Sulfur Dioxide Condition

NPS ARD's methods for evaluating the overall condition of air quality in National Parks (NPS ARD 2013a) do not include an assessment of ambient concentration of gaseous SO_2; however, because the amount of volcanic SO_2 emission at HAVO results in ambient concentrations high enough to be a significant health concern, a discussion of SO_2 is included in this report. Nine SO_2 monitoring sites provide up-to-date information on vog concentrations within the park, and alert health advisories to limit public exposure at unhealthy levels (NPS 2012). SO_2 concentrations are reviewed every 15 minutes and assigned one of six possible advisory levels (Table 4.1-2).

Table 4.1-2. HAVO sulfur dioxide advisory levels (NPS ARD 2012b).

Advisory Level	SO_2 concentration	Recommended action
Good	<0.2 ppm	Unusually sensitive individuals may want to limit their exposure in this area.
Moderate	≥0.2 ppm	Sensitive individuals may want to limit outdoor exertion, or stay indoors or in an air conditioned environment.
Unhealthy for Sensitive People	≥0.4 ppm	Physically active and sensitive individuals may want to limit outdoor exertion, or stay indoors or in an air conditioned environment.
Unhealthy	≥1 ppm	All individuals should limit or avoid outdoor exertion, or stay indoors or in an air conditioned environment.
Very Unhealthy	≥3 ppm	All individuals should avoid outdoor exertion and remain indoors.
Hazardous	≥5 ppm	All individuals should avoid outdoor exertion and remain indoors. Leave the area if directed by Civil Defense.

There are several NAAQS standards for SO_2. The primary standard, designed to protect public health, is a daily maximum 1-hour average of 75 ppb (EPA 2012a). This report used the NAAQS secondary standard for SO_2, which states that a concentration of 0.5 parts per million (ppm) over a 3-hour period should not be exceeded more than once per year (Ray 2013). This standard is designed to provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings (EPA 2012a).

A reference condition for SO_2 concentrations is not defined. SO_2 levels are the result of volcanic eruptions, which are classified as natural events (EPA 2013). However, in this assessment, SO_2 concentrations recorded in HAVO are compared to the NAAQS secondary standard and the NPS advisory levels to provide context for comparison.

Existing Data

Guidelines for evaluating air quality are provided by NPS ARD (2010, 2013a). The following literature and datasets were used to evaluate O_3 in HAVO.

- O_3 concentration data from HAVO between 1999 and 2002 is provided in the NPS ARD annual data reports for Thurston Lava Tubes (NPS ARD 1999, 2000, 2001, 2002). A summary of ozone data collected at the Thurston Lava Tubes station in 2003 is included in NPS network-wide gaseous pollutant monitoring program report (NPS ARD 2003). Data from these data summaries (1999–2003) were used to derive a 5-year average O_3 concentration for HAVO. Due to budget constraints, O_3 recording was concluded in 2004 when the Clean Air Status and Trends Network (CASTNet) discontinued the monitoring program at HAVO, as well as other National Parks with low ozone concentrations (NPS ARD 2004).
- ARD maintains a database of all active and inactive ozone monitoring sites at HAVO (NPS ARD 2012a).
- The EPA provides national standards and background information on ground-level O_3 concentrations (EPA 2012b).

The following literature and datasets were used to evaluate wet deposition totals in HAVO.

- National Atmospheric Deposition Program (NADP) provides atmospheric wet deposition data collected at HAVO between 2000 to 2005 (NADP 2013a, 2013b). Atmospheric wet deposition of nitrogen and sulfur compounds were measured at HAVO from 2000 to 2005 using the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) site ID HI99. Data was no longer collected after 2005. Typically, NPS calculates wet deposition by multiplying sulfur or nitrogen concentrations by a normalized precipitation amount. However, normalized precipitation amounts are not available for HAVO so 5-year averages of on-site deposition are used instead, when available.
- Guidelines and protocol for wet deposition monitoring in national parks are covered in NPS ARD (2005).
- Atmospheric dry deposition was measured from 1999 to 2004 under the CASTnet using site ID HVT424. CASTNet data uses NADP/NTN wet deposition data to provide total deposition of sulfur and nitrogen in the Park (NPS ARD 2005).

The following literature and datasets were used to evaluate visibility at HAVO.

- Visibility has been monitored at HAVO through IMPROVE since 1986. This program used an aerosol sampler from 1988 to 1992, and an automatic 35mm camera from 1986 to 1995 (NPS ARD 2012a). IMPROVE resumed monitoring at HAVO in 2000, and continues at present (NPS ARD 2007, 2012a). For this assessment, IMPROVE data from 2001 to 2010 (IMPROVE 2011) are used to report the average annual current visibility condition at the HAVO1 monitoring site, located on the northeastern rim of Kīlauea crater.
- The EPA technical support document (2012c) summarizes atmospheric data collected at HAVO for the Regional Haze Program implementation plan for the State of Hawaiʻi (EPA 2012c, 2012d). Haze Index values of the clearest days and haziest days are reported. The program establishes baseline visibility condition estimates for HAVO using IMPROVE data from the HAVO1 monitoring site from the years 2001 through 2004, as specified in the

Regional Haze regulations under Title 40 Code of Federal Regulations §51.308(d)(2)(i) (EPA 2012c). Measures used to determine visibility conditions under the Regional Haze Rule program are visibility on the 20% clearest (best) days and visibility on the 20% haziest (worst) days. Baseline conditions are the reference point against which EPA tracked visibility impairment (EPA 2012c).

- The average estimated natural visibility at HAVO and other national parks is provided by NPS ARD (2013b).

An assessment of SO_2 emissions at HAVO was conducted using the following literature and datasets.

- Data on elevated SO_2 emission rates from Kīlauea Volcano from 2007 through 2010 were summarized by Elias and Sutton (2012).
- The annual reviews of the gaseous pollutant monitoring program (GPMP) includes SO_2 emission data from HAVO from 2007 through 2011 (Ray 2008, 2009, 2010, 2011, 2013).
- In 2012, NPS deployed an additional seven SO_2 monitors throughout the Park (Nāmakanipaio Campground, Steam Vents, Kīlauea Visitor Center, Thurston Lava Tube, Devastation, Kealakomo Overlook, and end of Chain of Craters Road). The HAVO SO_2 Advisory Program website (NPS ARD 2012b) discusses the criteria used to determine if emissions are a concern for human health; concentrations of SO_2 are reviewed every 15 minutes, and assigned an advisory level. An unpublished report from NPS discusses the results of the SO_2 monitoring during FY 2012 (NPS 2012).

<u>Current Condition</u>
As stated in *Air quality in national parks: trends (2000–2009) and conditions (2005–2009)* (NPS ARD 2013b): air quality "estimates and conditions are not available for most parks in Alaska and the Pacific Islands because data are too sparse to interpolate." Air quality summaries for HAVO only report on visibility conditions, while the remainder of the air quality indicators are not determined. Ozone concentration, as well as Wet Deposition (Sulfur and Nitrogen), do not meet the criteria for assigning condition values due to a lack of current monitoring data at HAVO. As a result, an overall condition for air quality at HAVO cannot be assigned. However, data from earlier monitoring years are discussed below.

<u>Ozone Concentrations</u>
CASTNet monitoring of ozone was discontinued in 2004 at HAVO and other parks with low ozone concentrations (NPS ARD 2004); thus, current conditions for ozone concentration are unavailable for HAVO (NPS ARD 2012a). Ray (2013) states that ground-level ozone concentrations have been decreasing in all monitored National Parks in recent years.

Ozone concentrations recorded at Thurston Lava Tube between 1999 and 2003 ranged from 37 to 48 ppb (NPS ARD 1999, 2000, 2001, 2002, 2003) (Figure 4.1-2). The 3-year average fourth-highest daily maximum 8-hour ozone concentration between 2000 and 2002 was 40 ppb (NPS ARD 2002). The 5-year average fourth-highest daily maximum 8-hour ozone concentration between 1999 and

2003 was 42 ppb. Thus, historic ozone concentrations at HAVO are considered good by NPS standards (<60 ppb) (NPS ARD 2013).

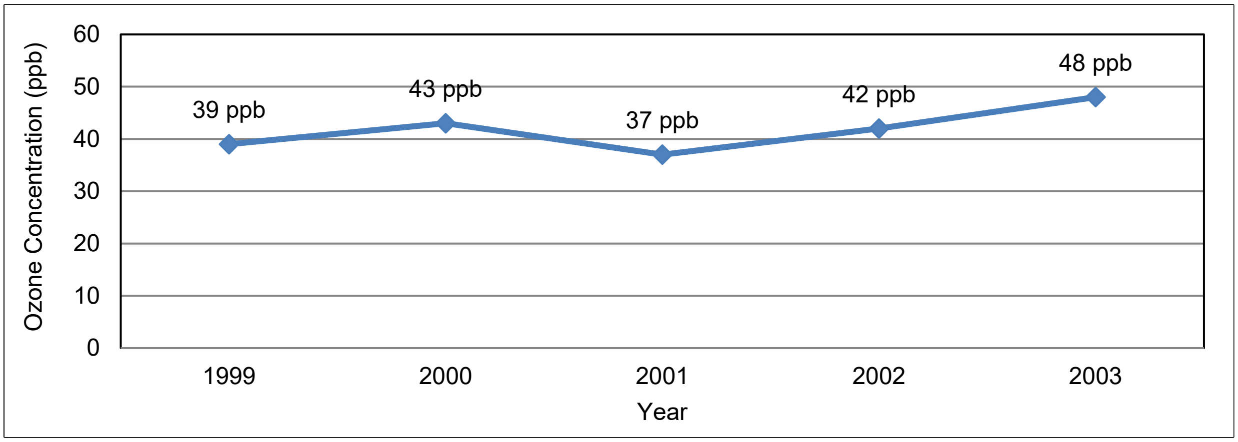


Figure 4.1-2. Annual average of the fourth-highest daily maximum 8-hour ozone concentration at Thurston Lava Tube monitoring site between 1999 and 2003 compared to NPS ARD evaluation guidelines for good condition (< 60 ppb) (NPS ARD 1999 - 2003).

Atmospheric Deposition of Sulfur and Nitrogen

Atmospheric deposition occurs in two types, wet and dry. Wet deposition occurs when atmospheric pollutants mix with precipitation and are deposited on the earth. The process of wet deposition primarily occurs through rain, but can also occur through clouds, fog, and snow. The process of dry deposition is more complicated, involving the transference of particles and gases onto surfaces such as the ground and plants. Not all parks are equipped to measure dry deposition. Consequently, the ARD only uses wet deposition measurements to standardize air quality for national parks.

The amount of wet deposition of sulfur at HAVO is very high, due to extreme sulfate concentrations primarily attributed to Kīlauea Volcano (NPS ARD 2012a, Ray 2013). A 5-year average is unavailable for HAVO. While NADP/NTN maintained wet deposition monitoring from 2000 to 2005, data only met NADP/NTN completeness criteria for the years 2001 through 2003 (NADP 2013a, 2013b). The 3-year average of wet deposition of sulfur, calculated from NADP measurements from 2001 through 2003, was 8.9 kg/ha/yr (NPS ARD 2013). This far exceeds the NPS significant concern threshold for wet deposition of sulfur, set at greater than 3.0 kg/ha/yr (NPS ARD 2013). However, exceedances in the wet sulfur deposition reference condition is attributed primarily to natural volcanic emissions rather than anthropogenic causes; the EPA classifies volcanic and seismic activity as an exceptional event and air quality monitoring data associated with such events are subject to exclusion to avoid violations and nonattainment designations (EPA 2007, 2013). It is assumed that data associated with volcanic emissions has not been excluded from the NADP measurements.

While deposition monitoring ended in 2005, it is likely sulfur deposition increased greatly after a fissure eruption began at Kīlauea in late 2007, and an explosive event opened a gas-emitting vent at the summit in March 2008. Emissions peaked in 2008, when Kīlauea SO_2 rates exceeded 7,000 tonnes per day. Emission rates returned to pre-2002 levels in 2010 (Elias and Sutton 2012).

Wet deposition of nitrogen at HAVO has historically been in good condition. A 5-year average of wet deposition of nitrogen compounds is unavailable for HAVO. NADP only met data completeness criteria for 2001 through 2003 (NADP 2013b). The 3-year average, 2001 through 2003, calculated from NADP data, was 0.85 kg/ha/yr (Figure 4.1-3) (NADP 2013b). This amount places HAVO wet deposition of nitrogen in good condition according to the NPS criteria (Table 4.1-1) (NPS ARD 2010, 2013).

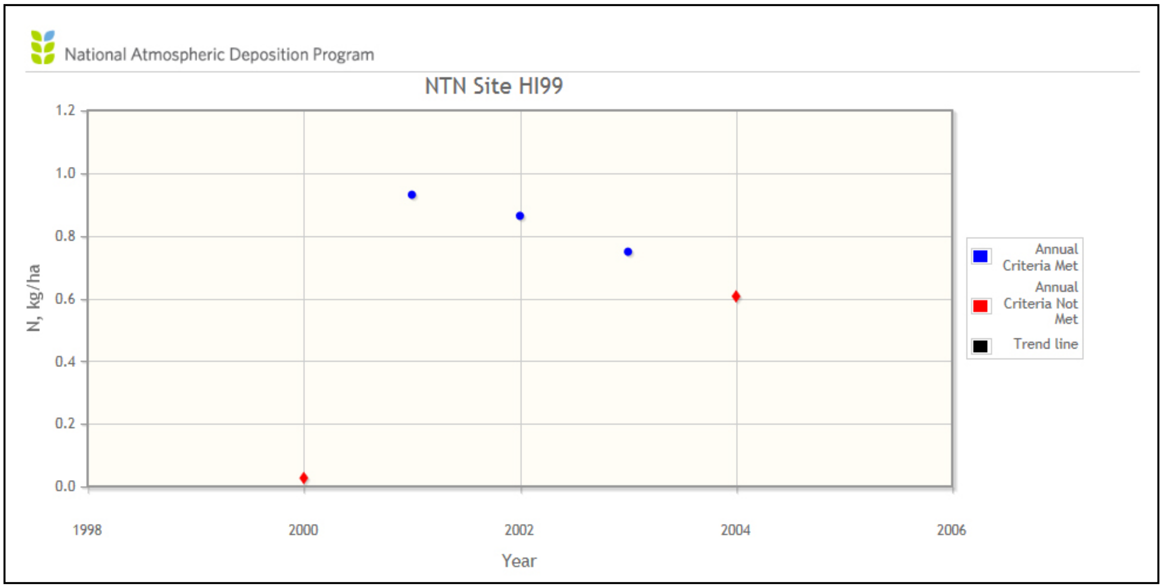


Figure 4.1-3. NADP/NTN atmospheric wet deposition of nitrogen at HAVO from 2000 through 2005. Complete criteria years in blue (NADP 2013b).

<u>Visibility</u>

Visibility is measured in dV, a Haze Index Metric. One dV change in the haze index is likely perceptible by the human eye (EPA 2012c). The lower the dV, the better the visibility.

Baseline visibility at HAVO, from data collected between 2001 and 2004, was 4.1 dV for the 20% best days and 18.9 dV for the 20% worst days. The estimated natural visibility (i.e., condition that would occur in the absence of anthropogenic impairment) at HAVO is 2.2 dV on the 20% best days and 7.2 dV on the 20% worst days (EPA 2012c). Estimated natural visibility does not include dV increases due to volcanic emissions from Kīlauea Volcano. Emissions from the volcano are unpredictable, and can vary from year to year, so were excluded from the estimated natural visibility value (EPA 2012c). Therefore, observed current conditions at HAVO are typically worse than EPA estimated natural visibility. Figure 4.1-4 shows varied visibility conditions at HAVO and is intended to provide an understanding of what a best, moderate, and hazy condition looks like at the Park (IMPROVE 2001).

Sulfate emissions from Kīlauea Volcano are identified as the overwhelming contributor of natural haze in the Park (EPA 2012c). Reported human-caused visibility impairment is decreasing, and reasonable progress is being made to eliminate human-caused haze in the state of Hawaiʻi (EPA 2012d). Statewide, anthropogenic emissions of nitrogen oxides (NOx) and volatile organic compounds (VOCs) are decreasing, and are estimated to be 21% lower than 2005 levels by 2018 (EPA 2012c). Other potential visibility-reducing sources include sea salt sulfates and transported Asian dust (EPA 2012c).

Figure 4.1-4. IMPROVE monitoring at HAVO showing best (2 dV, upper left), moderate (8 dV, upper right), hazy (19 dV, lower left), and extreme vog event (lower right) (IMPROVE 2001).

The average estimated natural visibility at HAVO is 4.9 dV (NPS ARD 2013a). Annual average visibility values from 2001 to 2010, as well as differences from the estimated average natural visibility at HAVO, are shown in Table 4.1-3.

The visibility condition for HAVO is a moderate concern with a degrading trend (NPS ARD 2013b). Visibility trends on the 20% worst days were significantly degrading between 2000─2009 (NPS ARD 2013b), and showed no improvement between 2001─2009, although this is likely due to the increase in volcanic activity in that timeframe (EPA 2012b). However, monitoring data on 20% best days show visibility has been fairly constant with no significant trend from 2001 to 2009 (EPA 2012b, NPS ARD 2013b).

Table 4.1-3. Average annual visibility at HAVO from 2001 to 2010 compared to the estimated average natural visibility. Although the 5-year average current visibility is not reported, the average annual values are between 2.4 and 3.7 dV worse than the average estimated natural visibility at HAVO.

Year	Average annual visibility*	Difference from estimated average natural visibility (4.9 dV)
2001	7.7	2.8
2002	7.8	2.9
2003	8.3	3.4
2004	8.2	3.3
2005	7.7	2.8
2006	8.1	3.2
2007	7.3	2.4
2008	8.2	3.3
2009	8.6	3.7
2010	7.9	3.0

* Mean of the values on the days with the dv between the 40th and 60th percentiles (IMPROVE 2011).

Sulfur Dioxide Concentrations

Within the National Park System, SO_2 is only measured at HAVO, Great Smoky Mountains, and Mammoth Cave. HAVO has the highest SO_2 concentration of these parks (Ray 2013). The number of days that the secondary NAAQS (0.5 ppm or 549 ppb over a 3-hour period more than once per year) was exceeded at the Observatory/Jaggar Museum and Visitor Center sites between 2007 and 2011 are shown in Table 4.1-4 (Ray 2008, 2009, 2010, 2011, 2013).

Table 4.1-4. Number of days 3-hour maximum SO_2 concentrations (≥0.5 ppm, 549 ppb) were exceeded per year between 2007 and 2011.

Site Name	2007 (Ray 2008)	2008 (Ray 2009)	2009 (Ray 2010)	2010 (Ray 2011)	2011 (Ray 2013)
Observatory Jaggar Museum	5 days	28 days	39 days	32 days	2 days
Visitor Center	2 days	5 days	27 days	20 days	0 days

The total number of days that SO_2 concentrations met or exceeded moderate and unhealthy advisory levels in FY 2012 is shown in Figure 4.1-4. SO_2 concentrations met or exceeded moderate advisory levels (≥0.2 ppm) between 14 and 240 days at the nine stations, while unhealthy levels (≥1 ppm) were reached between 0 and 76 days. Occurrence of moderate or unhealthy levels was most frequent at the Chain of Crater Road site (NPS 2012).

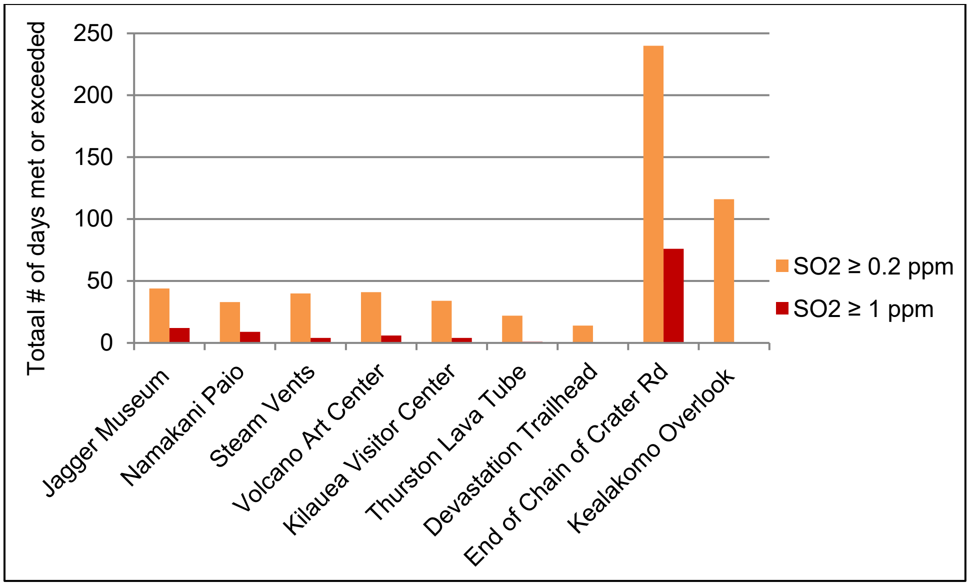


Figure 4.1-5. Total number of days when sulfur dioxide concentrations met or exceeded moderate or unhealthy levels (point recorded >15 minutes of elevated SO_2 concentration) in FY 2012 (NPS 2012).

Threats and Stressors

Volcanic emissions are the dominant stressor to air quality at HAVO (NPS ARD 2007, 2012b, EPA 2012c). Lesser sources of stress may include smoke from burning events (e.g., agriculture, brush fire), attribution of local dust from high winds, global dust (e.g., Asian dust), oil or biomass combustion for power generation, and sea salt (EPA 2012c).

Overall Condition

Data collected at HAVO for ozone concentration, as well as wet deposition of sulfur and nitrogen deposition, were insufficient to assess overall air quality condition (NPS ARD 2012a, 2013b). Visibility was rated a moderate concern with a degrading trend (NPS ARD 2013b). Appropriate reference conditions for SO_2 concentrations have yet to be determined at HAVO, and this measure is not included in NPS' methodology for determining the condition of air quality in national parks. However, monitoring efforts to protect public health and understand impacts to natural resources have been significantly increased (NPS 2012).

As stated above, the EPA recognizes volcanic and seismic activities as exceptional events, for which the normal regulatory process established by the Clean Air Act is not appropriate (EPA 2007, 2013). Certain data included in the assessment above may be subject to exclusion, but does not appear to have been excluded from available data.

Information Gaps/Level of Confidence

Overall, the extent of the data for this indicator is ranked as B due to the availability of long-term quantitative data for all measures, but a lack of current data. The level of confidence for the data is relatively high because estimates are based on interpolated data from monitoring stations within the Park (NPS ARD 2013).

HAVO does not currently support a permanent O_3 monitoring station. Ozone was originally measured at the Kīlauea Visitor Center from 1986 to 1995, and then measured at Thurston Lava Tubes from 1999 to 2003. Due to budget constraints, O_3 recording was concluded in 2004 when the CASTNet discontinued the monitoring program at HAVO and other Parks with low O_3 concentrations (NPS 2004, NPS ARD 2012a). The risk of O_3 injury on vegetation at HAVO could not be determined due to the lack of information on exposure at the Park (NPS 2004). Information on this risk could adjust the condition category of O_3 in the Park.

Additional monitoring for wet deposition of nitrogen and sulfur compounds through NADP/NTN is recommended, as data collected between 2000 and 2005 only met completeness criteria for 3 of 5 years. NPS requires a minimum 5-year average of deposition for condition and trend analysis (NPS ARD 2013a). The majority of air quality measurements for ozone and wet deposition were made prior to the marked increase in volcanic activity from 2007 to 2010. This is particularly important for sulfur given that the condition for wet deposition of sulfur at HAVO exceeds the significant concern threshold.

As HAVO experiences nearly continuous, significant air pollution due to volcanic emissions, a practical method of addressing affected data is not known at this time. Although the EPA is in the process of finalizing methods to address data affected by exceptional events, it is unknown whether this will include guidance for air quality specialists at HAVO.

Subject Matter Experts Consulted

- Danielle Foster, Environmental Protection Specialist, NPS HAVO
- The National Park Service's Air Resources Division oversees the national air resource management program for the NPS. Together with parks and NPS regional offices, they monitor air quality in park units, and provide air quality analysis and expertise related to all air quality topics. For current air quality data and information for this park, please visit the NPS Air Resources Division website at https://www.nps.gov/subjects/air/index.htm.

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4.2. Volcanic Features and Processes

Background

As stated in HAVO's *Geologic Resources Inventory Report* (Thornberry-Ehrlich 2009), "geology is the foundation of park ecosystems." The geology of a landscape determines many factors, including topography and substrate, hydrology, types and densities of organisms present, and how ecosystems respond and change over time (Rutherford and Kaye 2006). Geologic features and processes can be considered both resources and stressors due to their impacts to park ecosystems. As such, NPS values both the management of geologic features as well as the protection of geologic processes. Many national parks exist specifically to conserve geologic resources (NPS 2004).

Volcanic features and processes are an important component of geology. Fifteen national parks contain active volcanoes (i.e., erupted in the last 10,000 years) of the Pacific Rim (NPS 2004). Volcanic activity creates a unique management situation for national parks. While many visitors come to the parks to enjoy viewing lava and land formations, active volcanoes are a hazard for public safety, facilities, and natural resources and processes (Cumming 2006).

The original purpose for establishing HAVO was to protect and study the significant volcanic processes and features within the Park. It is one of only 22 U.S. national parks that hold volcanic resources (Heggie and Heggie 2004). The most notable volcanic features in the Park – MaunaLoa and Kīlauea Volcano – are considered two of the most active volcanoes in the world. Since the on-going eruption of Kīlauea, which began in January 1983, the Park has experienced volcanic activity almost daily. Other volcanic features at HAVO include craters, calderas, lava tubes, littoral cones, spatter and cinder cones, fissures, steam vents, sea arches, cracks, and lava tubes (Figures 4.2-1 and 4.2-2) (Thornberry-Ehrlich 2009).

After magma from the earth issues at the surface, lava can flow on the surface or travel long distances to the ocean via lava tubes under the surface. Although lava flows are natural occurrences that add land area to the Park, these events can adversely impact natural resources. Lava flows destroy vegetation on contact, and create barren surfaces that are extremely harsh environments for new plants and animals to establish and survive (Walker 1999, Stone and Pratt 2002). Lava flows also ignite fires and few native Hawaiian plant species are able to survive and regenerate after fire (LaRosa et al. 2008). Lava tubes are volcanic features that are formed when the outer surfaces of lava flows cool and solidify, providing insulation and allowing the inner flow to persist (Thornberry-Ehrlich 2009). These features have great biological and cultural significance, and are discussed in Section 4.18.

Mass wasting (landslides and rockfalls) as a result of volcanic activity is a significant concern at HAVO. The combination of on-going volcanic and seismic activity, steep terrain, and the fragility of lava tubes and new lava flows makes some areas of the Park very dangerous. Heavy rainfall can further reduce structural integrity and can either result in or exacerbate mass wasting events

(Thornberry-Ehrlich 2009). These events can modify or destroy natural and geologic resources, infrastructure, and endanger visitors. Slope failures can occur as slow-moving, wide slumps or fast-moving, long debris avalanches (Thornberry-Ehrlich 2009).

Figure 4.2-1. Halemaʻumaʻu Crater (Photo: Tanya Johnson 2013).

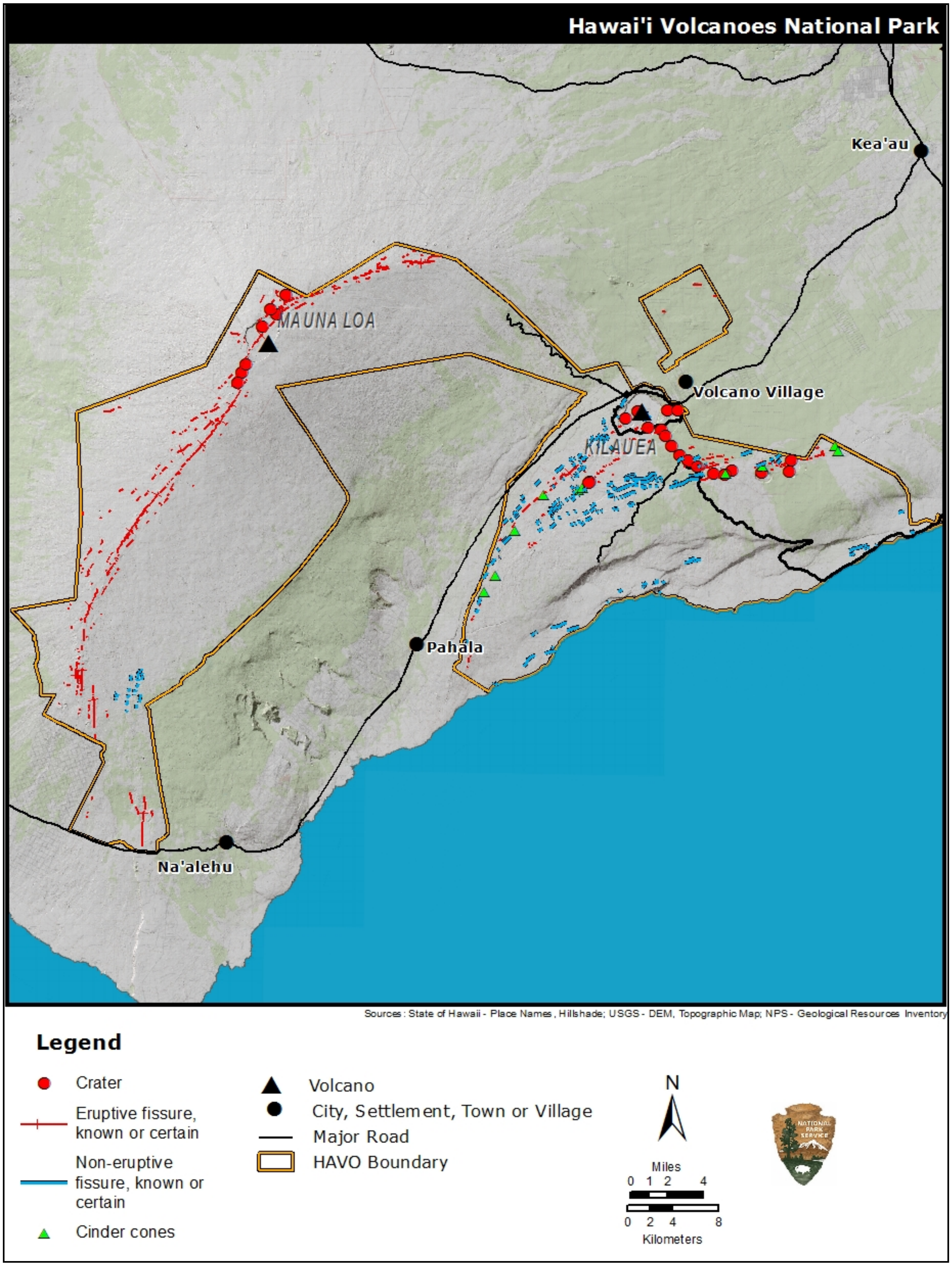

Figure 4.2-2. Selected geologic features in the Park from Thornberry-Ehrlich (2009).

The Hawaiian Volcano Observatory (HVO), which is run by USGS, studies and monitors volcanic activity in the Park to better understand volcanic processes, and to protect and minimize risk to people and property from various volcanic hazards (HVO 2013). Resource managers at HAVO also play a vital role in protecting Park visitors and preventing and mitigating damage from volcanic hazards, as well as protecting lava tubes and the unique species and biological processes that exist within them (Thornberry-Ehrlich 2009).

Due to the active nature of HAVO's volcanoes, as well as the ability to study these features and processes at relatively close range, the Park is considered a valuable tool for understanding similar resources worldwide. HAVO offers unparalleled opportunities into unique fields of study, from volcanology and seismology to speleology, archaeology, and biology. Furthermore, it is also one of the few places were the general public can view these active processes and gain an appreciation of such phenomena (Tilling et al. 2010).

Measures

- Number of volcanic eruptions
- Area covered by lava flows
- Number of mass wasting events

Reference Condition/Value

Defining reference conditions for volcanic features and processes is not appropriate given the unique and dynamic nature of these naturally occurring features and events. An historical reference site, management targets, and desired conditions do not exist for this indicator. Geologic maps of the park provide a baseline of geologic rock units that are exposed on the surface. This includes older lithified lava flows and ash deposits against which contemporary and future lava flows and volcanic eruptive events can be compared for chemical signature, place of origin, time of origin, and area of coverage. While not referencing "condition" of the resource, it does provide a reference for other things that can be identified and included here in this report.

Existing Data

The following resources were used to assess the condition of volcanic features and processes at HAVO.

- Rutherford and Kaye (2006) identify geologic features, processes, and concerns within the PACN including HAVO.
- Thornberry-Ehrlich (2009) conducted a geologic resource inventory for HAVO. The purpose of this inventory was to identify geologic features and processes and resource management issues. MaunaLoa, Kīlauea, and lava flows/tubes were identified as the primary features of concern in HAVO.
- HVO maintains a website with information on eruptions in the Park (USGS 2009).
- Tilling et al. (2010) discuss the history of eruptions at HAVO's shield volcanoes, as well as lava flows, landforms, and structures in the Park.
- GPS files which contain information on pre-historic and historic (1790-1995) lava flows that have occurred within the Park (NPS 2007).

Current Condition

Volcanic Eruptions

MaunaLoa has erupted 33 times since the first historical eruption in 1843 (Figure 4.2-3). It last erupted in 1984 for a 3-week period (NPS 2008, Thornberry-Ehrlich 2009). Three rift zones (i.e., extensive zones of cracks that provide passage for magma) extend down the sides of the shield of MaunaLoa. Eruptions are estimated to occur once every 3.6 years at these rift zones throughout recorded history (Thornberry-Ehrlich 2009); however, eruptions have been less frequent in the last 50 years compared to the 50 years prior.

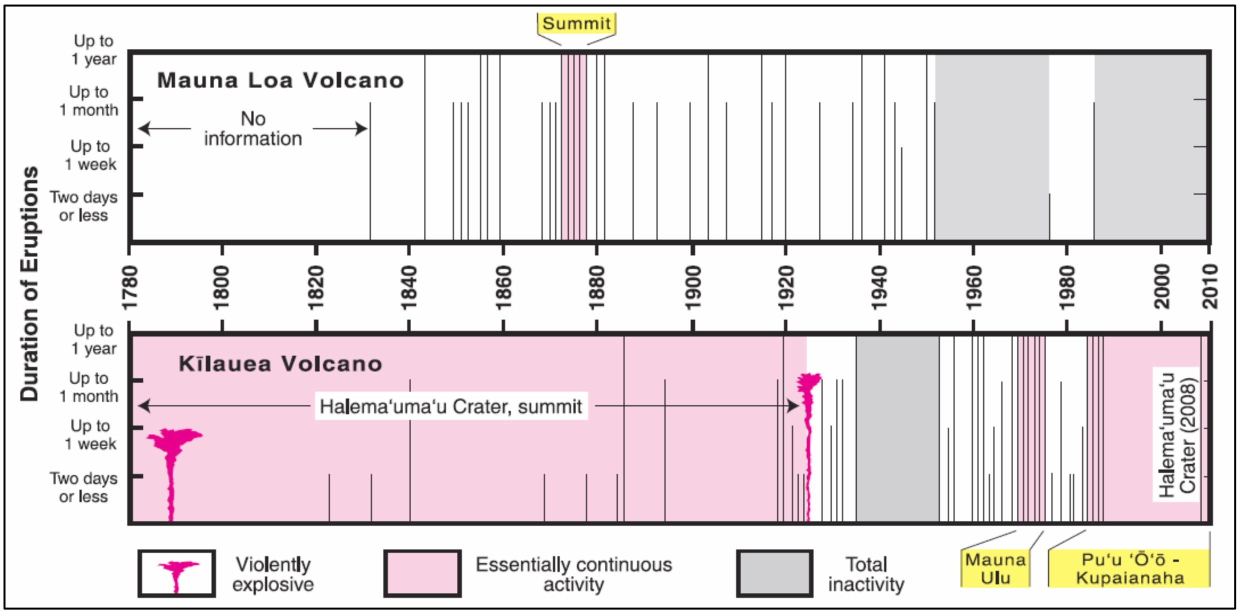

Figure 4.2-3. Eruptions of MaunaLoa and Kīlauea from Tilling et al. (2010). Vertical bar indicating total duration of eruptions may represent a single event or several separate eruptions.

Kīlauea, although younger and smaller than MaunaLoa, is the most active volcano in the world. It was extremely active between the late 1700s and 1920 (Figure 4.2-3) (Tilling et al. 2010). Nearly continuous lava-lake activity on the crater floor occurred from before 1824 until 1924 and resumed in 2008. Elsewhere on the volcano, sixty eruptive events occurred between 1924 and 1983 (Macdonald, G. A., et al. 1986, USGS 2012). These included significant eruptive events such as the MaunaUlu flow series (1969–1974) and the present day Pu‘u ‘Ō‘ō-Kipuaianaha that began in 1983 (USGS 2012). Kīlauea has been erupting almost continuously since 1983, adding an estimated roughly 202 ha (500 ac) to the southern shore of Hawai‘i Island as of 2012 (USGS 2012). Most activity outside of the summit crater has occurred along the two rift zones that extend from the summit of Kīlauea: East Rift and Southwest Rift (Thornberry-Ehrlich 2009).

Lava Flows

Eruptions of MaunaLoa and Kīlauea have resulted in extensive lava flows covering large areas of the Park. Flows from MaunaLoa have been reported to travel at least 50 km (30 mi). Most lava flows in HAVO are less than 750 years old (Thornberry-Ehrlich 2009). Lava flows generated from MaunaLoa since 1843 have covered over 806 km^2 (Lockwood and Lipman 1987). From 1983 to 2012, the total area covered by lava flows generated from Kīlauea has been 124.4 km^2, including 202 ha of new land. These include areas inside and adjacent to the park. Historical flows between 1790 and 1995 have affected approximately 25% (69,723 ha [172,216 ac]) of the park (NPS 2007). These include significant portions of the park's alpine (29% or 10,878 ha [26,870 ac]), subalpine (24% or 7,453 ha [18,410 ac]), montane seasonal (17% or 1,852 ha [4,576 ac]), mesic/wet forest (41% or 7,856 ha [19,405 ac]), mid-elevation seasonal (19% or 5,551 ha [13,711 ac]), and coastal lowland habitats (27% or 4,548 ha [11,233 ac]).

Mass Wasting Events

Several mass wasting events are known to have occurred in HAVO or are in the process of occurring. In 1997, the Puʻu ʻŌʻō cone collapsed and between 2005 and 2010 there were multiple collapses of the once actively growing East Laeʻapuki lava (Tilling et al. 2010). HilinaPali is an example of an ongoing slow-moving slump that began at least 43,000 years ago and is the subject of intensive monitoring (Okubo 2004). The Hilinaslump covers most of the southern flank of Kīlauea Volcano (Rutherford and Kaye 2006, Thornberry-Ehrlich 2009). Other than HilinaPali, observations of mass wasting events have been generally associated with active volcanic eruptions. The total number of mass wasting events that have occurred in the park over the years is unknown.

Although the immediate impact of volcanic or mass wasting events can be dramatic, there is a wide range with regard to the net effect. For example, the East Laeʻapuki lava delta grew to 14 ha (34 ac) before its first collapse in 2005, grew again to 26 ha (64 ac) by 2007, and was eventually destroyed by 2010 due to multiple collapses (Tilling et al. 2010).

Threats and Stressors

Human-influenced accelerated erosion and destabilization of soils have been identified as significant threats to geologic resources in other national parks (Bennetts et al. 2012). Roads and other impervious surfaces can concentrate runoff and affect the integrity of geological features. It is unknown if this is a concern for HAVO. Also, volcanic eruptions and active lava flows can serve as threats and stressors to park resources including plant communities, small populations of plants and animals, and anchialine pools (Cuddihy et al. 1986).

Overall Condition

Defining reference conditions for volcanic features and processes is not appropriate given the unique and dynamic nature of these naturally occurring features and events. Volcanic processes such as eruptions, lava flows, and mass wasting are naturally occurring events that are unique to each location.

Information Gaps/Level of Confidence

According to Thornberry-Ehrlich (2009), HVO constantly monitors volcanic and seismic activity, as well as the formation of lava tubes. Active lava flows are tracked by researchers at HVO using GPS mapping aids and aerial photographs (Rutherford and Kaye 2006). Several mass wasting event such as the Hīlina Slump, collapse of active volcanic vents and lava delta are monitored by researchers at

HVO. The associated effects of human activity currently are not being monitored at HAVO. As such, the extent of knowledge for this indicator for this assessment is ranked B.

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4.3. Invasive Terrestrial Plants

Background

The Hawaiian Islands are estimated to have more invasive species per square mile than anywhere else on the globe (Beard and Gibbons 2011), and the archipelago is particularly susceptible to invasion by nonnative plants. Many of the over 10,000 plant species and cultivars introduced to the Hawaiian Islands have become invasive (Staples and Herbst 2005, Zouhar et al. 2008). High habitat diversity, favorable climate, high resource availability, low biotic resistance, and small native populations are among the factors that contribute to the islands' vulnerability (Clements and Daehler 2007, Denslow et al. 2008).

Invasive plants are believed to gain a competitive advantage over native species through natural enemy release (DeWalt et al. 2004). Additionally, invasive plants are often reported to be faster growing and better able to quickly colonize, establish, and displace native species (Pattison et al. 1998, Funk and Vitousek 2007, Van Kleunen et al. 2010).

The impacts of invasive plants are wide-ranging. Invasive plants compete with native plants for space, light, and nutrients. Native plants are generally slower growing than nonnatives and thus are often physically displaced after disturbances. This enables invasives to form monotypic stands, reducing biodiversity (Smith 1985). At the ecosystem level, invasive plants have been shown to be capable of changing fire regimes (D'Antonio and Vitousek 1992), altering nutrient cycling patterns (Vitousek 1990), preventing the natural succession of native vegetation communities, and modifying the surface runoff of water (Vitousek 1992). Invasive plants can remove wildlife habitat and adversely impact animals that depend on native plants (College of Tropical Agriculture and Human Resources 2003, Parham et al. 2008, Seitz et al. 2012). Invasive vegetation can also change hydrologic regimes in lakes, streams, wetlands, and other freshwater habitats. Compared to native plants, nonnative invasive plants can have greater transpiration rates, thereby impacting several hydrological processes, such as streamflow or groundwater recharge (Gordon 1998, Going and Dudley 2008, Kagawa et al. 2009).

The proportion of nonnative to native plant species has increased with every vascular plant survey conducted in HAVO (Pratt et al. 2012). Over 600 nonnative vascular plant species are known to occur within HAVO. Of these, 134 species are considered invasive and highly disruptive to native ecosystems (Table 4.3-1) (Benitez et al. 2012). These species have been identified as target invasive plants for the Park. Many are included in the International Union for Conservation of Nature's list of the world's worst 100 invasive species. Additional invasive plant species found at Kahuku may also be added to this list in the future based on the results of the recent surveys in that section of the Park (Benitez et al. 2008).

Table 4.3-1. Invasive plant species targeted for management in the MaunaLoa, Kīlauea, and ʻŌlaʻa sections (excludes Kahuku) and their relative distributions and control strategy. Reported in Benitez et al. 2012 (2) David Benitez, Ecologist, NPS HAVO, pers. comm (2014).

Scientific Name	Common Name	Relative Distribution	Control Strategy
Abrus precatorius	Black-eyed Susan	Localized	Eradicate
Acacia confusa	Formosa koa	Localized	Eradicate
Acacia mearnsii	Blackwattle	Localized	Eradicate
Acacia melanoxylon	Blackwood acacia	Localized	Eradicate
Acca sellowiana	Guavasteen	Localized	Eradicate
Aechmea sp.	Aechmea	Localized	Eradicate
Agave americana	Century plant	Localized	Eradicate
Agave sisalana	Sisal	Localized	Eradicate
Andropogon virginicus	Broomsedge	Widespread	Projects
Anemone hupehensis	Japanese anemone	Widespread	Monitor
Ardisia crenata	Hilo holly	Localized	Eradicate
Arundo donax	Giant reed	Localized	Eradicate
Asclepias physocarpa	Balloon plant	Widespread	Monitor
Banksia cf. integrifolia	Boast banksia	Localized	Eradicate
Benincasa hispida	Chinese melon	Localized	Eradicate
Buddleia asiatica	Butterfly bush	Widespread	Monitor
Buddleia davidii	Bummer lilac	Localized	Eradicate
Casuarina equisetifolia	Ironwood	Localized	Eradicate
Cenchrus clandestinus	Kikuyu grass	Widespread	Projects
Cenchrus purpureus	Elephant grass	Localized	Eradicate
Cenchrus setaceus	Fountain grass	Widespread	Eradicate
Cestrum nocturnum	Night cestrum	Localized	Eradicate
Chlorophytum cosmosum	Spider plant	Localized	Eradicate
Cinnamomum burmanii	Padang cassia	Localized	Eradicate
Clidemia hirta	Koster's curse	Localized	Eradicate
Commelina diffusa	Honohono grass	Widespread	Projects
Coreopsis lanceolata	Tickseed	Localized	Monitor
Cotoneaster pannosa	Cotoneaster	Localized	Eradicate
Delairea odorata	Cape ivy	Localized	Eradicate
Desmodium cajanifolium	Tree desmodium	Localized	Eradicate
Dicksonia fibrosa	New Zealand tree fern	Localized	Eradicate
Digitaria insularis	Sourgrass	Localized	Eradicate
Ehrharta stipoides	Meadow ricegrass	Widespread	Projects
Elaeagnus umbellata	Elaeagnus	Localized	Eradicate

Table 4.3-1 (continued). Invasive plant species targeted for management in the MaunaLoa, Kīlauea, and ʻŌlaʻa sections (excludes Kahuku) and their relative distributions and control strategy. Reported in Benitez et al. 2012 (2) David Benitez, Ecologist, NPS HAVO, pers. comm (2014).

Scientific Name	Common Name	Relative Distribution	Control Strategy
Erigeron karvinskianus	Daisy fleabane	Localized	Eradicate
Eriobotria japonica	Loquat	Localized	Eradicate
Eucalyptus globulus	Blue gum	Localized	Contain
Eucalyptus robusta	Swamp mahogany	Localized	Contain
Falcataria moluccana	Albizia	Localized	Eradicate
Ficus carica	Common fig	Localized	Eradicate
Ficus macrophylla	Moreton bay fig	Localized	Eradicate
Ficus pumilla	Creeping fig	Localized	Eradicate
Fraxinus uhdei	Tropical ash	Localized	Eradicate
Fuchsia hybrida	Fuchsia	Localized	Eradicate
Fuchsia magellanica	Hardy fuchsia	Localized	SEA
Fucshia paniculata	Fuchsia	Localized	Eradicate
Grevillea banksii	Kāhili flower	Localized	Eradicate
Grevillea robusta	Silk oak	Widespread	Contain
Hebe speciosa	Hebe	Localized	Eradicate
Hedera helix	English ivy	Localized	Eradicate
Hedychium gardnerianum	Kāhili ginger	Widespread	SEA
Heterocentron subtriplinerveum	Pearl flower	Localized	Eradicate
Heterotheca grandiflora	Telegraph weed	Localized	Eradicate
Hyparrhenia rufa	Thatching grass	Widespread	Contain
Ipomea triloba	Little bell	Localized	Eradicate
Jasminum humile	Jasmine	Localized	Eradicate
Justicia betonica	Shrimp tail plant	Localized	Eradicate
Kalanchoe pinnata	Air plant	Localized	Eradicate
Kalanchoe tubiflora	Chandelier plant	Localized	Eradicate
Lantana camara	Lantana	Widespread	SEA, Projects
Lathyrus odoratus	Sweet pea	Localized	Eradicate
Leucaena leucocephala	Koa haole	Widespread	Projects
Ligustrum ovalifolium	Chinese privet	Localized	Eradicate
Ligustrum sinense	California privet	Localized	Eradicate
Lonicera japonica	Japanese honeysuckle	Localized	Eradicate
Lophosperma erubescens	Roving sailor	Localized	Eradicate
Luculia gratissima	Luculia	Localized	Eradicate
Lupinus hybridus	Lupine	Localized	Eradicate

Table 4.3-1 (continued). Invasive plant species targeted for management in the MaunaLoa, Kīlauea, and ʻŌlaʻa sections (excludes Kahuku) and their relative distributions and control strategy. Reported in Benitez et al. 2012 (2) David Benitez, Ecologist, NPS HAVO, pers. comm (2014).

Scientific Name	Common Name	Relative Distribution	Control Strategy
Macaranga tanarius	Bingabing	Localized	Eradicate
Marrubium vulgare	Common horehound	Localized	Eradicate
Melaleuca quinquenervia	Paperbark	Localized	Eradicate
Melinis minutiflora	Molasses grass	Widespread	Projects
Melochia umbellata	Melochia	Localized	Eradicate
Morella faya	Faya tree	Widespread	SEA, Projects
Muehlenbeckia complexa	Wire vine	Localized	Eradicate
Nephrolepsis multiflora	Swordfern	Widespread	Projects
Olea europaea	Olive	Widespread	SEA, Projects
Opuntia ficus-indica	Prickly pear	Localized	Monitor
Paederia foetida	Maile pilau	Localized	Eradicate
Passiflora edulis	Purple granadilla	Widespread	Monitor
Passiflora tarminiana	Banana poka	Widespread	SEA, contain
Persea americana	Avocado	Localized	SEA
Persicaria capitata	Knotweed	Widespread	Projects
Philodendron sp.	Philodendron	Localized	Eradicate
Phoenix dactylifera	Date palm	Localized	Eradicate
Phoenix robelenii	Dwarf date palm	Localized	Eradicate
Phormium tenax	New Zealand flax	Localized	Eradicate
Phyllostachis nigra	Bamboo	Localized	Eradicate
Pinus caribaea	Slash pine	Localized	Eradicate
Pittosporum undulatum	Orange pittosporum	Localized	Eradicate
Plumbago auriculata	Plumbago	Localized	Eradicate
Prosopsis pallida	Kiawe	Localized	Eradicate
Prunus sp.	Prunus	Localized	SEA
Psidium cattleianum	Strawberry guava	Widespread	SEA, Projects
Psidium guajava	Common guava	Widespread	SEA
Pterolepis glomerata	Pterolepis	Localized	Eradicate
Pueraria lobata	Kudzu	Localized	Eradicate
Pyracantha koidzumii	Firethorn	Localized	Eradicate
Ricinus communis	Castor bean	Localized	Eradicate
Rosa laevigata	Cherokee rose	Localized	Eradicate
Rosa multiflora	Multiflora rose	Localized	Eradicate
Rosa sp.	Wild rose	Localized	Eradicate

Table 4.3-1 (continued). Invasive plant species targeted for management in the MaunaLoa, Kīlauea, and ʻŌlaʻa sections (excludes Kahuku) and their relative distributions and control strategy. Reported in Benitez et al. 2012 (2) David Benitez, Ecologist, NPS HAVO, pers. comm (2014).

Scientific Name	Common Name	Relative Distribution	Control Strategy
Rubus argutus	Florida prickly blackberry	Widespread	SEA
Rubus ellipticus	Yellow raspberry	Widespread	SEA
Rubus glaucus	Andean raspberry	Widespread	SEA
Rubus rosifolius	Thimbleberry	Widespread	Monitor
Samanea saman	Monkeypod	Localized	Eradicate
Sambucus mexicanus	Mexican elderberry	Localized	Eradicate
Scaevola cf. aemula	Fairy fanflower	Localized	Eradicate
Schefflera actinophylla	Octopus tree	Localized	Eradicate
Schefflera arboricola	Dwarf octopus tree	Localized	Eradicate
Schinus terebinthifolius	Christmasberry	Widespread	SEA, Projects
Schizachyrium condensatum	Bush beard grass	Widespread	Projects
Sechium edule	Pipinella	Localized	Eradicate
Senecio madagascarensis	Fireweed	Localized	Eradicate
Setaria palmifolia	Palm grass	Widespread	Projects
Solanum linneaum	Apple of Sodom	Localized	Eradicate
Solanum pseudocapsicum	Jerusalem cherry	Widespread	SEA
Soliva sessilis	Soliva	Localized	Eradicate
Spermacoce sp.	Buttonweed	Localized	Eradicate
Sphaeropteris cooperi	Australian tree fern	Localized	Eradicate
Spiraea cantonensis	Spirea	Localized	Eradicate
Syzygium cumini	Java plum	Localized	Monitor
Syzygium jambos	Rose apple	Localized	Eradicate
Tecoma stans	Yellow elder	Localized	Eradicate
Thunbergia alata	Black-eyed Susan vine	Localized	Eradicate
Tibouchina herbacea	Cane tibouchina	Widespread	SEA
Tibouchina urvilleana	Glorybush	Localized	Eradicate
Trema orientalis	Gunpowder tree	Localized	Eradicate
Tropaeolum majus	Common nasturtium	Localized	Eradicate
Ulex europaeus	Gorse	Localized	Eradicate
Urochloa maxima	Guinea grass	Localized	Eradicate
Verbascum thapsus	Mullein	Widespread	Contain
Yucca filamentosa	Yucca	Localized	Eradicate

Invasive plant species have been documented in all of the ecological units of HAVO. Higher proportions of nonnative plants (including invasive species) are found in high traffic areas, such as visitor centers, administrative and residential areas, roadsides and trails, and at lower elevations (Benitez et al. 2012).

There have been various attempts to remove individual invasive species at HAVO, but it wasn't until the early 1980s that a systematic approach to managing invasive plants was adopted. Because it is not feasible to control all invasive plants throughout the entire Park, control strategies differ by species. Species with discrete populations with relatively few individuals are generally controlled in order to be contained or eradicated. More widespread invasive species are strategically controlled in high-priority SEAs (Figure 4.3-1) and their surrounding buffer area (Benitez et al. 2012). Within SEAs, efforts are initially focused to knockdown infestations and follow-up treatments are applied every 1 to 4 years depending on the species and habitat (Loh et al. 2014). The SEA approach was implemented at HAVO in 1985. Since that time, the amount of area within the SEA system has expanded 500% to 26,687 ha (65,945 ac) (Loh et al. 2014). Continuous invasive plant management and monitoring of incipient invaders is a major component of the natural resources management program at HAVO.

Figure 4.3-1. Volunteers removing invasive plants alongside Halemaʻumaʻu Trail (Photo: David Boyle 2013).

Measures

- Range Within Park
- Abundance within SEAs
- Number of incipient species that become established

Reference Condition/Value

Complete eradication of all invasive plants within the Park is not realistic given current infestation levels, the size of the Park, and available resources. Thus, the reference condition for range within Park differs by species and is based on the control strategy developed for each species. Control strategies for each target invasive plant species in the Park are listed in Table 4.3-1. Because distributions and ranges have not been estimated for the entire Kahuku section, this reference condition is restricted to the older sections of the Park (MaunaLoa, Kīlauea, and ‘Ōla‘a sections).

For species with eradication as the control strategy, the reference condition is complete absence within the Park. For species with containment as the control strategy, the reference condition is no net spread since containment was implemented. For species with exclusion as the control strategy (e.g., species controlled in SEAs and specific project areas), the reference condition is low cover abundance (<1 % crown cover) or low density (100 individuals/ha) within these areas. For species where the control strategy is monitoring (total of eight species), there is no reference condition available.

At HAVO, intensive control of widespread invasive plant species is restricted to high value areas known as SEAs. The reference condition for invasive species abundance in SEAs is low cover abundance (<1 % crown cover) or low density (100 individuals/ha).

High visitation rates, particularly from off-island tourists, make the Park vulnerable to inadvertent introduction of invasive plants. The reference condition for the number of incipient invasive species is that no incipient species (not recorded on previous Park checklists) become established within the Park.

Existing Data

The following reports and datasets were used to assess this indicator.

- Fosberg (1966) provided a checklist of all vascular plants recorded in the Park based on lists generated in 1994 and 1947, published literature, and personal observations. General locality descriptions are given.
- Whiteaker and Gardner (1985) estimated the distribution of faya trees in the Hawaiian Islands, including HAVO, during the early 1980s.
- Higashino et al. (1988) provided a checklist of all vascular plants observed during surveys conducted since 1944, noting habitat types where each species was observed.
- From 1983 to 1985, Tunison et al. (1992) conducted the first large-scale systematic inventory and mapping of invasive plants across the older sections of HAVO. In total, 41 nonnative plant species were identified as target species for concern.
- Benitez et al. (2008) quantified the distribution and cover of invasive or potentially invasive species in segments within the Kahuku Unit.
- Benitez et al. (2012) conducted nonnative plant surveys within the MaunaLoa, Kīlauea, and ‘Ōla‘a sections of the Park between 2000 and 2010. Distributions of 134 nonnative plants were quantified and provided in a geodatabase by projecting point features or drawing a

polygon around all confirmed point locations and incidental field observations. Data from the survey were compared to earlier plant surveys.

- Pratt et al. (2012) surveyed roadsides within and adjacent to HAVO from 2001 to 2005 to determine the frequency and distribution of 240 invasive and potentially invasive plant species.

Loh et al. (2014) evaluated invasive plant control data at 10 SEAs for which long-term datasets were available (1984–2007). Long-term invasive plant abundance data were also evaluated for four of these SEAs between 1985 and 2008.

Current Condition

Range within Park

Table 4.3-1 provides the relative distributions of the 134 invasive plant species within the MaunaLoa, ʻŌlaʻa, and Kīlauea sections of the Park. Of the 134 invasive plants identified within these sections, 33 species are considered widespread. Over 75% (101 species) are classified as having localized distributions (i.e., small, discrete populations) (Benitez et al. 2012). Large portions of the older sections of the Park are infested with invasive plants. The greatest number of localized invasive plant species was found in the Kīlauea summit area (Benitez et al. 2012).

The majority of the invasive target plants evaluated within the MaunaLoa, ʻŌlaʻa, and Kīlauea sections of the Park (95 taxa or 71%) are managed for eradication (Table 4.3-1). Fifteen species within this category are believed to have been eradicated from the Park, but the potential for dispersal from outside or residual in the seed bank remains. All but two of the remaining taxa with the eradication strategy are considered localized within the Park; only fountain grass (*Cenchrus setaceus*) and guinea grass (*Urochloa maxima*) are considered widespread.

Six species are managed to be contained to the same ranges as when control was implemented. Thatching grass, mullein (*Verbascum thapsus*), and banana poka (*Passiflora tarminiana*) are currently limited to their original known limits. The range of swamp mahogany (*Eucalyptus robusta*) and blue gum (*Eucalyptus globulu*) have declined since control began in 1983. Extensive control efforts and localized eradication at ʻĀinahou have also resulted in a decrease in silk oak (*Grevillea robusta*) when compared to its initial range (Benitez et al. 2012).

Species-specific abundance data is not available for all 30 active SEAs or exclusion projects. However, low cover abundance and low density has been reported for many target invasive species in specific SEAs. These species include strawberry guava (*Psidium cattleianum*), kāhili ginger (*Hedychium gardnerianum*), Florida prickly blackberry (*Rubus argutus*), and faya tree (Loh et al. 2014).

Relative to earlier surveys, some species have increased in range, while others have decreased. Eight species mapped by Tunison et al. (1992) were found to have increased in abundance since the surveys in 1992, while 30 species were reported as less abundant (Benitez et al 2012). It is estimated that 13 species noted during previous survey (Higashino et al. 1988, Tunison et al. 1992) have been extirpated due to control efforts.

Faya tree is particularly notable for its increase in range throughout the Park. In 1977, small populations of faya tree were reported to cover 600 ha (1,483 ac). The infestation increased to 12,200 ha (30,147 ac) in 1985 (Whiteaker and Gardner 1985) and 15,900 ha (39,290 ac) in 1992 (Benitez et al. 2012). The most recent estimate of the range of faya tree in HAVO is 30,495 ha (75,355 ac). The species is considered to have relatively dense infestations in over half of its range (Benitez et al. 2012).

During the survey of HAVO's roadsides and buffers, seven target plant species had frequencies of 50% or more of roads surveyed (Pratt et al. 2012). These species include broomsedge (89%), molasses grass (95%), swordfern (82%), kikuyu grass (58%), common guava (*Psidium guajava*) (50%), bush beardgrass (85%), and knotweed (58%) (Pratt et al. 2012). However, this frequency calculation may over-represent the abundance of these species along HAVO's roadsides and buffers because it does not account for the number of observed individuals within the surveyed segment (i.e., single observed occurrence versus multiple observed occurrences).

In the Kahuku section, 50 species on the HAVO target invasive plant list were observed. This included all life forms: trees (13 spp.), shrubs (10 spp.), herbs (16 spp.), fern (1 sp.), and grasses (10 spp.). Of the invasives plants found in Kahuku, 10% of the species are considered abundant, 22% are considered common, 38% are considered uncommon, and 26% are considered rare. Two species were removed (Benitez et al. 2008).

Lower elevation areas in Kahuku tended to contain more invasive plant species and plants were more widespread than higher elevation areas. Recent lava flows (1868 and 1926) and steep-sided pit craters were also reported as relatively free of invasive plants (Benitez et al. 2008).

<u>Abundance within SEAs</u>
Invasive plant abundances vary greatly among HAVO's SEAs (see Figure 2.2-7 for SEA locations). In general, on-going invasive plants control in SEAs has reduced densities of most species to low levels (Loh et al. 2014).

In the mid-elevation seasonal SEAs, recent estimates for the average number of plants per hectare ranged from less than one individual/ha (e.g., HilinaPali, Keʻamoku, Kīpuka Kahaliʻi) to an average of 124 individuals/ha for the last three treatment intervals (e.g., Keanakākoʻi) (Loh et al. 2014). As shown in Figure 4.3-2, densities of invasive plants generally decreased as treatment years increased. Faya tree was the dominant invasive plant found in these six SEAs (Loh et al. 2014).

For the three SEAs in rain forests (Thurston, ʻŌlaʻa Small Tract, and ʻŌlaʻa Koa), invasive plant densities decreased in Thurston, and remained the same for Small Tract and Koa units (Figure 4.3-3). For ʻŌlaʻa Small Tract and Thurston, average infestation levels during recent treatment cycles were estimated at about 250 individuals/ha or <1% crown cover abundance. Densities were higher at ʻŌlaʻa Koa-SEA, which had an average of 973 individuals/ha across all four treatment cycles (Loh et al. 2014). By 2008, species cover in ʻŌlaʻa-Koa was typically <1% crown cover. In Thurston SEA, abundances of target invasive plants (faya tree, strawberry guava, and Florida prickly blackberry) decreased following several treatment cycles; however, their frequency of occurrence along transects did not change significantly (Loh et al. 2014).

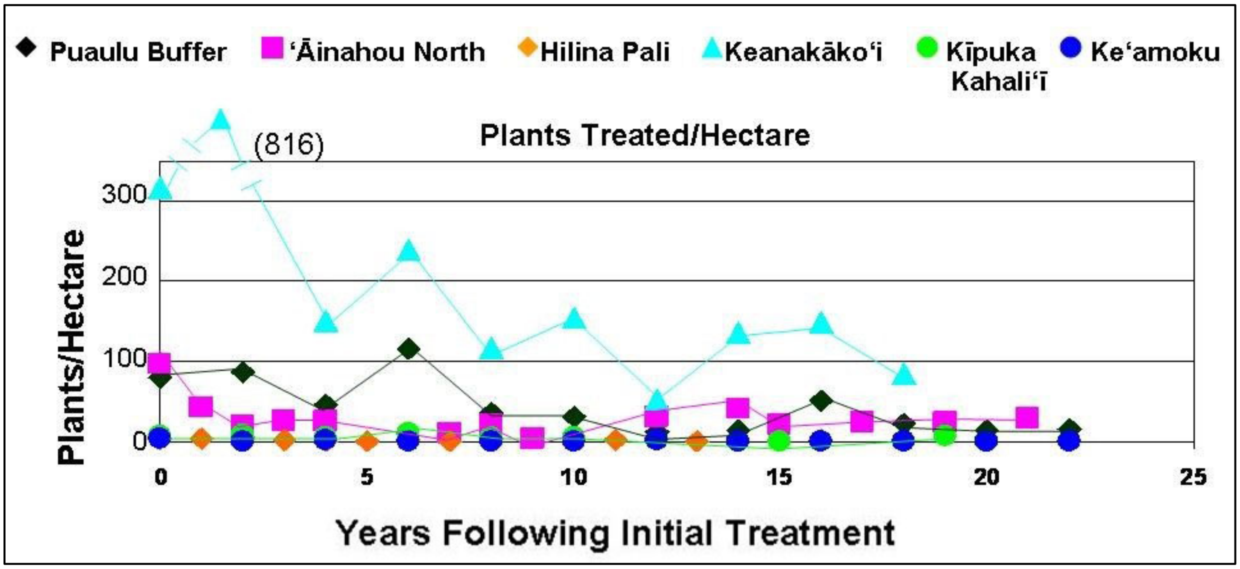

Figure 4.3-2. Number of invasive plants treated in six Mid-elevation Seasonally Dry Special Ecological Areas, 1984–2007, from Loh et al. (2014). Year 0 indicates initial year of control (Puaulu Buffer-1984, Keʻāmoku-1985, ʻĀinahou North-1985, Kīpuka Kahaliʻi-1986, Keanakākoʻi-1988, and HilinaPali-1989).

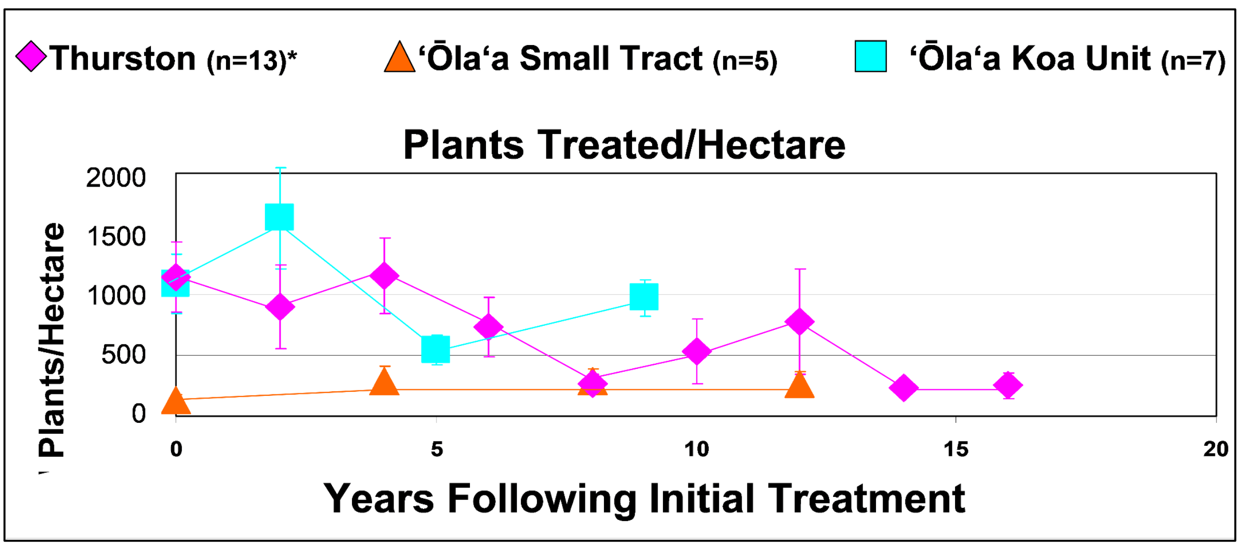

Figure 4.3-3. Number of invasive plants treated in control blocks (n) in three rain forest Special Ecological Areas, 1985-2007, from Loh et al. (2014). Year 0 indicates initial year of control (Thurston-1985–1990, ʻŌlaʻa Small Tract-1985–1993, ʻŌlaʻa Koa-1998–1999).

In the Kīpuka Puaulu SEA, located in montane mesic forest, the number of invasive plants observed/ha has decreased to low levels (<5 individuals/ha) (Figure 4.3-4). Not initially targeted for control, herbicide treatment of dense thickets of Florida prickly blackberry has expanded over the years. Crown cover remained relatively high (~15%) during the last monitoring and crews continue to treat dense thickets (Loh et al. 2014).

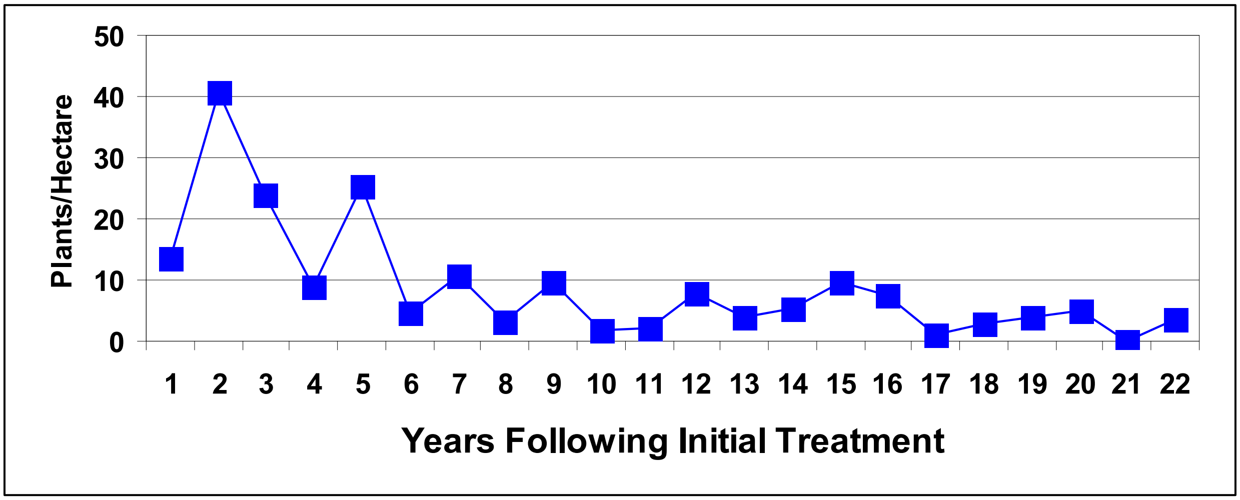

Figure 4.3-4. Number of invasive plants treated in Kīpuka Puaulu Special Ecological Area, 1985–2007, from Loh et al. (2014).

Number of Incipient Species that Become Established

Several species that were not documented during early comprehensive plant surveys (Fosberg 1966, Higashino et al. 1988) have become widespread in the Park. These include butterfly bush (*Buddleia asiatica*) and cane tibouchina (*Tibouchina herbacea*) (Benitez et al. 2012).

Between 2000 and 2010, Benitez et al. (2012) recorded 16 new species not previously recorded in the Park. The majority of these were found near roads, trails, and visitor areas. While rapid response has prevented the majority of these plants from becoming established after the initial sightings, several species appear to have established small populations, including Koster's curse (*Clidemia hirta*), sourgrass (*Digitaria insularis*), Kāhili flower (*Grevillea banksii*), and Australian tree fern (*Sphaeropteris cooperi*) (Benitez et al. 2012).

Pratt et al. (2012) also identified 15 new species that were previously not known in HAVO (Table 4.3-2). These were primarily encountered along Highway 11 and Crater Rim Drive. Many were only found at single sites or at a low frequency and therefore are not considered established with the Park. However, glycine (*Neonotonia wightii*) had high frequency on Highway 11 (Pratt et al. 2012). Although fireweed (*Senecio madagascariensis*) was only found at several occurrences and all were destroyed, the species is known to be a highly disruptive invader (Pratt et al. 2012).

Table 4.3-2. New nonnative plant species found within HAVO along roadsides and buffers and frequency recorded by Pratt et al. 2012.

Scientific Name	Common Name	Location	Frequency*
Axonopus compressus	Wide leaf carpetgrass	Highway 11, Crater Rim Drive	4.0%
Crotalaria lanceolata	Rattlepod	Highway 11, Crater Rim Drive	2.0%
Digitaria cf. abyssinica	–	Crater Rim Drive	1.0%
Euphorbia hyssopifolia	Spurge	Highway 11	1.0%
Heliotropium amplexicaule	Heliotrope	Highway 11	2.0%
Leonotis nepetifolia	Lion's ear	Highway 11	1.0%
Lepidium africanum	Pepperwort	Highway 11	1.0%
Neonotonia wightii	Glycine	Highway 11	17.0%
Paspalum notatum	Bahia grass	Highway 11, Crater Rim Drive	9.0%
Paspalum paniculatum	–	Highway 11, Crater Rim Drive	9.0%
Schedonorus arundinaceus	Reed fescue	Crater Rim Drive	1.0%
Senecio madagascariensis	Fireweed	Highway 11	6.0%
Setaria sphacelata	Foxtail	Highway 11	2.0%
Sphagneticola trilobata	Wedelia	Crater Rim Drive	5.0%
Sporobolus indicus	Indian dropseed	Chain or Craters, Crater Rim, HilinaPali Roads	3.0%

*Number of surveyed segments containing the species divided by the total number of segments surveyed.

Threats and Stressors

Even if target and incipient species are eradicated from the Park, invasive plants are a constant threat to the Park's resources because plants can disperse from nearby unmanaged areas and are unintentionally introduced by visitors. Annual park visitation averaged 1.3 million visitors between 1990 and 2011 (NPS PUSO 2012). Many visitors arrive in private and commercial vehicles coming from other parts of the island. HAVO is also located adjacent to several residential communities (Volcano Golf Course, Volcano Village, MaunaLoa Estates, Hawai'i Ocean View Estates) that are often landscaped with ornamental plantings that have the potential to escape cultivation and spread into the Park. Many nonnative plant species that have invasive characteristics appear to be naturalized in other areas outside of the Park, such as along roadways (Pratt et al. 2012), and potential exists for these to disperse into the Park.

Increased ungulate management, particularly in the Kahuku section, may result in increased abundances of invasive plant species that are currently being controlled by herbivores. However, the implementation of weed and fire management programs is expected to minimize invasions (NPS 2013).

Finally, climate change also has the potential to enhance existing invasive species issues by increasing the number or abundance of invasive plant species within the Park. Changes in temperatures, precipitation amounts, and other climatic factors can alter the geographical distribution of species (Both and Visser 2001). Changes in climatic conditions may increase the dispersal ability of nonnative flora (Walther et al. 2002). Parmesan and Matthews (2006) suggest that invasive species might be better able to adapt to a changing climate than native ones.

Overall Condition

Despite the success of the SEA program, as well as containing and eradicating some species, invasive terrestrial plants remain a major concern for the Park. Many species managed for eradication remain within the Park and ranges have increased for some species. Despite continuous control efforts, invasive plant abundances remain high for some species in several SEAs. Outside of SEAs, widespread species continue to increase in abundance and to spread. Finally, roughly eight plant species that were not recorded in the Park during comprehensive surveys in the 1960s and 1980s have become established in the Park. Therefore, the condition of invasive terrestrial plants at HAVO is considered “of concern.” An overall trend cannot be accurately determined because while some species have increased in abundance since historical surveys, others have decreased.

Information Gaps/Level of Confidence

Two recent reports provided particularly useful data to assess this indicator. Benitez et al. (2012) provides a recent summary of the abundance and distribution of the target invasive plant species in the older sections of the Park and compares current distribution to previous estimates. Loh et al. (2014) summarizes quantitative data for long-term plant control in numerous SEAs. However, one important point, as noted by Ainsworth et al. (2012), is that invasive plant monitoring locations and methodologies are not consistent over time, resulting in difficulties in accurately assessing trends. Some areas are difficult to survey due to remoteness and ongoing volcanic eruptions. Additionally, with regard to the SEA information, differences in intensity or thoroughness of effort by work crews across treatments may influence data (Loh et al. 2014) and data is not assessed for all SEAs. Focused and consistent invasive plant monitoring is planned for the subalpine shrubland and wet forests of HAVO (Ainsworth et al. 2012).

Appropriate invasive plant management strategies are being formulated for plants recorded in Kahuku (Benitez et al. 2008), and in some cases control measures have begun. The larger distances between transect survey lines means that large areas were excluded from sampling; thus, not all species were observed and complete extent of infestations could not be determined (except for some species such as fountaingrass and gorse). Additional surveys in the Kahuku section may locate new invasive populations, particularly for the central survey region (Benitez et al. 2008).

Subject Matter Experts Consulted

- Rhonda Loh, Chief of Natural Resources Management, NPS HAVO
- David Benitez, Ecologist, NPS HAVO

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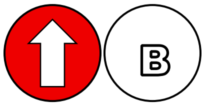
4.4. Invasive Ungulates



Background

Isolated island ecosystems that evolved without large mammalian herbivores, such as Hawai‘i, are particularly vulnerable to introduced ungulates because native species are not adapted to ungulate behaviors and impacts (Fosberg 1965, Clements and Daehler 2007). As a result, introduced ungulates (hooved mammals such as pigs, cattle, goats, deer, and sheep) are significant threats to Hawaiian natural resources wherever they occur. These animals are attributed as some of the leading causes for the decline of Hawai‘i’s native species and natural ecosystems.

Native Hawaiian plants, both rare and common, are particularly susceptible to ungulate impacts. The browsing, grazing, trampling, and rooting activities of these animals can eliminate native plant species or degrade their habitat (Scowcroft 1983, Drake and Pratt 2001). In fact, studies have found that some ungulates preferentially browse on native vegetation (Baker and Reeser 1972). Ungulates can consume large volumes of native vegetative material such as bark, leaves, fruits, and seeds (Diong 1982, Courchamp et al. 2003), and inhibit reproduction and suppress regeneration (Scowcroft and Hobdy 1987). They also facilitate the dispersal and establishment of invasive plants by transporting propagules and creating new areas for colonization (Smith 1985, Applet et al. 1991, Stone et al. 1992).

Loss of native plants can impact native birds and other Fauna by reducing or eliminating their habitat (Stone 1985, Moors et al. 1992, Scowcroft and Conrad 1992, Stone et al. 1992). Ungulate foraging behaviors are known to indirectly impact native birds by reducing the amount of nectar produced by understory plants (Stone 1985). Furthermore, ungulates directly influence understory invertebrates by removing food resources from lower trophic levels (Allombert et al. 2005). Pigs, in particular, augment the prevalence of avian diseases by creating wallows with standing water, thereby increasing breeding sites for vector mosquitoes (Atkinson et al. 2005).

A myriad of other ecosystem-level impacts have been documented as a result of ungulate introduction. Rooting and trampling can accelerate erosion by exposing soil (Ford and Grace 1998, Tep and Gaines 2003, Van Driesche and Van Driesche 2004). By reducing canopy cover and disturbing soil, ungulates also increase the amount of sunlight reaching the soil surface, which alters soil properties such as temperature, salinity, elevation, and structure. Cascading effects of changes to soil properties cause a disruption to ecosystem function by increasing the rate of decomposition and evaporation (Ford and Grace 1998). Constant trampling causes soil compaction that can deplete the soil of needed oxygen (Van Driesche and Van Driesche 2004).

Five ungulates species are currently known to occur at HAVO: pigs, cattle, goats, sheep, and mouflon sheep (Figure 4.4-1). These animals are known to have directly damaged or destroyed rare native plants within the Park, and have indirectly resulted in the loss or decline of other native plants and animals (Katahira 1980, Tunison et al. 1995, Belfield and Pratt 2002, Pratt et al. 2011, Cole et al.

2012, NPS 2013b). Axis deer do not currently occur within the Park, but have been sighted in the vicinity, and therefore remain a potential threat to Park resources (NPS 2013b).

Figure 4.4-1. Mouflon within the Kahuku section of the Park. (Photo: Ben Kawakami Jr [from Hess, Kawakami, et al. 2006]).

Various ungulate control and management tactics have been employed at HAVO since the 1920s. Systematic ungulate control has been implemented in the older sections of the Park (all sections excluding Kahuku) since the 1970s and more recently in the Kahuku section. This systematic strategy is primarily accomplished through four components: 1) barrier fences to isolate groups, 2) removal of individuals, 3) barrier fence inspection and maintenance, and 4) monitoring and removal to prevent ungulate population increase and ingress (NPS 2010, 2013b).

Despite these efforts, ungulates still remain in portions of the Park. Although grazing has been discontinued and the ungulate population greatly reduced, the lasting effects of the historical presence of ungulates continue to influence the Park's natural resources. Even after areas are fenced and ungulates removed, ecosystems may never fully recover. Furthermore, the large size, remoteness, and harsh environments of HAVO present many challenges that make managing ungulates in the Park problematic.

Measures

- Ungulate fencing
- Ungulate-free areas
- Abundance

- Breaches/ingress into ungulate-free areas

Reference Condition/Value

The reference condition for ungulate fencing is boundary fencing of the Park where necessary and the use of interior fencing to protect sensitive resources. Complete boundary fencing is not required to control/remove all animals because topography and vegetation naturally exclude animals from some areas. For example, on the east rift, active lava flows serve as a natural barrier to ungulate movement. Periodic fence breaching is common in managed areas in Hawaiʻi. Therefore, occasional fence breaches are considered acceptable within ungulate-free areas if animals are removed quickly following ingress. Removal of animals that have breached the fence as soon as they are discovered is a high priority for Park resource staff (NPS 2012).

As stated in the *Final Plan / Environmental Impact Statement for Protecting and Restoring Native Ecosystems by Managing Non-native Ungulates* (NPS 2013b), the desired ungulate abundance within the Park is zero, or as low as practicable, in managed areas. Although the long term goal is to exclude ungulates wherever they harm park resources, not all of the Park is currently managed for ungulates; and pigs, due to the higher difficulty in controlling their numbers, are managed in only a subset of ungulate managed units. Among the unmanaged areas of the park, the alpine zone above 2,740 m (9,000 ft) elevation is generally regarded as ungulate-free or with very few individuals and there are no documented impacts to resources by ungulates. For managed and unmanaged areas the reference condition for all ungulate species is zero.

Existing Data

Numerous studies have been conducted to monitor vegetation changes and recovery following mammal removal, or test the efficacy of ungulate control measures. However, very few of these provided estimates of ungulate population size or density. The following literature and datasets were used to evaluate this indicator.

- Katahira et al. (1993) summarized pig control efforts and investigated pig activity, density, and food habits in three montane mesic habitats within HAVO in the 1980s.
- Anderson and Stone (1994) monitored pig activity to assess pig populations in Hawaiʻi, including in Ōlaʻa.
- In the late 1990s, Belfield (1998) surveyed for pig activity and vegetation in three forested craters in the East Rift Zone of Kīlauea: Puʻu Huluhulu, Kane Nui O Hamo, and Napau Trail Pit Crater. Pig activity is described, but no quantitative data are provided.
- Pratt et al. (1999) monitored feral pig activity in the East Rift between 1993 and 1996, roughly 4 months after a barrier fence was constructed and control began.
- In 2004, Hess, Kawakami, et al. (2006) conducted aerial and vehicle-based surveys within the Kahuku Unit to provide an estimate of mouflon sheep abundance and population structure.
- Stephens et al. (2008) continued to monitor mouflon removal and abundance in Kahuku until 2007.

- In 2005, four ungulate proof exclosures were constructed in Kahuku to conduct an experimental forest recovery project (McDaniel et al. 2011).
- Annual natural resource reports for HAVO discuss ungulate removal efforts and the number of ingress ungulates in managed areas from FYs 2001 through 2012. The most recent annual natural resource reports were assessed in this document (NPS 2010, 2011, 2012, 2013a).
- Scheffler et al. (2012) estimated pig density across four pig management units in the ‘Ōla‘a Forest from 1998 through 2004 based upon pig activity (e.g., digging, plant feeding, scat). The goal of the study was to better understand the effect of low-density pig populations on native ecosystems.
- In 2013, the Park released a *Final Plan / Environmental Impact Statement for Protecting and Restoring Native Ecosystems by Managing Non-native Ungulates* (NPS 2013b), which provided the most current information on ungulate abundance and ingress into managed units.
- NPS maintains up-to-date GIS shapefiles of the fences and ungulate management areas throughout the Park (dated April–May 2013).

Current Condition

Ungulate Fencing

Ungulate fences are essential to the protection and restoration of HAVO’s native ecosystems. Over 228 km (142 mi) of ungulate exclusion fencing is currently in place at HAVO (Figure 4.4-2). Some boundary fences are currently being retrofitted to increase height from 1.2 m (4 ft) to 1.8 m (6 ft) high to order to reduce ingress of mouflon sheep (NPS 2013b).

All sections of the Park have portions not currently fenced (Figure 4.4-2). The upper elevation portions of the MaunaLoa section are not fenced due to the low potential for ungulates to access the Park through this area. Boundary fencing is not contiguous in the eastern Kīlauea section because active lava flows currently serve as natural barriers, blocking ingress of animals. In Ōla‘a, roughly half of the section is currently not fenced; however, construction of a complete boundary fence is planned for Ōla‘a (NPS 2013b).

Since the acquisition of the Kahuku section, boundary fences and cross fencing have been constructed to create more manageable sections for removal. Expanded boundary fences are currently being planned in Kahuku as shown in Figure 4.4-2. Proposed fences will terminate at roughly 3,353 m (11,000 ft) elevation where few, if any, ungulates exist and the potential for ingress is low (NPS 2013b).

In addition to boundary fences, localized internal fencing (about 100–182 cm [39–72 in] in height) has been constructed in portions of the Park to exclude pigs and to protect highly sensitive resources. Additional localized fencing has been proposed (NPS 2013b).

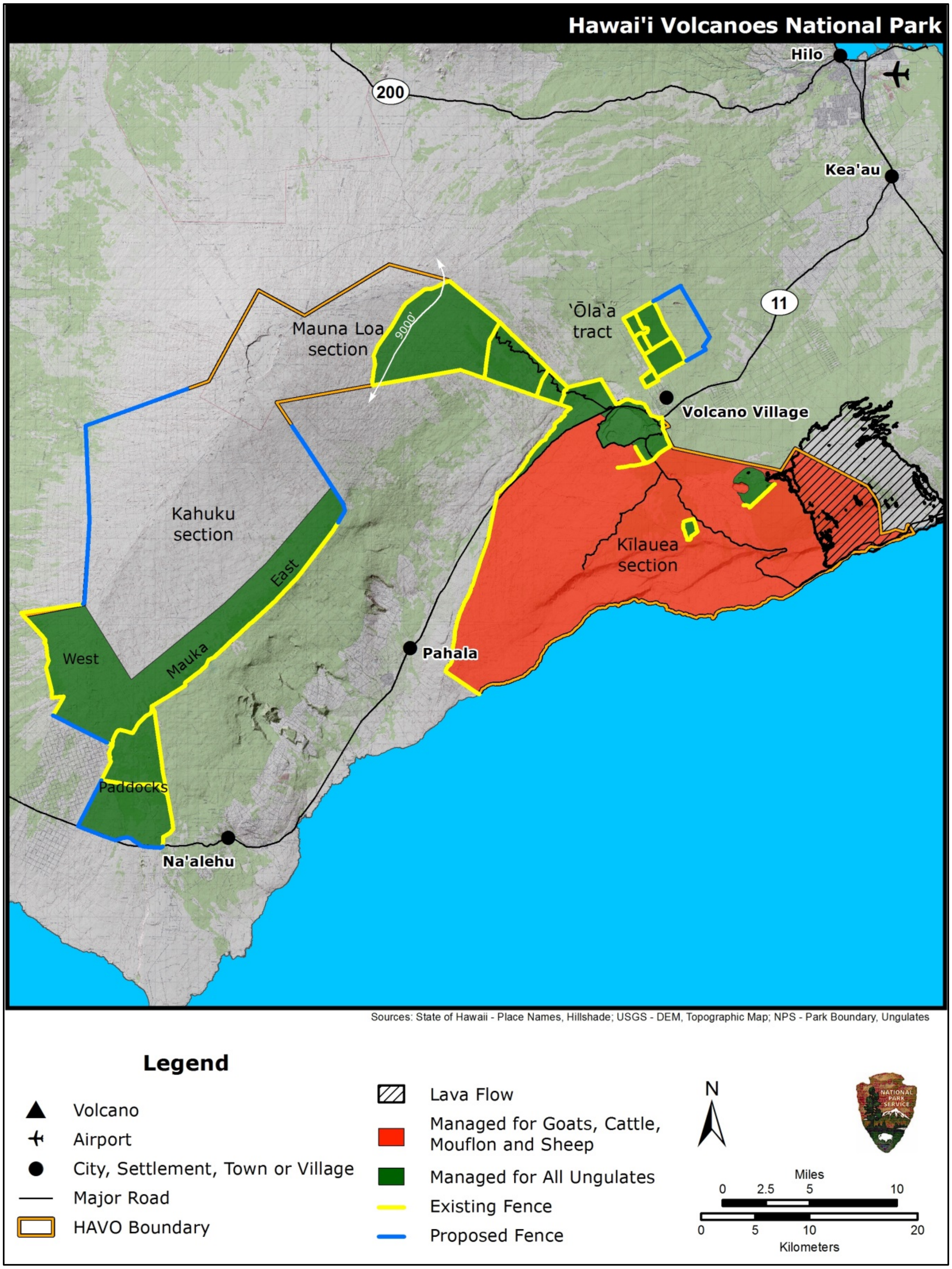


Figure 4.4-2. Existing and proposed fences and ungulate management areas at HAVO (Data from Rhonda Loh, Chief of Natural Resources Management, NPS HAVO, pers. comm. 2014).

Fence inspection and maintenance is required to prevent ingress of animals and re-establishment of populations in ungulate-free areas. In FY 2009, staff replaced and extended about 14 km (8.5 mi) of fence in HAVO (NPS 2010). Roughly 30 km (18.6 mi) and 6 km (4 mi) were replaced or added in FYs 2010 and 2011, respectively (NPS 2011, 2012).

Ungulate-Free Areas

Cattle, goats, sheep, and mouflon

Cattle, goats, sheep, and mouflon are excluded from 70,547 ha (174,252 ac) in the older sections of the Park (i.e., MaunaLoa, Kīlauea, and ʻŌlaʻa), below 2,740 m in elevation (Figure 4.4-2). An additional 1,830 ha (4,522 ac) of unfenced ʻŌlaʻa rain forest do not contain these animals (only pigs) and do not require park actions to exclude them. At higher elevations in alpine communities located above the current fenced units on MaunaLoa, animal densities are extremely low and the sparsity of vegetation and rare plants make this area a low priority for animal management (approx. 15,570 ha [38,458 ac]).

In Kahuku, mouflon are the most abundant and widespread ungulate, followed by local concentrations of sheep and pigs. Management to exclude these animals as well as goats and stray cattle is in progress and currently focused in four control units (East, West, Mauka, and Paddocks) spanning 20,404 ha (50,398 ac). Within these areas, animals occur in various abundances (see abundance sections below). Boundary fence construction is underway, and along these fences, animal numbers are being reduced to remnant populations. Between 2003 and 2010, 11 small (0.4-8 ha or 1-20 ac) ungulate proof exclosures (total of about 44 ha or 108 ac) were constructed across different habitats in Kahuku to protect rare plant species and to evaluate forest recovery and restoration techniques (McDaniel et al. 2011, NPS 2013a). Outside these exclosures, no other areas within the Kahuku section are considered ungulate free (Rhonda Loh, Chief of Natural Resources Management, NPS HAVO, pers. comm. 2014). In high elevation alpine communities above 2,740 m (9,000 ft) elevation (35,454 ha [14,354 ac]), animal densities are extremely low and the scarcity of vegetation and rare plants make this area a low priority for animal management.

Across the Park, roughly 72,426 ha (178,893 ac), or 49% of the park, is free of cattle, goats, sheep, and mouflon. These include areas fenced and actively managed to exclude these animals (including 44 ha [108 ac] in Kahuku), and rain forest in ʻŌlaʻa where animals are not present. An additional 29,924 ha (73,912 ac or 20% of the park) of high elevation alpine communities have very few, if any, animals and are considered a low priority for animal control. Animal numbers remain a concern in Kahuku below 2,740 m (9,000 ft), and across 46,719 ha (115,396 ac) or 31 % of the park. Management to remove these animals is currently being conducted across 20,444 ha (50,498 ac) of Kahuku, or 14% of the Park.

Pigs

Unlike the other ungulates at HAVO, feral pigs are controlled only within a portion of their expected range due to the greater management effort required for this species. Control and management is focused in localized interior fences of the Park. Areas managed for pigs tend to have higher conservation value, such as the more intact, manageable subalpine, mesic and rain forests that have high potential of recovery (NPS 2011).

In the 1980s, feral pigs were excluded from about 6,500 ha (16,062 ac) of the Park. Pig-excluded areas increased to about 7,800 ha (19,742 ac) by 1988 (Katahira et al. 1993). In late 1990s, it was estimated that pigs were controlled in roughly 10,117 ha (25,000 ac) in the older sections of the Park (NPS 1999).

Today, approximately 16,795 ha (41,486 ac) are estimated to be pig-free (Figure 4.4-3). This represents 11% of the Park (Table 4.4-1). These areas are mostly limited to the older sections of the Park. The only pig-free areas within Kahuku are the 11 exclosures mentioned above (McDaniel et al. 2011, NPS 2013a). Of the 102,081 ha (252,139 ac or 68% of the Park) where pigs remain a concern, approximately 21,164 ha (52,275 ac or 14% of the Park) are partially controlled or pig control is in progress (this includes areas in Kahuku and ‘Ōla‘a). Included among these are two upper elevation units (West and Mauka) in Kahuku where additional monitoring is needed to determine if they are pig free (NPS 2013b). The last reported pig was removed in 2011 in the Mauka unit. No pigs have been documented in the West unit. In high elevation alpine communities (above 2,740 m [9,000 ft] elevation in Kahuku and above the uppermost fence in the MaunaLoa section) the potential for pigs is low, and given the scarcity of vegetation and rare plants, this area is a low priority for animal management.

Table 4.4-1. Ungulate-free areas in the Park. Percentage of total area in the Park is provided in parenthesis.

Ungulate(s)	Ungulate-Free Areas	Areas Ungulates Remain a Concern	Remaining Area*
Cattle, goats, sheep, and mouflon	72,426 ha (49%)	46,434 ha (31%)	29,923 ha (20%)
Pigs	16,795 ha (11%)	102,081 ha (68%)	29,923 ha (20%)

*Area estimates are based on GIS which results in a total park boundary of 148,980 ha (368,138 ac). Actual areas are likely larger due to substantial topographic relief in the Park.

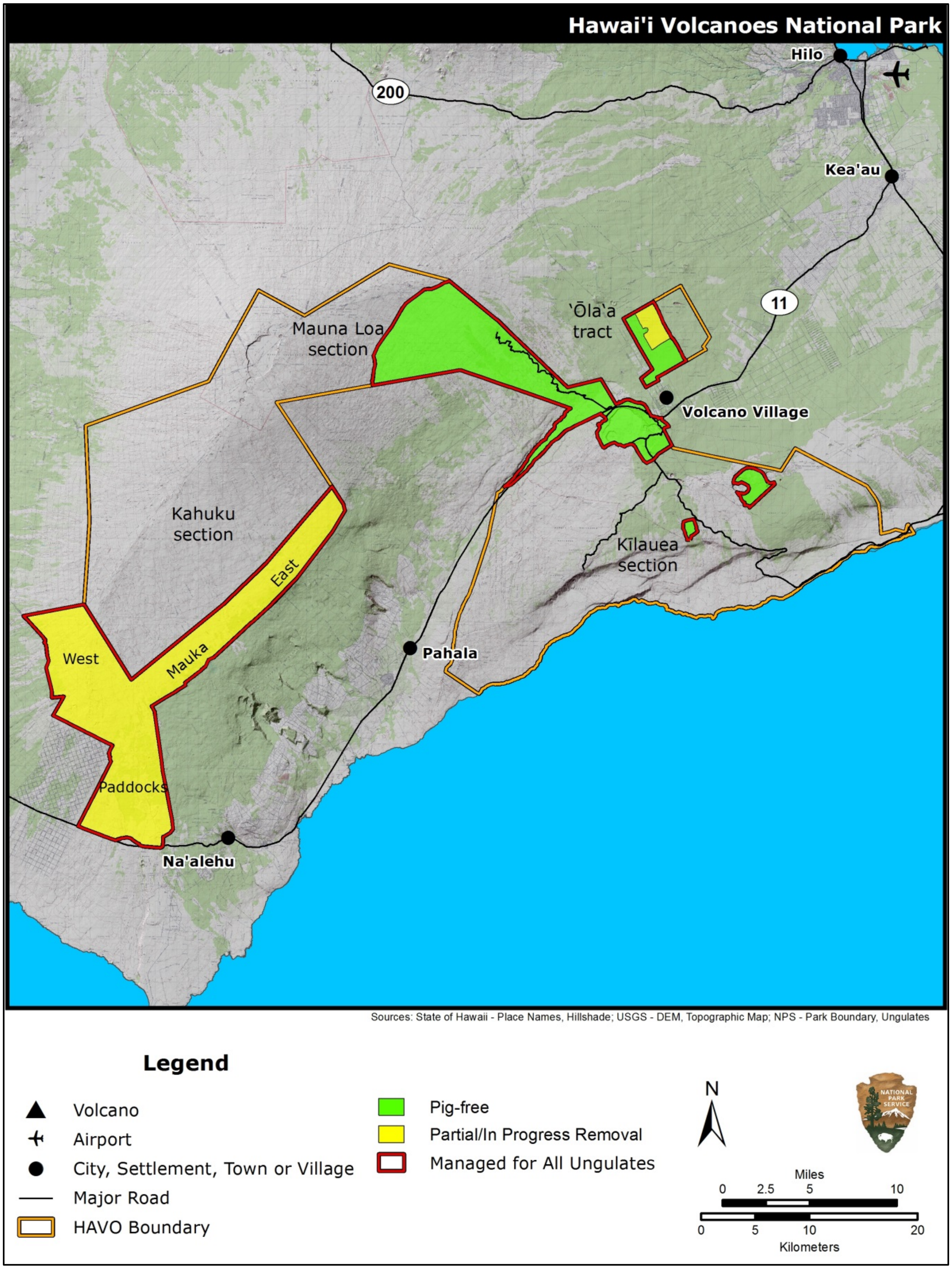


Figure 4.4-3. Pig-free areas and areas with partial/in progress pig removal (Data from Rhonda Loh, Chief of Natural Resources Management, NPS HAVO, pers. comm. 2014).

Abundance

A descriptive summary of ungulate presence throughout the Park is summarized in Table 4.4-2. More detailed descriptions of each ungulate's historical (if available) and current abundance in HAVO are provided below.

Table 4.4-2. Current estimated ungulate abundance within the Park. NPS (2013) unless otherwise noted.

Ungulate	Estimated Abundance	
	Older Sections (Kīlauea, MaunaLoa and ʻŌlaʻa)	**Kahuku Section**
Axis deer	None detected	None detected
Cattle	None detected	None detected[1]
Goats	Potentially a few individuals above 2,740 m	A few individuals
Pigs	Variable number of individuals depending on habitat[1]	Variable number of individuals depending on habitat [1]
Sheep	None detected	Several hundred individuals
Mouflon sheep	Potentially a few individuals above 2,740 m	1,797 ± 688 individuals[2]

[1] Rhonda Loh, Chief of Natural Resources Management, NPS HAVO, pers. comm. (2014)

[2] Stephens et al. 2008.

Axis deer

Currently, no axis deer are known within the Park boundaries (NPS 2013). A sighting was confirmed makai (seaward) of the Kahuku Unit in 2011 (NPS 2012).

Cattle

Historically, commercial cattle operations occurred on MaunaLoa, Kahuku, and ʻĀinahou. These operations were discontinued in the older sections of the Park prior to 1950, although unauthorized grazing continued until the 1970s (NPS 2013b). Today, the cattle population is estimated at zero in the Kīlauea, MaunaLoa, and ʻŌlaʻa sections of HAVO. Domestic cattle grazing ceased in Kahuku in 2010 and the last stray cow removed in 2012 (NPS 2013a). Small numbers of feral cattle occasionally wander into the Kahuku section from adjacent properties (NPS 2013b).

Goats

Early efforts to remove feral goats and pigs were initially conducted by the Territorial Government from 1927 to 1931 as part of a regional effort to protect island watersheds. In 1938, the Park took over control efforts. From 1927 to 1971, over 70,000 goats and 7,000 pigs were removed from the Park. Control was done at various times by park staff, Civilian Conservation Corps (CCC), private contractors and volunteers from the surrounding communities. Despite the large numbers of animals removed, control efforts did not keep ahead of reproduction rates. By 1970, the Park had over 14,000 goats remaining within its boundary (NPS 1972).

Beginning in the early 1970's, a systematic program of fencing and hunting, the latter conducted by park and volunteer staff, successfully eliminated goats from many parts of the Park. Today, goats have been virtually eliminated from HAVO due to systematic goat control (NPS 2013b). In the MaunaLoa and ‘Ōla‘a sections of HAVO, only a few goats may occur above 2,740 m in elevation. In Kahuku, the majority of goats were removed by 2006, with only a few individuals possibly remaining (NPS 2013b).

Pigs

Historical population estimates of feral pigs in HAVO are unknown. However, between 1930 and 1971, control efforts removed about 7,000 pigs from the Park. An additional 4,000 pigs were removed between 1971 and 1980 (Katahira et al. 1993). In the 1980s, the feral pig population at HAVO was estimated in the thousands. Additional pig control efforts have been implemented since that time; however, HAVO’s pig population increased when the Park acquired the Kahuku Unit due to the larger area with the Park’s boundary.

Outside pig free units, HAVO’s pig density is currently unknown. Assessments of pig abundance are more difficult than other ungulates because detections from helicopter are limited by dense vegetation. Pigs inhabit a wide range of ecosystem types within all sections of the Park. In general, pig densities are estimated to be higher in seasonally dry to wet environments (such as ‘Ōla‘a and Kīlauea) compared to densities in dry to arid environments (NPS 2013b).

An unknown numbers of feral pigs occur in the Kīlauea section outside of managed areas. In the East Rift, the estimated pig density between 1993 and 1996 was 2.4 pigs/km^2 (0.9 pigs/mi^2) (Pratt et al. 1999). Minimal to no pig activity has been seen on recent lava flows and in craters with steep slopes (Belfield 1998). Recent pig estimates throughout Kīlauea are not known.

Before eradication began in the ‘Ōla‘a section, feral pig density was estimated as 5.3 pigs/km^2 (2.0 pigs/mi^2) (Anderson and Stone 1994). Pigs have been removed from portions of ‘Ōla‘a, and where management is in progress (new unit), only a few individuals remain (NPS 2013a). A large number of pigs are believed to occur in unmanaged portions of the ‘Ōla‘a tract. Between 11.76 and 16.31 pigs/km^2 (4.5–6.3 pigs/mi^2) were recently reported from an unfenced area within ‘Ōla‘a (Scheffler et al. 2012), suggesting at least 300 individuals in the area. Data suggest there may be large year-to-year variation in pig reproductive success in ‘Ōla‘a (Scheffler et al. 2012). In comparison, feral pig densities in other non-managed wet forests in Hawai‘i Island have been estimated at 12.5 pigs/km^2 (Hess, Jeffrey, et al. 2006).

In Kahuku, NPS staff estimates that pig abundance is low and variable depending on the environment (NPS 2013 report), although no formal densities have been calculated. Only one pig was reported and removed in the mauka unit of Kahuku in 2011 (NPS 2012) and none were detected in 2012 (NPS 2013a). No pigs have been documented in the west unit of Kahuku since field observation first began in 2004 (Rhonda Loh, Chief of Natural Resources Management, NPS HAVO, pers. comm.). Pigs occur in the north corner of Kahuku, but abundance has not been determined. Forty-two pigs were removed and up to 200 animals are estimated remaining in lower elevation Kahuku in the former paddocks (NPS 2013a). In alpine communities above 2,740 m (9,000 ft) elevation in both the

Kahuku and MaunaLoa sections, the potential for pigs is low given the scarcity of vegetation in the area.

Sheep

A small population of feral sheep was eliminated from the older sections of the Park in the early 1970s. Sheep are believed to be eradicated within the Kīlauea, MaunaLoa, and ʻŌlaʻa sections of HAVO. Several hundred sheep currently occupy the remote northwest corner of Kahuku (NPS 2013a, b).

Mouflon Sheep

There are no established populations of mouflon sheep in the Kīlauea, MaunaLoa, and ʻŌlaʻa sections of HAVO; these areas are considered mouflon free with the exception of occasional ingress by individuals. In alpine on MaunaLoa (above the highest fenced unit) no formal surveys have been conducted of the area. However, the vegetation is considered too sparse to support resident populations. The Kahuku Unit has the largest population of mouflon sheep in the Park. Records suggest that the mouflon sheep population in HAVO was founded by only 11 individuals introduced between 1968 and 1974 (Hess et al. 2011). Over a decade later, the Kahuku mouflon population increased to several hundred animals (NPS 2013b). Hess, Kawakami, et al. (2006) estimated that by 1994 about 1,000 mouflon sheep were present in Kahuku. By 2004, more than 2,586 ± 705 mouflon were estimated within Kahuku (Hess, Kawakami, et al. 2006). Roughly 44% of the mouflon population was concentrated in forested areas and the remainder of the population occurred widely dispersed in subalpine shrubland and barren lava flows within Kahuku (Hess, Kawakami, et al. 2006).

Control efforts removed nearly 1,900 mouflon from the Kahuku Unit between 2004 and 2007 (Stephens et al. 2008). The Kahuku mouflon population is estimated to have decreased by 30% between 2004 and 2006 to 1,797 ± 688 (USGS 2006, Stephens et al. 2008). Although the population has decreased, age composition analysis revealed that mouflon reproduction increased significantly after density was reduced likely due to greater availability of resources. Overall, mouflon populations remain high in some areas of Kahuku due to an annual increase in recruitment of between 21.1% and 33.1% (USGS 2006, Stephens et al. 2008).

Mouflon sheep control efforts in Kahuku have been divided into four main areas: West, East, Mauka, and Paddocks (Figures 4.4-2). The majority of the remaining mouflon were reported in the Paddocks, with over 900 individuals estimated in 2011 (NPS 2012). Only one or two mouflon remain in the West unit and less than 50 mouflon are estimated to occur in the Mauka unit (Figure 4.4-4). Limited monitoring and control has occurred in the East unit because boundary fences have not been constructed in this area (NPS 2012). Only a few mouflon occur above fenced units in the older sections of the Park above 2,740 m in elevation (NPS 2013b).

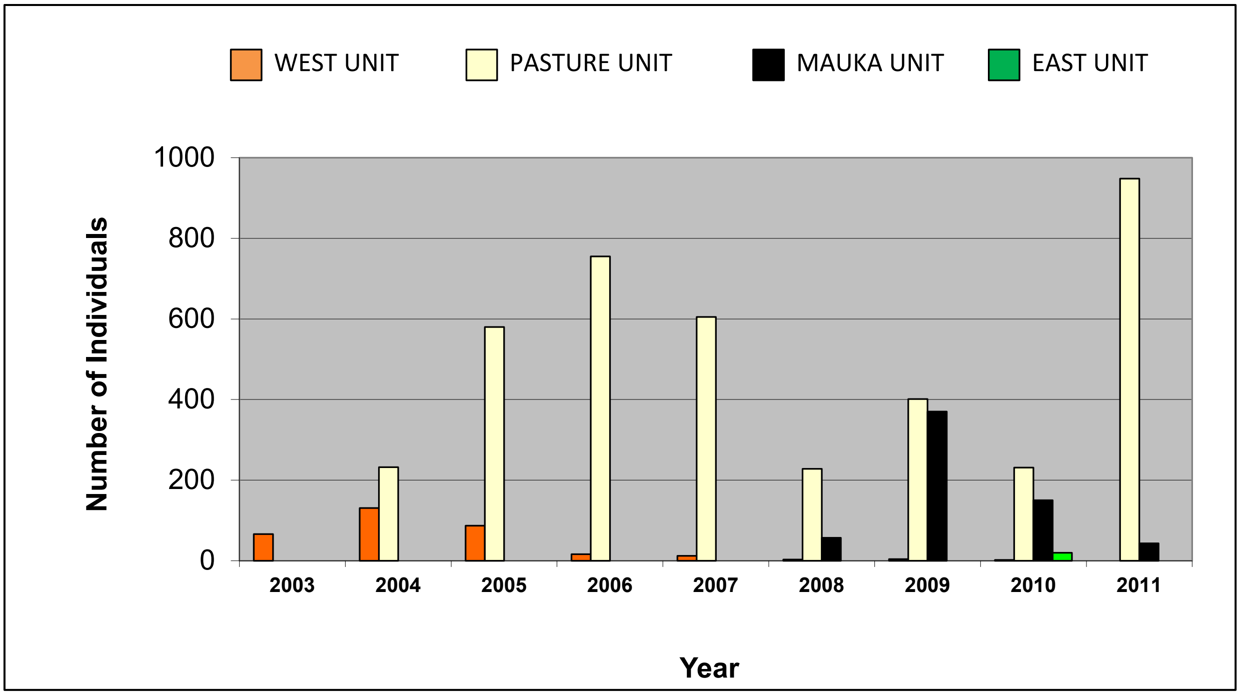


Figure 4.4-4. Number of mouflon sheep removed from the four units of the Kahuku Unit between 2003 and 2011 from NPS (2012).

Breaches/Ingress into Ungulate-Free Areas

Fence breaches into ungulate-free areas can be caused by fallen trees or deteriorating fences as a result of sea spray, volcanic gases, and other harsh conditions. Ungulate ingress into managed areas is monitored incidentally in conjunction with routine fence inspection, invasive plant control, and other administrative park activities (e.g., native planting projects, field surveys for rare plant and animal species, and monitoring recovery of vegetation) (NPS 2013b). Also, visitors may report animals they see for follow-up by Park staff.

Ingress of goats, mouflon sheep, pigs, and cattle into managed units has occurred throughout the past 100 years, but was not effectively managed until fenced units were constructed beginning in the 1970's (NPS 2013). Between October 2004 and September 2009, pig ingress was the most common, with an average of 12 pigs removed per year (NPS 2013b). Typically, between two to four of the 12 fenced units that exclude pigs will experience ingress in a year. The annual average rates of ingress by other ungulate species across all units were much lower: one goat, one mouflon sheep, zero sheep, and zero cattle (NPS 2013a). Between October 2009 and September 2010, five pigs and 13 goats were removed from ungulate-free areas. Three of these pigs were originally reported in spring/summer 2009 and were subsequently apprehended in fall 2009. One mouflon breach was reported, but no animal was found (NPS 2011). The following year, eight ingress animals were removed, including two pigs, two goats, and four mouflon. Several pigs were reported in the MaunaLoa section; one report that is considered credible was not found (NPS 2012). Three pigs and one goat were reported and removed between October 2011 and September 2012 (NPS 2013a). On average, 15 removal events were conducted per year for all ungulate-free areas between October

2004 and September 2009. Removal of ingress animals can be time-consuming and difficult, particular when the unit is large and remote, and wary individuals can hide in thick vegetation.

Threats and Stressors

Although the Park actively monitors and repairs ungulate fences, fence construction and maintenance is costly and time-consuming. The potential of increased fence breaches is enhanced by wildfire, extreme weather, volcanic fumes, or sea spray, all of which can damage or deteriorate the fence. Additionally, if active lava flows cease on the east end of Kīlauea, there is potential for ungulate ingress (NPS 2013b). Finally, increases in ungulate densities adjacent to the Park can put pressure on fences protecting ungulate-free areas within the Park. For example, rapid population growth of mouflon at the Kapapala Game Reserve and Ranch can threaten ingress into the MaunaLoa section.

Axis deer pose an imminent threat to natural resources in the Park and on the Island of Hawaiʻi. Current fences at HAVO are not designed to keep out these high-jumping animals. If necessary, 8-foot fences will be required to prevent ingress of axis deer.

Overall Condition

Data indicate that the current condition of ungulates in HAVO is of concern because the majority of the reference conditions are not met. Boundary and internal fencing has not been completed in the Park. For a large percentage of managed areas, control efforts are still in progress and areas not ungulate-free (Kahuku and ʻŌlaʻa new unit). Additionally, there are unmanaged areas where animal impacts are a concern. This includes sheep and pigs in the unfenced north portion of Kahuku, and pigs in the eastern portion of ʻŌlaʻa and throughout much of Kīlauea. Within units managed to zero ungulates, ingress is low, but individuals may be difficult to locate in large and more remote units. However, staff response to ingress is effective such that animals are removed before populations can re-establish. Differences between the current condition and reference conditions are much larger in the newly acquired Kahuku section of the Park compared to the older sections where ungulate management has been ongoing for several decades, and for pigs where a much smaller area of the Park is being managed to exclude them. Although the addition of Kahuku added more ungulate management areas to HAVO's jurisdiction, evidence indicates that the condition is improving throughout the Park because more areas are fenced and managed compared to historical estimates.

Information Gaps/Level of Confidence

The extent of the knowledge base of this indicator is ranked as B. Historical and recent quantitative data are provided for nearly all ungulates (except pigs) in most areas of the Park. A recent Park-wide assessment of pig abundance has not been conducted in HAVO due to difficulty in methodology compared to other ungulates. Further, estimates of pig densities in managed and unmanaged units are sporadic and methods likely are not consistent between surveys.

Abundance/density estimates of the other ungulates (except mouflon in Kahuku) are derived from the *Final Plan / Environmental Impact Statement for Protecting and Restoring Native Ecosystems by Managing Non-native Ungulates* (NPS 2013). These estimates are based on observations from HAVO staff.

At low population levels, it is more difficult to detect ungulates because populations are small and can be concentrated in a small area. Monitoring remnant populations in remote areas of the Park is difficult due to limited Park resources.

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- Rhonda Loh, Chief of Natural Resources Management, NPS HAVO
- David Benitez, Ecologist, NPS HAVO

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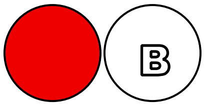
4.5. Invasive Small Mammals



Background

Small invasive mammals present within the Hawaiian Islands include the black rat, Norway rat, Polynesian rat, house mouse, and small Indian mongoose. Feral cats and dogs can also be considered invasive in some areas. All of these animals, except the Polynesian and Norway rats, are on the "100 of the World's Worst Invasive Alien Species" list (Lowe et al. 2000). Throughout the Hawaiian Islands, invasive small mammals have the potential to threaten native species and ecosystems by consuming a variety of native birds and eggs, invertebrates, and plants (Courchamp et al. 2003, Marshall et al. 2008, Shiels 2011).

Rodents are particularly damaging to native species and ecosystems. Rats are known to strip the bark from native trees, thereby inhibiting growth (Scowcroft and Sakai 1984). Rats and mice consume seeds of native plants (Male and Loeffler 1997, Sugihara 1997), decreasing or preventing regeneration (Allen 2000, Cabin et al. 2000). In addition to acting as seed predators, black rats can act as seed dispersers, especially for fruits bearing small seeds (Shiels 2011, Shiels and Drake 2011).

Rodents are also known to consume native invertebrates such as arthropods and molluscs. Native arthropods comprised a large percentage of the stomach content of black rats, Polynesian rats, and mice during studies conducted on Maui (Sugihara 1997, Cole et al. 2000). Mice may have a large impact on native arthropod populations; their diet is especially high in native Lepidoptera larvae in both Hawai‘i (Cole et al. 2000) and New Zealand (Ruscoe 2001). Other types of endemic Hawaiian invertebrates also have been affected by the introduction of rats. Many species of native Hawaiian land snails, once very numerous, are now extinct largely due to black rat predation (Atkinson 1977, Meyers and Shiels 2009).

Rodents, especially black rats, have similarly been implicated in the decline of native passerine birds (Atkinson 1977), the local extirpation of the Laysan Finch (*Telespyza cantans*), and the extinction of the Laysan rail (*Porzanula palmeri*) and Hawaiian rail (*Porzana sandwichensis*) (Tomich 1969, Berger 1981, Gorresen et al. 2009). Black rats are very good climbers and often prey on eggs, nestlings, and sitting adults. Predation by black rats is one of the largest causes of nest failure for many species of native Hawaiian birds (Amarasekare 1993, Levy 2003). Small invasive mammals also prey on nēnē.

Rats, cats, mongooses, and dogs have been observed preying upon ground-nesting seabirds or contributing to seabird nesting failures in Hawai‘i (Simons 1985, Stone 1985, Winter 2003, Kozar et al. 2007) and can quickly cause the extirpation of ground-nesting bird species (Hay and Conant 2007). Predation by cats is considered the "single most important limiting factor for petrels in their relictual alpine habitat" at HAVO (NPS 1999).

At HAVO, invasive small mammals are managed in the immediate vicinity of vulnerable listed and rare plants through cages and metal banding of trees to prevent rats from climbing the trunk and minimize seed predation (Figure 4.5-1). Trapping also occurs at beaches during the turtle breeding season and in the vicinity of nēnē breeding areas. Predator control (cat and rat) occurs within nesting colonies of the ground-nesting endangered Hawaiian petrel during their breeding season.

Figure 4.5-1. Metal banding to prevent rat predation of sandalwood seeds (Photo: NPS 2011).

Measures

- Abundance of invasive small mammals in sampled areas
- Observed predation events and impacts to sensitive, rare, or listed native species

Reference Condition/Value

Rats, mice, mongooses, cats, and dogs do not occur naturally in the Hawaiian Islands. Given that native Hawaiian species evolved without predation pressure from these small mammals, the presence of small mammals, however low, has the potential to adversely impact native species and ecosystems in HAVO. However, because management tools to control small mammals over large areas (such as HAVO) are still being developed, total absence of invasive small mammals is currently an unrealistic target.

A single quantitative reference value for abundance of invasive small mammals is not appropriate due to the wide range of habitat types throughout the Park and different habitat preferences of the species. For example, mice are considered ubiquitous in HAVO, except in wet forests, while Norway rats are primarily found at lower elevations, but are most abundant in wet areas (Stone and Pratt 2002). Additionally, a single individual can have detrimental impacts to an entire population of native species in some areas of the Park (e.g., a single cat in a Hawaiian petrel colony).

In HAVO, most reports of predation events by small mammals are anecdotal. A recent paper by Judge et al. (2012) provided videographic evidence of endangered Hawaiian petrel (*Pterodroma sandwichensis*) predation by feral cat. Without systematic surveys, it is not possible to determine if predation of a native species by invasive small mammals is actually occurring. Furthermore, without long-term monitoring it is difficult to conclude that small mammal predation is causing an adverse impact on native species.

Thus, reference conditions can only be determined for sensitive, rare or listed native species where predation or other impacts (e.g., bark stripping) by introduced small mammals is known or expected to occur and population or reproductive rates have been measured. The reference condition for this measure is that no observed impacts to these species' productivity or recruitment rates have been documented as a result of predation by small mammals and/or the impact is being managed to allow the continued persistence of the sensitive, rare or listed native species (i.e., a stable or increasing population), or an increase in reproductive output is observed after small mammal management.

Meeting the reference condition of no observed impact in these instances only implies that populations are stable or increasing despite the presence of invasive mammals. It does not indicate that listed or sensitive species have reached their optimal reproductive rates or population sizes which would occur in the absence of these invasive small mammals.

Existing Data

The following literature sources or datasets were used to assess this indicator.

- Hess et al. (2007, 2008) trapped feral cats within HAVO between 2000 and 2005 to determine feline disease prevalence, diet, daily movement rates, home range, and population genetics.
- Annual natural resource reports for HAVO discuss small mammal predation (NPS 2010, 2011, 2012).
- Pratt et al. (2010) examined rodent predation on five rare plants in Kīpuka Puaulu and Kīpuka Kī including hau kuahiwi (*Hibiscadelphus giffardianus*)*,* mokihana kūkae moa (*Melicope hawaiensis*)*,* Zahlbruckner's pelea (*Melicope zahlbruckneri*)*,* kāwaʻu (*Zanthoxylum dipetalum* var. *dipetalum*), and large-leaved ʻānunu (*Sicyos macrophyllus*). Rat predation was compared between hau kuahiwi and kāwaʻu excluded from rats and unprotected individuals. Seeds were also planted inside and outside rodent-proof exclosures for hau kuahiwi, mokihana kūkae moa, kāwaʻu, and ʻānunu. This report also summarizes the results of the unpublished study by Spurr et al. (2002) in Kīpuka Puaulu and Kīpuka Kī.
- VanDeMark et al. (2010) studied the impacts of rodents on ʻānunu (*Sicyos alba*) and observed two more rare plant species native to ʻŌlaʻa Forest (haʻiwale [*Cyrtandra giffardii*], many-flowered phyllostegia [*Phyllostegia floribunda*]).
- Pratt, Pratt, et al. (2011) discussed threats to rare and listed species in HAVO, noting evidence of rodent predation.

- Pratt, VanDeMark, et al. (2011) conducted rodent exclusion experiments, seed offering experiments, and monitored predation for two rare plants (poʻe [*Portulaca sclerocarpa*], ʻōhai). Additionally, ʻahakea (*Bobea timonioides*) seeds were offered in three open and three sealed rat bait stations to detect rodent chewing.
- Judge et al. (2011) provide trend data for the majority of the native Hawaiian forest birds in HAVO and discusses evidence of cat predation.
- Scheffler et al. (2012) determined seasonal and distribution patterns for four species of introduced rodents at five sites from 1986 through 1990 using baited snap traps. The researchers trapped for black rats, Polynesian rats, Norway rats, and house mice along an elevation gradient ranging from 90 to 1,820 m (295–5,971 ft) above sea level.

<u>Current Condition</u>

Abundance of Invasive Small Mammals in Sampled Areas

Park-wide abundance estimates of invasive small mammals within HAVO are unknown. Mongooses, rats, and cats are regularly caught in coastal areas where they prey on the endangered hawksbill sea turtles eggs during the nesting season (NPS 2010, 2011, 2012). Mongooses and cats are also present within montane areas where listed seabirds nest or could potentially nest. Dogs have been reported only incidentally (e.g., during predator control around nēnē breeding areas). Studies that quantified small mammal numbers in select areas of the Park are reviewed below.

Rodents

Black rats were the dominant rodent species found by Spurr et al. (2002) in Kīpuka Puaulu and Kīpuka Kī. In Kīpuka Puaulu, 15.4 black rats per 100 trap nights were recorded and in Kīpuka Kī 20 black rats per 100 trap nights were detected (Spurr et al. 2002 as cited in Pratt et al. 2010).

Between 1986 and 1990, Scheffler et al. (2012) caught 2,639 rodents over 39,726.5 corrected trap nights (Table 4.5-1). Black and Polynesian rats were widespread in almost all habitat types (within the five sites surveyed), whereas mice were limited to dry and mesic sites (i.e., MaunaLoa Strip and Kīpuka Puaulu). Norway rats (which are commonly associated with human habitation) were the least commonly caught and found only in wet montane forest (i.e., ʻŌlaʻa Forest) (Table 4.5-1). Breeding occurred throughout the year for all species at all sites but reproduction tended to be more common in the summer months at higher elevation sites and in the winter months at lower elevations (Scheffler et al. 2012).

Table 4.5-1. Total number of captures and mean number of captures per 100 trap nights per trapping season by species at five study sites from Scheffler et al. (2012).

	Mauna Loa Strip		Kīpuka Puaulu		ʻŌlaʻa Large Tract		ʻŌlaʻa Small tract		Lowlands	
Species	**# of Captures**	**Mean**	**# of Captures**	**Mean**	**# of Captures**	**Mean**	**# of Captures**	**Mean**	**# of Captures**	**Mean**
Mice	542	4.16	220	2.93	3	0.00	2	0.00	92	0.99
Black rats	274	2.10	351	4.78	169	2.88	285	2.36	196	2.12
Polynesian rats	12	0.09	248	3.33	23	0.39	155	1.26	221	2.39
Norway rats	0	0.00	0	0.00	40	0.68	11	0.09	0	0.00
Total	**828**	**–**	**819**	**–**	**235**	**–**	**453**	**–**	**509**	**–**

Mongooses and Cats

Cats are considered abundant in backcountry areas of the Park (Stone and Pratt 2002). No systematic assessment of mongooses has occurred at HAVO, but mongoose presence has been reported along with cat control measures. Cat control is conducted in HAVO through trapping. During a study by the Hawaiʻi Cooperative Studies Unit researchers (Hess et al. 2008) between November 2004 and December 2005, 11 feral cats and 37 mongooses were caught after 1,008 effective trap nights at HAVO. Data on specific locations of trapped animals are not provided in the report.

In addition, two bait stations (in Kīpuka Kī and along the MaunaLoa Strip Road) were set up to assess attraction of various mammalian predators to different bait types. At the bait stations (set from 2004–2005) mongooses were the principal mammals photographed followed by of rats, mice, and, lastly and very infrequently, feral cats (Hess et al. 2008) (Table 4.5-2).

Table 4.5-2. The number of photographs taken per species on MaunaLoa between 2004 and 2005 from Hess et al. (2007).

Species	Total Animals Photographed	Percent of Photographs
Cat	5	0.37
Mouse	9	0.67
Rat	487	29.50
Mongoose	975	69.50
Total	**1,476**	**–**

It is not possible to use photographs as an index of abundance because individual animals may have been photographed multiple times and different baits may not be equally effective or attractive to all species; however; mongooses were the most commonly photographed and the most commonly trapped species in areas of HAVO where live trapping and baiting have been conducted. Mongoose capture rate was positively correlated with the number of cats caught in the same trap (Hess et al. 2008); thus, wherever there are cats, there are likely to be mongooses and vice versa. Data suggest that mongooses are widely distributed and fairly common in HAVO.

Hess et al. (2008) determined that the effective cat population size, defined as the current number of successfully breeding individuals per population, was 24.2 (19.2–54.2 95% CI) at sampled locations at HAVO. On MaunaKea, cats have large home ranges ranging from 610 to 2,050 ha (1,507–5,066 ac) with a mean of 1,141 ha (2,819 ac). Male cats generally had larger home ranges than females (Hess et al. 2008). Using genetics Hess et al. (2008) estimated that cats (primarily males) migrate from MaunaKea to HAVO. An estimated 17.6% of cats per generation at HAVO are from MaunaKea (Hess et al 2008).

<u>Observed Predation Events and Impacts to Sensitive, Rare or Listed Native Species</u>

Rodents

At HAVO, rodent predation (including seeds, flowers, buds, fruit, bark) has been observed on several rare and listed plant species and has been identified as a limiting factor to their recovery. Rare species for which rodent predation has been recorded, as well as their assessed stand structure, are provided in Table 4.5-3. In addition to fruit and seed predation, Pratt et al. (2010) observed severe bark stripping of hau kuahiwi. Rodent predation has been suspected for various other rare and listed native plants in HAVO (Pratt, Pratt, et al. 2011); however, focused studies have not been conducted, and these species are thus not included in Table 4.5-3.

Table 4.5-3. Rare and listed plant species for which rodent predation has been recorded in HAVO.

Species Name	Common Name	Fruit/Seed Predation	Stand Structure	Source
Portulaca sclerocarpa	Po‘e	72%–100%	Declining	Pratt, VanDeMark, et al. 2011
Sesbania tomentosa	‘Ohai	33%	Unknown	Pratt, VanDeMark, et al. 2011
Hibiscadelphus giffardianus	Hau kuahiwi	Seeds in soil; 83% of fresh seeds; 10% of fruit	Planted	Pratt et al. 2010
Melicope hawaiensis	Mokihanakūkae moa	Seeds in soil; 54%–57% of fruit	Declining	Pratt et al. 2010
Melicope zahlbruckneri	Zahlbruckner’s pelea	Seeds in soil	Declining	Pratt et al. 2010
Sicyos alba	‘Anunu	93.3% of fresh seeds	Unknown	VanDeMark et al. 2010
Sicyos macrophyllus	Large-leaved ‘ānunu	Seeds in soil; 7%–28% of fresh seeds	Unknown	Pratt et al. 2010

Rat control is also conducted in nēnē breeding areas during the breeding season. Current management actions, including predator control, have resulted in an increase in nēnē fledging success from 2008 to 2011 compared to 1994 (see Section 4.13).

In HAVO, rat control is conducted every year during the breeding season along the coast at hawksbill turtle nesting locations. The hawksbill turtle hatch rates at HAVO are similar to the average for the species reported throughout its range with the predator trapping regime and other management actions that are being implemented (see Section 4.16).

No data are currently available on the impacts of rodents on native invertebrates within HAVO and declines in sensitive, rare or listed native species such as *Drosophila* are currently attributed to predation by the western yellow jacket wasp (see Section 4.17) (Foote and Carson 1995).

Rodents are known to prey on eggs and nestlings of native forest birds in Hawaiʻi, but are currently not controlled in areas of HAVO where native forest birds occur. Forest bird abundance for most native species was greater in the most recent survey than almost all previous surveys (see Section 4.13). In addition, trend data are positive for the majority of native species documented (Judge et al. 2011) with some species showing possible range expansion (see Section 4.13). These results were obtained despite the fact that rodents were present in all the surveyed habitats.

Rodents also are not systematically controlled in the nesting Hawaiian petrel colonies; most of the predator control efforts at HAVO nesting colonies have focused on cats (see below).

Mongooses and Cats

In contrast to rodents, the impacts of mongoose predation on native Faunaare largely undetermined. However, nēnē nest predation by mongooses has been documented fairly regularly at HAVO (Kathleen Misajon, Wildlife Biologist, NPS HAVO, pers. comm. 2014).

Stomach content analysis has shown that cats at HAVO mostly consume small mammals (43.9%), invertebrates (36.8%), and birds (8.8%) based on the frequency of prey items occurring in stomachs. Birds occurred in 27.8% to 29.2% of digestive tracts of all analyzed cats. Video footage of cat predation (NPS 2010) and the recovery of remains of one endangered Hawaiian petrel from a digestive tract of a cat from MaunaLoa provides direct evidence of predation during the nesting season (Hess et al. 2008).In addition to these two instances, HAVO staff have documented scores of cat killed petrels (Kathleen Misajon, Wildlife Biologist, NPS HAVO, pers. comm. 2014). The authors suggest that the presence of abundant small prey such as mammals and invertebrates may allow feral cats at high elevations to survive food shortages, maintain populations, and consequently persist in areas where cats are able to exploit seasonally abundant prey such as endangered nesting birds (Hess et al. 2008).

Since 2013, HAVO staff has documented cat predation on nine adult nēnē. Cat depredation on adult and young nēnē is believed to occur much more frequently; however, nēnē have a vast and often remote range, making location and identification of cat kills difficult (Kathleen Misajon, Wildlife Biologist, NPS HAVO, pers. comm. 2014).

Cats are also the definitive host of toxoplasmosis, a disease which has killed both endangered birds and marine mammals in Hawaiʻi (Work et al. 2000, Work et al. 2002, Honnold et al. 2005). On MaunaKea, 25 of 67 cats (37.3%) were seropositive to toxoplasmosis (Hess et al. 2008). The risk of infection with toxoplasmosis to birds in HAVO is currently unknown.

In HAVO, cat and mongoose control occurs yearly along the coast at hawksbill turtle nesting locations. The hawksbills turtle hatch rates at HAVO are similar to the average for the species reported throughout its range with the predator trapping regime and other management actions that are occurring (see Section 4.16).

Predator control aimed at mongooses and cats occurs in specific areas during the nēnē breeding season. Nēnē fledging success has shown an increase from 2008 through 2011 compared to 1994 (see Section 4.13). This increase can only partly be attributed to more predator control (Kathleen Misajon, Wildlife Biologist, NPS HAVO, pers. comm. 2014).

Evidence of cat predation has been documented for multiple years at Hawaiian petrel nesting colonies (Judge et al. 2011), even with ongoing predator control. Despite this, Hawaiian petrel nesting colonies at HAVO have shown a nesting success similar to managed populations at Haleakala Maui (see Section 4.14), which contains one of the largest Hawaiian petrel colonies in Hawaiʻi (USFWS 2008).

Dogs

Stray dogs have attacked nēnē at HAVO. In 2011, one nēnē death was attributed to a possible dog attack (NPS 2011). Trapping for dogs does occur in response to specific dog sightings, however, dog trapping is opportunistic and often unsuccessful (i.e., does not directly contribute to reproductive success.). Feral dogs pose a risk to nēnē at Kahuku, particularly during the summer flocking period when nēnē use of Kahuku is the highest.

<u>Threats and Stressors</u>

An increase in Park visitors and residents around HAVO could mean an increase in the number of invasive small mammals in HAVO. Many of these animals are attracted to trash receptacles, campgrounds, and other similar sites. HAVO is also adjacent to several residential areas and there is a possibility of domestic cats and dogs adding to feral populations in the Park. Finally, an increased prey base (e.g., nonnative birds, mouflon) could support higher cat or dog populations in HAVO. This is most applicable to Kahuku, where the presence of mouflon sheep attracts dogs.

<u>Overall Condition</u>

Although Park-wide population estimates for rodents, cats, mongooses, and dogs do not exist, most of these small invasive mammals (except dogs) are widespread throughout the Park. Several plant species have documented predation by rats and rat predation has been identified as a limiting factor for at least six listed plant species or SOC (also see Section 4.8). Impacts of small mammal predation to wildlife have been quantified to a greater degree, and current management for small mammal predators has allowed three species (such as ground-nesting seabirds, nēnē, and hawksbill turtles) to persist or increase (also see Sections 4.13, 4.14, and 4.16). Overall, native landbirds are also stable or increasing without active predator management (also see Sections 4.13). However, while the condition of certain monitored individuals for these species may meet the reference condition of no observed impact of predation on population persistence or reproductive output, information is not known for seabirds and landbirds that are not monitored or managed. Additionally, effects of small mammals are suspected for various other (less rare) species that are not monitored or managed at

HAVO based on anecdotal information or inference from other sites in the Hawaiian Islands. Therefore, the condition of this indicator is considered "of concern" and an overall trend cannot be determined.

Information Gaps/Level of Confidence

Yearly monitoring is conducted for three listed ground-nesting wildlife species impacted by small mammals; small mammal impacts to these species are managed seasonally, on a local scale and to the degree possible. Little data, however, exist on whether small mammals have contributed to the decline of invertebrate species or many of the rare and listed plants. More specific, quantifiable studies for these species are warranted.

Subject Matter Experts Consulted

- Kathleen Misajon, Wildlife Biologist, NPS HAVO

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4.6. Invasive Terrestrial Insects

Background

Invasive insects have been documented to adversely affect native Hawaiian ecosystems and biodiversity through herbivory, predation, parasitism, pollination disruption, and hybridization and competition with native species (Haines and Foote 2005, Krushelnycky et al. 2005, Lach 2008, Junker et al. 2011). Insects have the greatest rate of yearly establishment of all animal or plant groups in the Hawaiian Islands (Staples and Cowie 2001). More than 2,500 nonnative insects are known to have established in Hawaiʻi (Kenis et al. 2009). Most native flora and Faunamay lack natural defenses against these generalist predators because they evolved in the absence of social insects.

Invasive terrestrial insects of particular concern in HAVO include Argentine ant, big-headed ant, yellow crazy ant (*Anoplolepis gracilipes*), western yellowjacket wasps, and the two-spotted leafhopper. The southern house mosquito, (*Myoporum)* thrip (*Klambothrips myopori*), as well as numerous species of parasitoid wasps, have also been documented in the Park (Peck et al. 2008). No data exist for *Myoporum* thrip in the Park, therefore it is not discussed in this report. Several projects have been implemented at HAVO to monitor the extent and impacts of invasive insects and test control measures (Gambino and Loope 1992, Magnacca and Foote 2006, Foote et al. 2011, Peck et al. 2013).

Approximately 60 species of ants have established in Hawaiʻi from the coast to subalpine areas (Peck et al. 2013). Ants threaten native arthropod species and community structure by directly preying upon native insects or competing for food resources, nesting areas, or shelter sites (Zimmerman 1978, Cole et al. 1992, Krushelnycky et al. 2004, Krushelnycky et al. 2005, Krushelnycky and Gillespie 2008, Peck et al. 2013). This may indirectly impact native plants by reducing essential pollinator populations and available nectar resources, thereby decreasing reproductive success of native plants (Krushelnycky et al. 2005, Lach 2008, Junker et al. 2011). Ants also have the potential to reduce hatching success, growth rates, and overall reproductive success of ground-nesting birds (Plentovich et al. 2009). Ants can spread through many vectors such as vehicles, backpacks, equipment, soil, fill, and plants (Peck et al. 2013).

The western yellowjacket wasp is a problem in Hawaiʻi's natural areas because it threatens public safety, especially at picnic grounds and camping areas; preys on endemic arthropods; and competes for food with both native invertebrates and endemic forest birds (Gambino and Loope 1992, Gruner and Foote 2000, Hanna et al. 2013). In HAVO there are reports of endemic insects, such as picture-wing *Drosophila*, becoming scarce following the spread of yellowjackets into the Park in 1978 (Foote and Carson 1995, Foote 2000) (see Section 4.17). Yellowjacket predation on invertebrate plant pollinators may also disrupt native plant-native pollinator mutualisms (Hanna et al. 2013).

Western yellowjacket wasps in montane forest ecosystems in Hawaiʻi undergo seasonal changes with peak numbers recorded during the summer and fall months (Gambino and Loope 1992, Gruner and

Foote 2000). Most nests are annual, but a small fraction of nests can overwinter and consequently produce a disproportionately large number of workers and thousands of queens (Gambino and Loope 1992).

The two-spotted leafhopper was first detected on Hawaiʻi Island in 1989 (Lenz et al. 2006). This insect feeds on a wide variety of plants and causes various symptoms such as foliar chlorosis, reduction in leaf area, increased auxiliary shoots and leaves, and damage to leaf vascular tissue (Lenz 2000, Jones et al. 2000, Lenz et al. 2006). Of the estimated 307 host plant species for the two-spotted leafhopper in Hawaiʻi (Fukada 1996), roughly 21.8% are native, and 4.6% are listed or candidates for listing (Lenz et al. 2006). The invasive faya tree appears to be a preferred host plant of the two-spotted leafhopper, potentially due to its high nitrogen content or lack of leaf pubescence (Lenz et al. 2006).

Measures

- Number, distribution, and abundance of ant species
- Distribution and abundance of western yellowjacket wasps
- Abundance of two-spotted leafhopper abundance

Reference Condition/Value

Ants do not occur naturally in the Hawaiian Islands and therefore an ideal reference condition is complete absence of these species; however, this is not currently a feasible goal for ants given that ants have invaded large portions of Hawaiʻi Island, are easily spread, and no effective large-scale control measures have been developed. Thus, the reference condition for ants is that no new species establish and population boundaries do not expand beyond those identified during surveys in the 1960s and 1970s.

Currently, no reference condition exists for the western yellowjacket wasps or the two-spotted leafhopper; however, generally a low number of wasps nest or two-spotted leafhopper eggs is considered preferable conditions.

Number of new invasive insect species documented in the Park was considered as a reference condition, but dismissed due to the lack of data.

Existing Data

The following resources were used to assess the condition of ants within HAVO.

- In 1994, Wetterer (1998) surveyed for ants in the Kīlauea Caldera region of the Park using 211 bait stations. His report also summarized species found in previous surveys at HAVO.
- Between 2008 and 2010, Peck et al. (2013) identified and mapped distributions of ants within the MaunaLoa Strip and Kahuku sections at 1,625 stations covering nearly 200 km (124 mi). The efficacy of baits for two ant species was also tested. This report also summarized the history of ants in HAVO, summarizing the results of earlier surveys (Medeiros et al. 1986, Huddleston and Fluker 1968, Gagné 1979, Gagné 1981, Wetterer 1998), as well as unpublished data.

The following resources were used to assess western yellowjacket wasps.

- Gambino and Loope (1992) report on biology of western yellowjacket wasps at HAVO, describing populations, nest sites, colonies, and queen behavior. They also measure the effects of yellowjacket predation and evaluate abatement techniques. Traps were set at 13 sites from 900 to 2,165 m (2,953–7,103 ft) in wet and dry forest from 1984 to 1990.
- Gambino (1992) describes and identifies the prey items of western yellowjacket wasps at HAVO.
- Foote et al. (2011) discuss the effectiveness of using fipronil for wasp abatement.
- Hanna et al. (2013) examine the effects of western yellowjacket wasps control on visitation rates of pollinators to ʻōhiʻa and ʻōhiʻa fruit production rates.

The following surveys were used to assess the two-spotted leafhopper.

- Johnson et al. (2001) discusses the history of the two-spotted leafhopper in HAVO.
- Between January and November 1999, Lenz et al. (2006) compared abundance of the two-spotted leafhopper in areas with faya tree to areas in which faya tree had been cleared. The study sites were Devastation, Hilina Pali, and Kīpuka Kahaliʻi.
- In 2000, Alyokhin et al. (2004) surveyed the density of leafhopper eggs at Escape Road, Puhimau Crater, Kīpuka Kahaliʻi, Halemaʻumaʻu Crater, and Kulanaokuaiki.

Current Condition

Number, Distribution, and Abundance of Ant Species

Twenty-three ant species have been reported in HAVO since the first species was detected in 1934 (Table 4.6-1) (Wetterer 1998, Peck et al. 2013). Two of these species, the Argentine ant and the big-headed ant, are considered particularly destructive to native species and ecosystems.

Table 4.6-1. Ant species recorded in HAVO and the number of stations detected by Peck et al. (2013). An "X" indicates that the species was identified as being inside the park for that study.

Species Name	Previous Surveys Detected*						Number of Stations Detected by Peck et al. (2013)	
	1944	1968	1979	1986	1990s	1998	MaunaLoa Strip (n = 1064)	Kahuku (n = 561)
Anoplolepis gracilipes	–	–	–	X	X	X	2	1
Camponotus variegatus	–	–	–	–	X	–	Not detected	Not detected
Cardiocondyla emeryi	–	–	X	–	X	X	2	0
Cardiocondyla kagutsuchi	–	–	–	–	X	X	61	65

*1994 = C. Davis cited in Medeiros et al. 1986; 1968 = Huddleston and Fluker 1968; 1979 = Gagné 1979; 1986 = Medeiros et al. 1986; 1990s = Jorgensen et al. cited in Wetterer 1998; 1998 = Wetterer 1998.

Table 4.6-1 (continued). Ant species recorded in HAVO and the number of stations detected by Peck et al. (2013). An "X" indicates that the species was identified as being inside the park for that study.

Species Name	Previous Surveys Detected*						Number of Stations Detected by Peck et al. (2013)	
	1944	1968	1979	1986	1990s	1998	MaunaLoa Strip (n = 1064)	Kahuku (n = 561)
Cardiocondyla minutior	–	–	–	–	X	X	3	0
Cardiocondyla obscurior	–	–	–	–	–	–	0	1
Cardiocondyla wroughtonii	–	–	–	–	–	–	2	1
Hypoponera opaciceps	–	X	–	X	X	X	2	0
Hypoponera punctatissima	–	–	–	–	X	X	Not detected	Not detected
Hypoponera sinensis	–	–	–	–	X	–	Not detected	Not detected
Linepithema humile	–	–	X	X	X	X	210	121
Monomorium monomorium	–	–	–	–	X	X	Not detected	Not detected
Monomorium pharaonis	–	–	–	–	–	X	Not detected	Not detected
Nylanderia bourbonica	–	X	–	X	X	X	32	18
Nylanderia vaga	–	–	–	–	X	–	Not detected	Not detected
Paratrechinalongicornis	–	–	–	–	X	X	3	0
Pheidole fervens	–	–	–	–	X	X	Not detected	Not detected
Pheidole megacephala	–	X	X	–	X	X	14	80
Plagiolepis alluaudi	–	X	X	–	X	–	0	1
Tapinoma melanocephalum	–	–	–	–	X	X	0	1
Technomyrmex albipes	X	–	–	–	X	–	Not detected	Not detected
Tetramorium bicarinatum	–	X	–	–	X	X	3	0
Tetramorium simillimum	–	–	–	–	–	–	0	5

*1994 = C. Davis cited in Medeiros et al. 1986; 1968 = Huddleston and Fluker 1968; 1979 = Gagné 1979; 1986 = Medeiros et al. 1986; 1990s = Jorgensen et al. cited in Wetterer 1998; 1998 = Wetterer 1998.

During the most recent survey, 15 ant species were recorded in the MaunaLoa Strip and Kahuku areas. Of these, two species (*Cardiocondyla obscurior* and *C. wroughtonii* [no common names]) were new records for HAVO (Peck et al. 2013). Ants were detected at 30% of the stations on the MaunaLoa Strip and over 31% of the stations in Kahuku (Table 4.6-1). The most widespread ant species in both areas was *Cardiocondyla kagutsuchi* (no common name) (Peck et al. 2013).

Argentine ants were found in the lower elevation section of the MaunaLoa Strip by Peck et al. (2013), covering approximately 560 ha (1,384 ac) (Figure 4.6-1). During the 1970s, Gagné (1979, 1981) also reported the Argentine ants at higher elevation areas (between 1,600 and 2,400 m [5,250–

7,874 ft]). Big-headed ants were found to be less abundant by and were found only along the southernmost transect and along the western boundary (Figure 4.6-1).

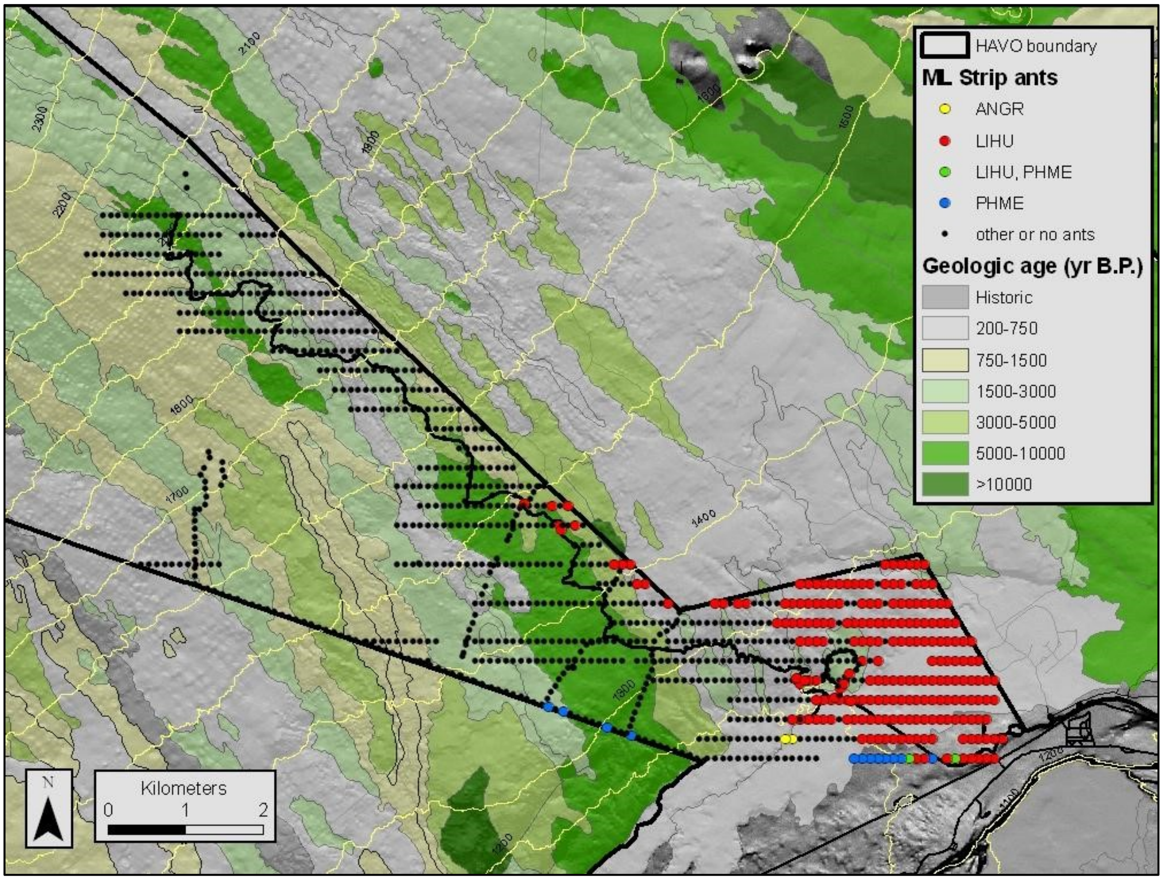

Figure 4.6-1. Distribution of yellow crazy ant (ANGR), Argentine ants (LIHU), and big-headed ants (PHME) in the Mauna Loa Strip between 2008 and 2010 from Peck et al. (2013).

In Kahuku, Argentine ants were found immediately northeast of the Hawaiian Ocean View Estates subdivision. This population is slightly larger than the one in the MaunaLoa Strip, and encompasses roughly 585 ha (1,446 ac). The big-headed ant population in Kahuku extended downslope from the Argentine ant population to about 760 m (2,493 ft) elevation and was largely restricted west of the main road (Figure 4.6-2). The population was estimated to cover at least 825 ha (2,039 ac). No ants were detected above the Kaʻū Forest Reserve or along the road northwest of Hawaiian Ocean View Estates (Peck et al. 2013).

Several ant species that were formerly believed to be restricted to the Park's lowlands were documented in higher elevation areas during the recent survey, suggesting range expansion. Furthermore, Peck et al. (2013) estimate that Argentine ants could colonize additional mesic and dry habitats at HAVO, occupying roughly 85,000 ha (210,040 ac). This represents a distribution increase of more than 70 times the area the species currently occupies. A least three other ant species are likely to have the potential to expand their ranges within HAVO (Peck et al. 2013).

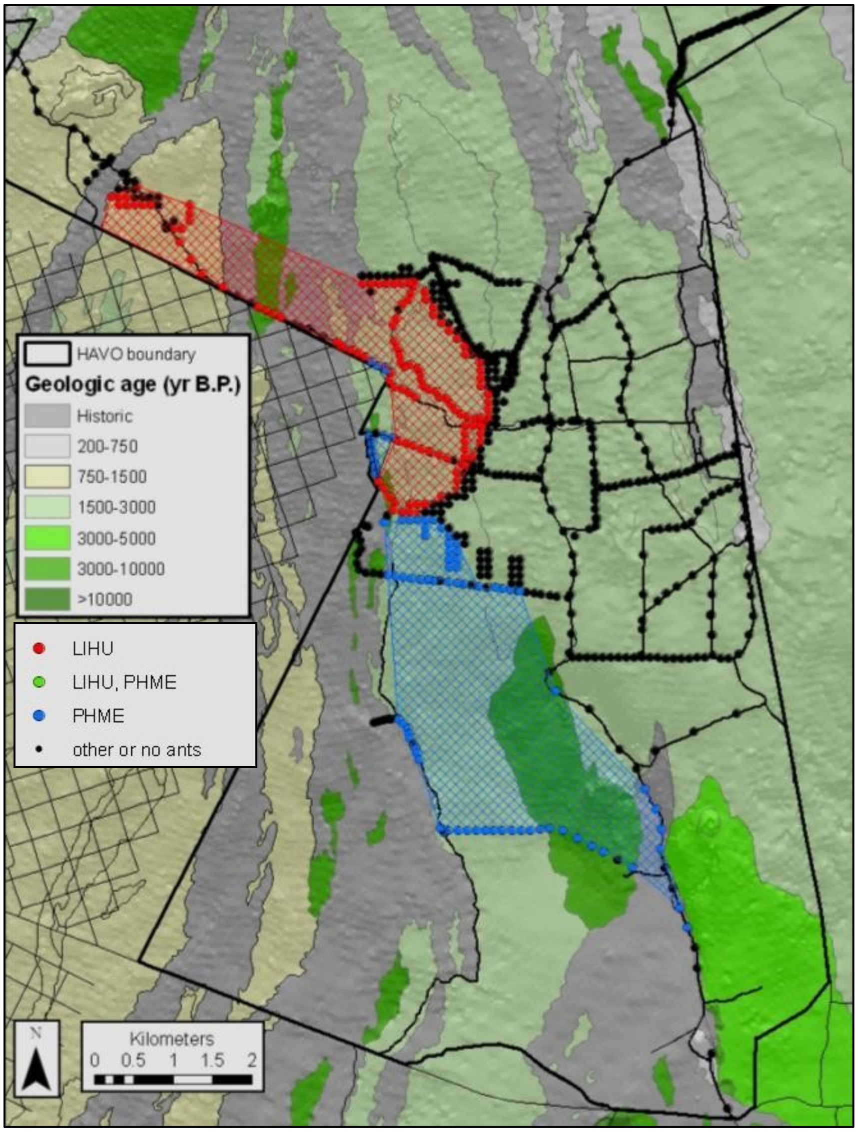

Figure 4.6-2. Distribution of Argentine ants (LIHU) and big-headed ants (PHME) in Kahuku between 2008 and 2010 from Peck et al. (2013).

Distribution and Abundance of Western Yellowjacket Wasps

Between 1986 and 1990, 74 yellowjacket nests were discovered in HAVO by Gambino and Loope (1992). The yellowjacket population in HAVO peaks around late September in seasonal submontane habitat and is followed by a steep decline in November. Evidence suggests that a small fraction of the nests are able to overwinter (Figure 4.6-3). Most nests at HAVO were subterranean in soil cavities or in roots and logs. Populations in different regions were not synchronized; the general pattern was for earlier population build-ups in drier regions such as Ka‘ū and Kīpuka Nene. However, some populations declined swiftly, while others lingered on erratically for several months (Gambino and Loope 1992).

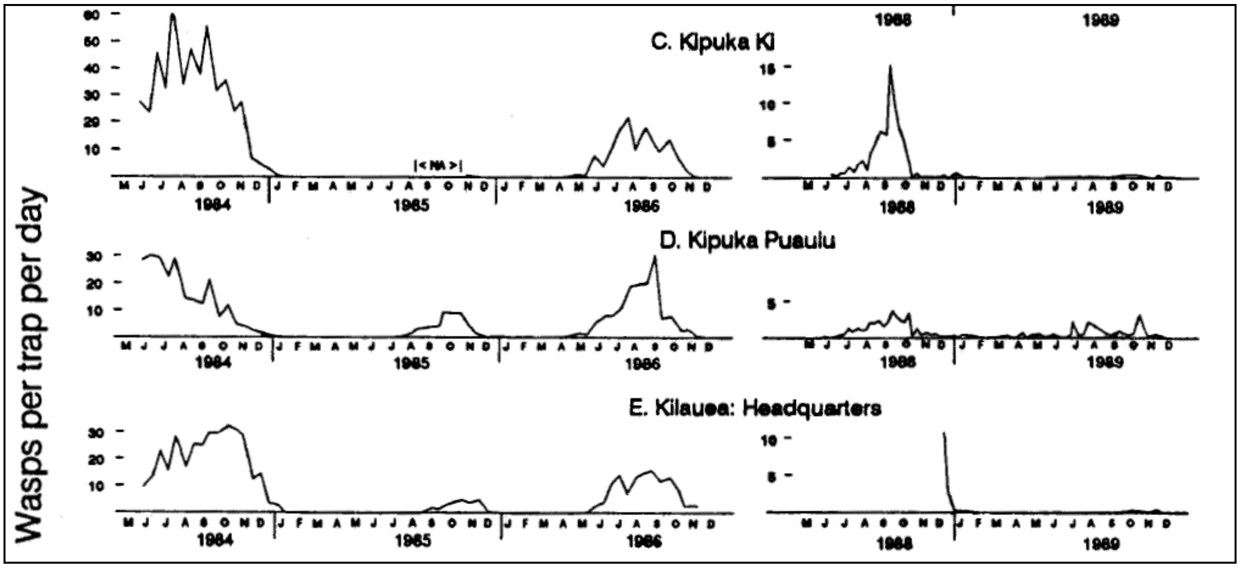

Figure 4.6-3. Yellowjacket abundances in traps at selected sites at HAVO from 1984 to 1990 from Gambino and Loope (1992).

Yellowjacket wasps can impact endemic Hawaiian insects. Gambino (1992) documents that of 170 prey items identified at HALE and HAVO, 66% were taxa endemic to Hawai‘i. The impacts of predation potentially could be very large given that Gambino and Loope (1992) estimated that an active colony could conservatively collect well over one million prey items. Hannaet al. (2013) also reported that the reduction of yellowjacket wasps in managed sites at seasonal submontane habitats within HAVO resulted in a significant increase in the visitation rates of effective bee pollinators (e.g., introduced honey bees and native bees) and in the fruit production of ‘ōhi‘a when compared to unmanaged sites.

An effective method to control yellowjackets has been developed by Foote et al. (2011) using 0.1% of the insecticide fipronil mixed with canned chicken meat. Trials were conducted in mesic montane and seasonal submontane forests and in four of the five trials wasp traffic ceased at all yellowjacket nests in sites treated with fipronil within 1 month after baiting. However, fipronil is currently unapproved in Hawai‘i to control yellowjackets and has been shown to have non-target effects (David Benitez, Ecologist, NPS HAVO, pers. comm. ~2013). In mesic montane habitat, activity at active yellowjacket colonies located at distances 125 m (410 ft), 210 m (700 ft), and 250 m (820 ft) from the treatment sites was reduced 85% to 95% compared to pre-treatment levels. In seasonal submontane habitat, wasp nests 75 m (246 ft), 105 m (344 ft), and 120 m (394 ft) outside the treatment areas completely ceased activity following application of fipronil bait (Foote et al. 2011).

<u>Abundance of Two-spotted Leafhopper</u>

Since 1994, large populations of the two-spotted leafhopper have been detected in the Park (Johnson et al. 2001). At the three sites surveyed by Lenz et al. (2006), two-spotted leafhopper abundance ranged from zero individuals to over 140 individuals (Figure 4.6-4). Population densities were significantly higher in areas containing faya tree (control) compared to areas where it had been cleared (SEA). Abundances were also significantly greater at Kīpuka Kahali‘i than at either

Devastation or HilinaPali (Lenz et al. 2006). Data suggest that two-spotted leafhopper abundances fluctuate throughout the year depending on precipitation, with abundances lowest during the winter and early spring (Lenz et al. 2006).

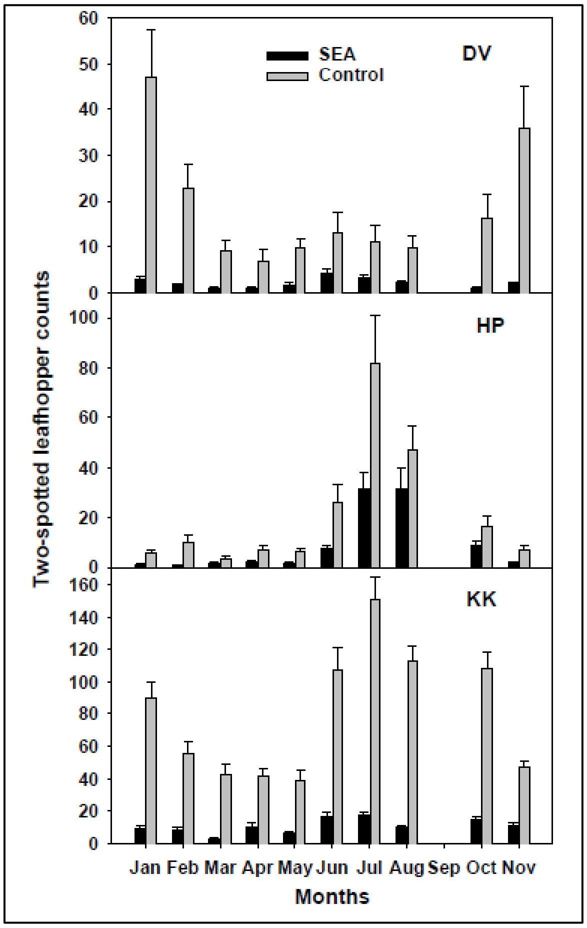

Figure 4.6-4. Two-spotted leafhopper abundance at Devastation (DV), HilinaPali (HP), Kīpuka Kahali'i (KK) in control areas and SEA sites between January and November 1999 from Lenz et al. (2006).

Alyokhin et al. (2004) also found that the two-spotted leafhoppers deposited their eggs more frequently on faya tree than the native ʻōhiʻa. Mean egg densities ranged from 165.64 eggs/m^2 on faya tree at Escape Road to 6.80 eggs/m^2 on ʻōhiʻa at Halemaʻumaʻu Crater (Table 4.6-2).

Table 4.6-2. Mean egg density of two-spotted leafhopper on faya tree and ʻōhiʻa at various sites throughout HAVO from Alyokhin et al. (2004).

Site	Mean Egg Density/1 m^2 (SE)	
	Faya Tree	ʻŌhiʻa
Puhimau Crater	130.65 (14.05)	12.55 (3.02)
Escape Road	165.64 (43.00)	45.37 (31.74)
Halemaʻumaʻu Crater	95.78 (13.25)	6.80 (3.57)
Kulanaokuaiki	111.41 (29.76)	27.21 (15.80)
Kīpuka Kahaliʻi	132.34 (16.81)	41.15 (10.78)

Threats and Stressors

High visitation rates continually threaten to increase the number or distribution of some invasive insects in HAVO. Ant populations in areas adjacent to the Park can act as sources of continuous incursion (Peck et al. 2013). Many ant species can stow away in vehicles, backpacks, potting soil, gravel, and packing material (Peck et al. 2013) and two-spotted leafhopper adults are highly mobile (Alyokhin et al. 2004).

Overall Condition

While the addition of new ant species to HAVO may be due to increased sampling efforts, the two most recent ant inventories in HAVO suggest that ants are increasing their range in HAVO compared to earlier surveys. Yellowjacket wasps remain present at HAVO, and impact native Hawaiian insects. Finally, the two-spotted leafhopper is abundant in areas where faya tree occurs. Because reference conditions or values do not exist for the yellowjacket wasps or two-spotted leafhopper is it difficult to determine a condition for this indicator. Because all three groups occur relatively widely in the Park and are known to adversely impact a variety of native species and ecosystems, invasive insects are classified as "of concern" in HAVO.

Information Gaps/Level of Confidence

Quantitative data are available for multiple years for ants, yellowjacket wasps, and two-spotted leafhopper. As described by the authors, the methods used by Peck et al. (2013) to survey for ants may underestimate abundances for some ant species that do not recruit strongly to bait, have cryptic habits, or sustain small population densities. However, available data provide a comprehensive survey of the most aggressive species, which are of greatest management concern at HAVO.

Most areas within HAVO are not regularly managed for yellowjacket wasps and all control has been mostly experimental to date. Some nest treatment does occur to mitigate safety hazards to humans (David Benitez, Ecologist, NPS HAVO, pers. comm. ~2013). Areas requiring yellowjacket control should be identified and an annual monitoring and control protocol developed and implemented.

Subject Matter Experts Consulted

- Paul Banko, Wildlife Biologist, USGS Pacific Island Ecosystems Research Center

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4.7. Coqui Frogs

Background

The common coqui frog, endemic to Puerto Rico, is an invasive species in Hawaiʻi. The small frog was introduced to the state in the late 1980s, likely an unintentional hitchhiker through the plant nursery trade (Kraus et al. 1999). By 2001, more than 200 populations of coqui frogs had become established on Hawaiʻi Island, as well as 50 on Maui. In addition, single populations on Oʻahu and Kauaʻi were also identified (Kraus and Campbell 2002). These populations grew quickly, reaching extremely high densities in some areas. Population estimates as high as 91,000 frogs/ha (37,000 frogs/ac) were recorded on Hawaiʻi Island, more than three times the density found in their native Puerto Rican forests (Beard et al. 2008, Stewart and Woolbright 1996). Parasites that may limit coqui frog densities in its native range have not been found in Hawaiʻi (Marr et al. 2008, Beard et al. 2009).

Mature coqui frogs measure about 2.5 cm (1 in) long, although length may vary by altitude, as temperature affects frog metabolism and growth rate (Staples and Cowie 2001, Beard et al. 2009). Coloration ranges from light to dark brown on the back, white to yellow on the undersides, with a variety of patterns on the dorsal surface (Figure 4.7-1) (Woolbright 2005). Male frogs produce a loud "Ko-KEE" call, primarily at night. A single calling male can be as loud as 85 to 90 decibels (dB) at 0.5 m (1.6 ft) away (Beard et al. 2009). In areas of high frog density, the chorus can drown out all other noise. The call is known to negatively affect human health and welfare (Department of Health, Hawaiʻi Revised Statutes Section 324F-1, as reported in Beard et al. 2009).

Figure 4.7-1. Coqui frog with a single stripe dorsal pattern (*Eleutherodactylus coqui*) (Photo: Kim Tavares 2008).

Coqui frogs prey on small invertebrates. In dense populations, coqui frogs have been estimated to consume up to 690,000 invertebrates per ha per night (Beard et al. 2008). Stomach contents of coqui frogs collected from three Hawaiian Islands showed that the species consumes mostly nonnative, leaf litter invertebrates (Beard and Pitt 2005). Although the frog primarily consumes nonnative insects, they still pose a risk to native invertebrate populations. In addition, the frogs may compete with native birds and other Faunafor food resources, although evidence of detrimental competition with endemic Hawaiian bird species has not yet been found (Beard and Pitt 2005).

Beard et al. (2003) demonstrated that the coqui frog may affect ecosystem functions by decreasing prey items and increasing nutrient cycling rates by increasing the concentrations of several nutrients, increasing leaf litter decomposition rates, and increasing the number of new leaves on an invasive plant species. This acceleration of the nutrient cycle could negatively impact slow-growing native plant species, while giving nonnative species a competitive advantage (Sin et al. 2008).

Breeding can occur year-round (Townsend and Steward 1994), and like other *Eleutherodactylus* species, coqui frogs do not require a waterbody to reproduce (Culbertson 2005). Females reach sexual maturity between 8 and 9 months, breeding approximately once every 2 months. Egg clutches of 16 to 41 eggs are deposited by the female, and are then guarded by the male until hatching (Beard et al. 2009). Young lack a free-living tadpole phase, and instead hatch as tiny froglets (Townsend and Steward 1985). Thus, coqui frogs have the potential to inhabit a wide range of Hawaiian environments, requiring only high humidity and adequate refuge to survive (Schwartz and Henderson 1991).

The majority of Hawaiian coqui populations have been found in damp, lowland nonnative forests below 500 m (1,600 ft) (Beard et al. 2009). However, the upward elevation limits for coqui on Hawaiʻi Island remain unclear at present. It is unknown if the frogs are unable to establish at elevations over 1,200 m (4,000 ft), or if coqui have yet to be introduced at higher altitudes (Beard and Pitt 2005, Beard et al. 2009).

The current tools and resources for controlling the coqui frog on Hawaiʻi Island are not sufficient to eradicate populations and the incursion continues to spread through vehicle traffic and infested vegetation. A large portion of HAVO falls within the potential invasion range of the coqui frog and a number of coqui frogs are reported annually in the Park. Detected coqui are either hand-captured, or treated with a field standard 8% to 16% citric acid solution drench, targeting the frog and the area at risk (Pitt and Sin 2004, Sin and Radford 2007). Coqui are also treated in adjacent subdivisions, creating a coqui buffer-zone. Nonnative plants which promote habitat for coqui are removed from certain areas of the Park (Dillman 2010). However, coqui abundance throughout the island, coupled with HAVO's high vehicle traffic and incursion from adjacent residential subdivisions, increases the likelihood of translocating individuals and make coqui frogs an ever-present ecological threat to the Park.

Measures

- Number of frogs reported and removed
- Extent of invasion
- Evidence of reproduction

Reference Condition/Value

Coqui frogs, like other terrestrial amphibians, are not native to HAVO or the Hawaiian Islands. Coqui frogs are not considered completely eradicable from Hawai‘i Island given current methods and monetary resources (Beard et al. 2009). However, the reference condition for this indicator in HAVO is the absence of coqui frogs within the Park boundaries.

Existing Data

The following literature and datasets, specific to HAVO, were used to evaluate this indicator.

- Kraus (2005) surveyed for reptiles and amphibians along accessible roads in HAVO in August and September 2005. He provided a general description of coqui distribution.
- Culbertson (2005) searched for coqui along road-accessible areas within 11 subdivisions, the Park, and the immediate vicinity. The survey was conducted between July 2003 and January 2004.
- Tavares (2006, 2008, 2009) summarized annual coqui data for the 2006, 2008, and 2009 HAVO coqui season, including information on number of frogs reported and removed, as well as data on reproduction. Male coqui seem to call less vigorously and less frequently in cold weather and high wind, so coqui activity, monitoring, and control methods at HAVO and outlying areas occur primarily in the warmer months of April through October. This is referred to as the ‘coqui season’ (Culbertson 2005, Dillman 2012).
- Coqui data (including number of frogs treated and at-large) collected during the HAVO coqui season are summarized in the Park’s Natural Resources Annual Reports for FYs 2009, 2010, 2011, and 2012 (NPS 2010, 2011, 2012, 2013).
- Annual reports by Dillman (2010, 2012) summarize coqui data collected between 2001 and 2012. The data include information on the number of frogs reported/captured/treated/at-large, number of females, and number of eggs. The information is summarized for the Park’s 40 monitoring sites. These sites are primarily located along roadsides and major thoroughfares in mesic/wet forest habitats (Figure 4.7-2). Monitoring is conducted by slowly driving along roadways, and walking trails to listen for males calling (Kim Dillman, Big Island Plants, pers. comm. ~2013).

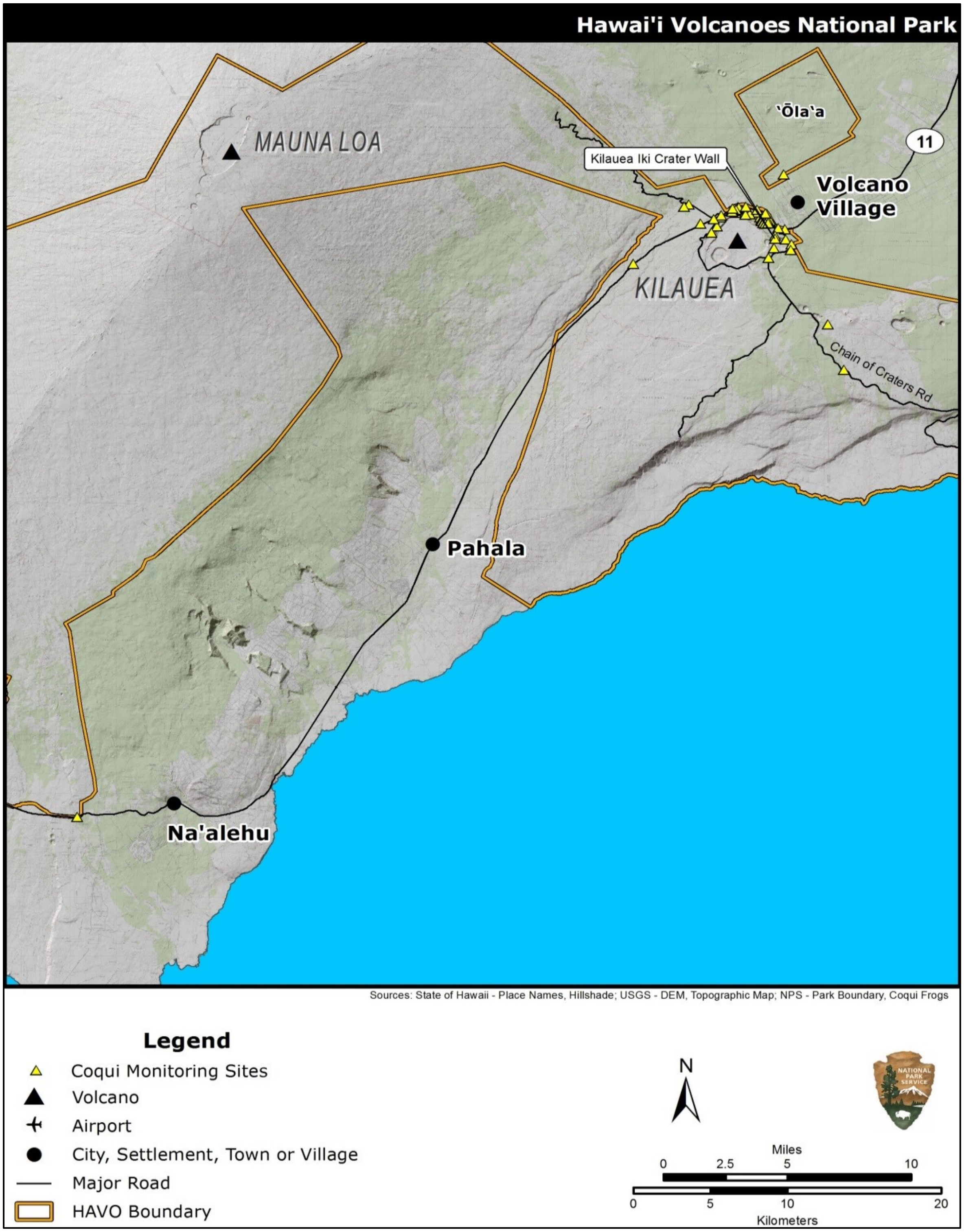

Figure 4.7-2. The location of 40 coqui monitoring sites throughout the Park (Dillman 2012).

Current Condition

Number of Frogs Reported and Removed

The first recorded frogs at HAVO appeared in 2001, near the Park entrance sign. Since the initial sighting, coqui presence has been monitored and reported. From 2001 to 2012, 385 frogs were removed (i.e., captured or treated) from the Park (Dillman 2012). The number of frogs removed at HAVO remained relatively low between 2001 and 2008, with annual frogs removed averaging less than 50 per year. In 2009, the number of frogs removed peaked (n = 128), potentially due to warmer weather, unfavorable control conditions, and greater invasion in the residential communities adjacent to HAVO (NPS 2012). In addition, forty-one frogs were unaccounted for (at-large) that year (Figure 4.7-3).

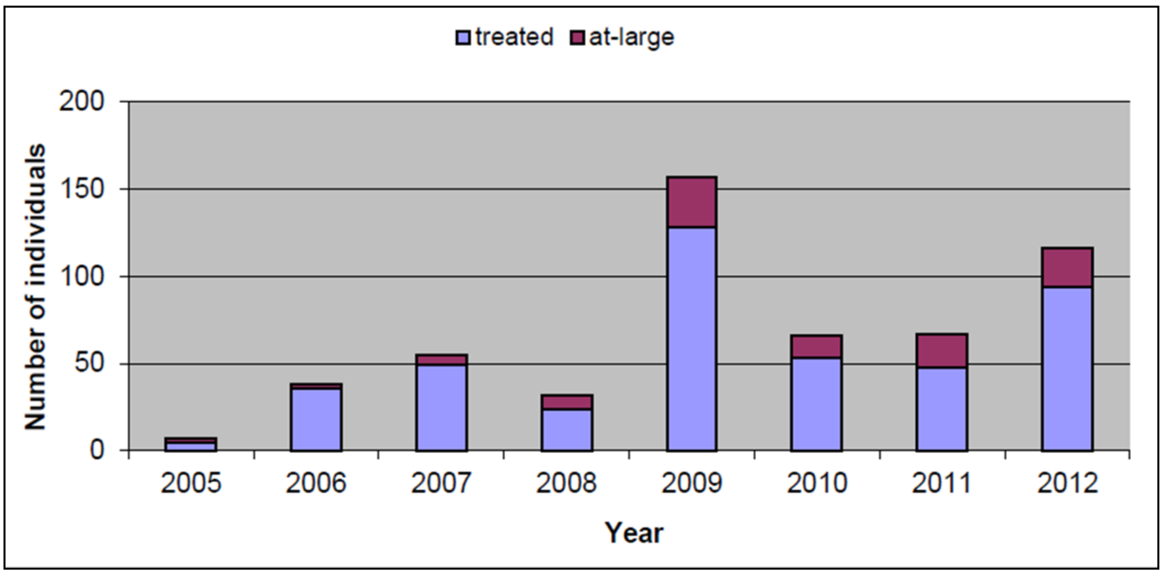

Figure 4.7-3. Number of coqui frogs treated and at-large (not caught or treated) at HAVO between 2005 and 2012 from NPS (2013).

Following the 2009 peak, the annual coqui reports decreased closer to 2007 numbers, but increased again in 2012, with 62 reports, 94 frogs removed, and 22 frogs at-large (Dillman 2012). The decline in 2010 could have been attributed to a severe drought period, during which environmental conditions were unfavorable for detection and conditions may have resulted in increased natural coqui mortality (Dillman 2010). More than half the frogs removed in 2012 were from a steep area along Kīlauea Iki crater wall, suggesting a controlled yet persistent population. Outside the Kīlauea Iki area, frogs were reported around the crater rim drive, primarily in service areas and visitor parking lots along major roads. Most reports occurred within 25 m (82 ft) of a road. Of 40 coqui monitoring sites, only 12 were frog-free in 2012 (Dillman 2012).

Extent of Invasion

Understanding the population distribution of the coqui to vulnerable areas is key to controlling the coqui at HAVO. The primary means of coqui distribution are believed to be anthropogenic; vehicular transport, merchandise including nursery products, and construction material. In most cases, coqui reports occur within 25 m (82 ft) of roadways, service areas, and parking lots near Kīlauea crater (Dillman 2012). The Park's research complex and visitor center have recorded the highest number of reports of all the monitoring sites (Figure 4.7-4). Isolated coqui reports are common along the crater rim drive, at major intersections along Highway 11, and at the visitor areas in the Kīlauea crater section of the Park. The three areas in HAVO with the highest coqui removal numbers are Kīlauea Iki crater wall, the research complex, and the Park's visitor center (Figure 4.7-4).

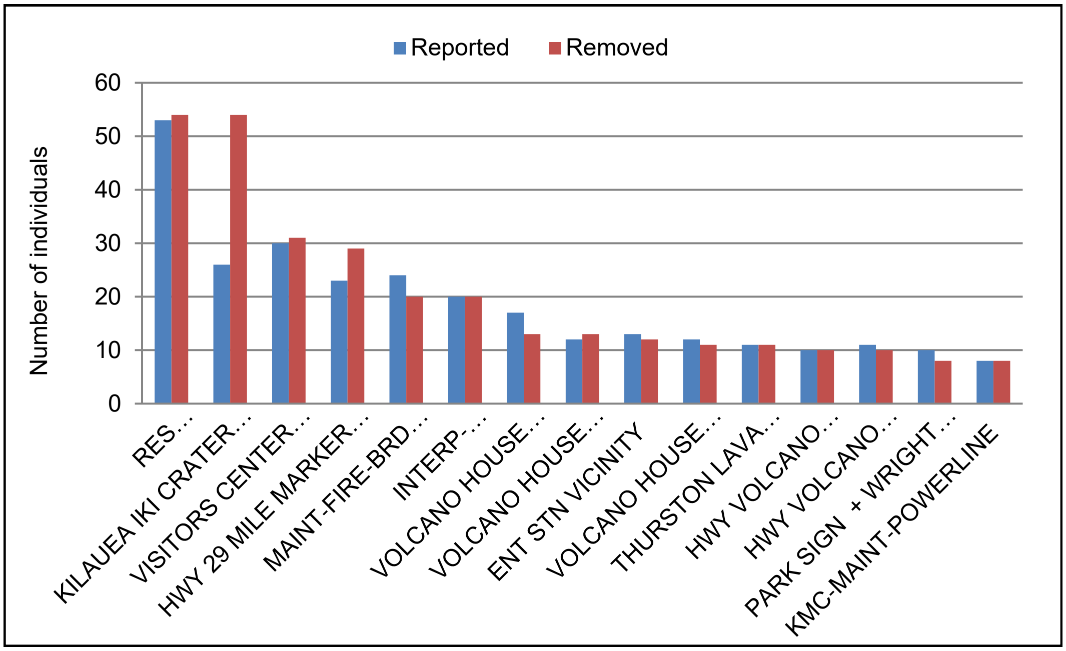

Figure 4.7-4. The cumulative total of coqui detections and removals at the 15 most active coqui monitoring sites at HAVO between 2001 and 2012 (NPS unpublished data 2001 – 2012).

While HAVO coqui are typically reported individually or in small numbers, the most recent coqui survey verified the continued existence of one breeding population at the Northwest Kīlauea Iki crater wall (Figures 4.7-2, 4.7-3). While control methods have been implemented, steep slope and dense vegetation are a contributing factor to the resilience of this population (NPS 2010 unpublished report, Dillman 2012). A second population, located near Highway 11, appears to have been successfully controlled, and reports have decreased since 2009 (NPS 2011 unpublished report, Dillman 2010, 2012).

Coqui distributions in other areas of the Park are limited, or not known to exist. Many areas of the Park are believed to be too dry to sustain coqui frog populations (Kim Dillman, Big Island Plants, pers. comm.). Eight frogs were removed on the Ka'ū/ Kīlauea boundary of the Park in 2008 (Tavares 2008). A single frog was reported in the Kahuku section of HAVO, but escaped capture in 2009 (NPS 2010). There have been limited reports of coqui in these areas, and no established populations have been recorded thus far.

Evidence of Reproduction

HAVO maintains records on numbers of female coqui bearing eggs and egg clutches found in the Park since 2001. Gravid females and egg clutches are used as evidence of reproduction, and can indicate areas with breeding populations. Staff use these data in deciding where to allocate coqui control efforts.

Fifteen female coqui frogs and three egg clutches have been recovered within the Park to date (Figure 4.7-5), including six in 2012 (Dillman 2012). Although no froglets have been found within HAVO boundaries, breeding is assumed to be occurring at least at the Kīlauea Iki site due to the large increase in frogs reported (Dillman 2012).

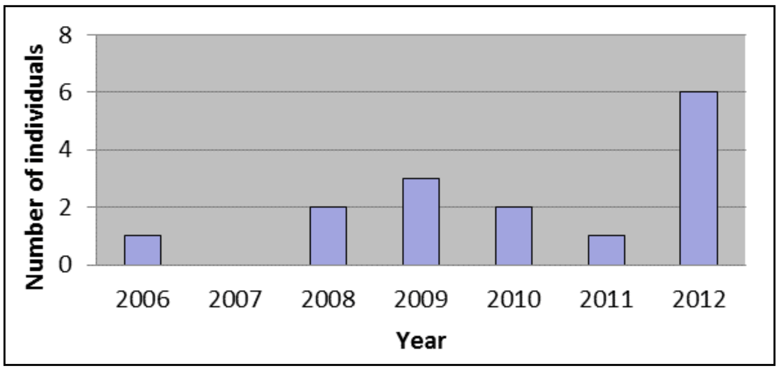

Figure 4.7-5. Number of egg bearing female coqui frogs recovered from HAVO between 2006 and 2012 (Tavares 2006, 2008, 2009, Dillman 2010, 2012).

Threats and Stressors

Because coqui have established in a large portion of Hawai'i Island, and are easily transported through vehicles and other anthropogenic activities, high park visitation rates are threats to increased coqui in HAVO. Growing populations in adjacent residential areas and subsequent dispersal in the Park through vehicles and other anthropogenic means may contribute to increased coqui frogs at HAVO. Annual variations in environmental conditions may favor coqui growth in HAVO. Further, the price of citric acid continues to increase, making widespread applications to control coqui less economically viable (NPS 2010).

Overall Condition

Currently, the condition of coqui at HAVO is moderate with a degrading trend. The most recent coqui survey verified the existence of a breeding population at the northwest Kīlauea Iki crater wall and many frogs remain at-large, even after treatment in 2012. The number of coqui frogs reported in HAVO has increased since the initial sightings in 2001, indicating that the condition is on a degrading trend. While coqui numbers continue to increase, the overall population level is manageable and well below the epidemic levels reported at other locations on Hawai'i Island (Tavares 2008, Beard et al. 2008, Dillman 2012).

Information Gaps/Level of Confidence

Records of coqui in HAVO are well documented; the extent of the knowledge base is ranked as A. Current monitoring methods allow for updated data on a continual basis. Quantitative data on the number of coqui reported and removed are available every year since 2001. Tavares (2006, 2008, 2009) and Dillman (2010, 2012) provide comprehensive reports on coqui seasons 2006–2012. Additional information on coqui numbers are summarized in the Park's annual reports (NPS 2011, 2012). Coqui control events and collection details, including location and statistics, are included in these reports. Data is also provided from outlying areas, including Volcano Village.

Current monitoring is limited to wet and mesic forests adjacent to roadways, parking areas where frogs are more likely to occur, and locations where coqui were previously reported; however, it is probable that coqui occur outside of these areas and the current monitoring program is not detecting the full extent of the frogs. Roadside surveys are limited in that data can only be collected within observational and hearing distance (in the case of males). Exact monitoring locations and monitoring intervals may change annually depending on construction and high-volume traffic areas. This allows for a greater likelihood to hear or observe coqui, but can influence trends in the number of frogs reported, removed, and treated at different sites. The higher detection rate around the visitor center and research complex is likely a function of the area's human use rather than the density of frogs. Further, long-term use of an area can lead to multiple detections of the same individual versus yearly surveys elsewhere.

Subject Matter Experts Consulted

- Kim Dillman, Owner, Big Island Plants.

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4.8. Focal Native Plant Taxa

Background

The Hawaiian Islands have the most endangered species per square mile than anywhere else on the globe, designating the archipelago as the endangered species capital of the world. Plants comprise a large proportion of Hawaiʻi's endangered and threatened species. Currently, 370 Hawaiian plant taxa are federally and state-listed as threatened or endangered and an additional 343 plant taxa are proposed endangered, candidates for listing, or considered SOC by the U.S. Fish and Wildlife Service (USFWS) (Mehrhoff 2013). It is estimated that 110 plant taxa have already gone extinct throughout the Hawaiian Islands and 14 taxa no longer occur in the wild. All together, these taxa represent about half of the native Hawaiian flora (Mehrhoff 2013).

HAVO supports a high proportion of listed, proposed endangered, and candidate taxa, as well as SOC. Sixty-four plants with these designations have previously or are currently known to occur within HAVO (Pratt, Pratt, et al. 2011, Rhonda Loh, Chief of Natural Resources Management, NPS HAVO, pers. comm. 2014). Together, these plants (subsequently referred to as "focal native plant taxa") comprise over 15% of HAVO's vascular flora.

The majority of the focal native plants in HAVO occur in the wet forests or mesic forests (Pratt, Pratt, et al. 2011). However, focal native plants exist in all of the ecological units of the Park. Many rare plants occur in pit craters, or areas protected from ungulates by natural topography. While some of these taxa may naturally be rare throughout the Hawaiian Islands, others are unnaturally rare or declining because of past land use, invasive species, and ongoing disturbance.

Figure 4.8-1. The endangered hāhā (*Cyanea stictophylla*) is among the extant native focal plant taxa at HAVO (Photo: NPS 2009).

Similar to other plants and animals, focal native plants contribute to biological diversity and may provide ecosystem services. These rare plants can be used as key indicators of ecosystem health. A decrease in these species may serve as an early warning of ecosystem degradation (Niemi and McDonald 2004).

Efforts to protect focal native species in HAVO (ungulate control, fencing, weed removal, rare plant propagation) occurred at various times beginning in the 1920s. It wasn't until the 1970's that effective control of ungulates with large-scale fencing began followed by systematic control of nonnative plants in the 1980's and intensification of rare plant recovery in the 1990s. Park managers also began a focused planting program for threatened, endangered, and rare plants during that time.

Restoration and stabilization projects for focal native plants are ongoing. For some species, such as the endangered poʻe, HAVO supports the stateʻs largest known population. HAVO contains one of only three wild populations of MaunaLoa silversword (Pratt, Pratt, et al. 2011). Because of the Park's protected status and wide range of habitats, HAVO offers the best refuge for some of these focal plants to avoid extinction.

Measures

- Number of extirpated taxa
- Number of extant taxa
- Number of individuals/extant taxa
- Number of taxa protected from ungulates
- Natural recruitment of plants

<u>Reference Condition/Value</u>

One of the rare species recovery goals listed in HAVO's Resource Management Plan is to "restore lost biodiversity in Park ecosystems by recovering endangered, threatened, and rare plant and animal species, and by reintroducing locally extirpated species" (NPS 1999). Thus, the reference condition for number of extirpated taxa is zero and the reference condition for number of extant taxa is 56 taxa (i.e., the number of focal native plant taxa that have been recorded to naturally occur within HAVO).

Potential reference conditions for the number of individuals/extant taxa include 1) recovery or delisting criteria established by the USFWS in recovery plans, or 2) stability goals recommended by the Hawaiʻi and Pacific Plants Recovery Coordinating Committee. Both of these criteria are based on attaining a specific number of reproducing or mature individuals within a specified number of populations. Currently, a reference condition for number of individuals does not exist for each focal plant taxa at HAVO. However, a species with a small number of individuals is typically at a greater risk of extinction than a species with more individuals.

Focal rare plants in poor or degraded habitat may be at a greater risk of extinction than those in a more stable or pristine habitat (Elzinga et al. 2001). Because the physical or biological features essential to the survival of the focal plants differ by taxa, it is difficult to generalize high versus poor habitat quality for all of the focal plants in HAVO. One factor that may distinguish poor-quality habitat from high-quality habitat for Hawaiian plants is protection from disturbance (i.e., fire, ungulates, and invasive plants). Ungulates are recognized as a major threat to the survival of native species. Therefore, the reference condition for protection from ungulates is that all focal native individuals are in locations that are protected from ungulates. Other habitat measures, such as abundance of invasive plants in the vicinity, are also important, but are not included in this assessment due to the lack of available data for each focal plant.

Finally, the reference condition for recruitment is that evidence exists that each taxon in the Park is recruiting. Such evidence can include quantitative data or reliable observations.

Existing Data

Numerous rare plant inventories have been conducted throughout the Park. The following literature and datasets were reviewed and used to evaluate the condition of this indicator.

- Higashino et al. (1988) compiled a checklist of all vascular plants observed during surveys conducted in the Park since 1944, including listed and rare plants.
- Between 1993 and 1995, Abbott and Pratt (1996) mapped rare plants in Nāulu Forest and other kīpuka on Hōlei and Poliokeawe Pali. They collected information on population structure, abundance, and threats of these species.
- Systematic rare plants searches were conducted by Pratt and Abbott (1997) in the ʻŌlaʻa tract in 1992 through 1994. Incidental sightings were also recorded from 1995 to 1998.
- Belfield and Pratt (2002) surveyed the montane and subalpine portions of the MaunaLoa Strip in 1992 and 1993 to determine the distribution and status of rare and listed plants.
- In 1994, Pratt et al. (1999) surveyed the flora in the rainforests of Kīlauea's East Rift after construction of a feral pig barrier fence. Rare plants encountered were counted, mapped, and compared to data collected in earlier surveys.
- In the late 1990s, Belfield (1998) surveyed vegetation in three forested craters in the East Rift Zone: Puʻu Huluhulu, Kane Nui O Hamo, and Napau Trail Pit Crater.
- In 2001, Waite and Pratt (2007) inventoried vegetation in the Ōlaʻa Trench, a complex of craters in the remote northeastern portion of the ʻŌlaʻa tract. Data were collected on rare plants encountered during the inventory.
- A checklist of vascular plants was collected for a pit crater in Kahuku in 2006 (Bio et al. 2005 as cited in Benitez et al. 2008).
- Between 2004 and 2006, Benitez et al. (2008) conducted a plant inventory in the Kahuku Unit to identify vegetation communities, rare and listed plants, and disruptive invasive plants. Rare plants were recorded along predetermined transects, in localized habitats, and during aerial searches. Location information was recorded with a GPS unit.
- VanDeMark et al. (2010) studied four rare plant species native to ʻŌlaʻa Forest (haʻiwale [*Cyrtandra giffardii*], many-flowered phyllostegia [*Phyllostegia floribunda*], ʻānunu [*Sicyos alba*], and haʻiwale [*Cyrtandra tintinnabula*]). Information was collected on stand structure, mortality rates, reproductive phenology, fruit production, seed germination rates in the

greenhouse, presence of soil seed bank, role of rodents as seed predators, and survival of both natural and planted seedlings. Haʻiwale (*Cyrtandra tintinnabula*) was not intensively monitored due to its remote locality.

- Pratt et al. (2010) studied five rare or endangered plant species in Kīpuka Puaulu and Kīpuka Kī during a 2-year period to determine their status and limiting factors. The species included hau kuahiwi, mokihana kūkae moa, Zahlbruckner's pelea, kāwaʻu, and large-leaved ʻānunu (*Sicyos macrophyllus*).
- Pratt, VanDeMark, et al. (2011) examined the status and limiting factors of three rare plants (poʻe, ʻōhai, and ʻahakea) in the coastal lowlands and mid-elevation woodlands. The research assessed stand structure, mortality rates, reproductive phenology, fruit production, rodent predation, floral visitor composition, seed germination rates in the greenhouse, and survival.
- Pratt, Pratt, et al. (2011) created a comprehensive handbook that provides detailed descriptions and distribution maps of all rare and listed plants and plant communities within the Park. Much of the information in this report is derived from unpublished Park documents.
- Belfield et al. (2011) conducted and monitored rare plant restoration/stabilization programs in the Park from 1998 through 2010. The report summarizes the results of efforts to stabilize 42 rare plant species across 30 locations within seven ecosystems: coastal strand, lowland dry-mesic forest, mid-elevation woodland and scrub, montane rain forest, montane mesic forest, upper montane, and lower subalpine.
- Two rare plants (*Phyllostegia stachyoides* [no common name] and Hawaiian catchfly [*Silene hawaiiensis*]) were monitored in montane dry communities by Pratt et al. (2012). The research assessed stand structure, mortality rates, reproductive phenology, fruit production, floral visitor composition, seed germination rates in the greenhouse, and survival.
- In 2012, USFWS released a 5-year review for several listed species including ʻānunu (*Sicyos alba*). These reviews discuss population size at the different occurrences such as the Park (USFWS 2012a).
- In 2012, USFWS published a proposed rule to list several plant species as endangered and designate critical habitat for three plants. Five of the plants in the proposed rule occur within HAVO. The rule contains information on locations and population sizes (USFWS 2012b).

<u>Current Condition</u>

Number of Extirpated Taxa

Nine focal plant taxa that naturally occurred at HAVO are likely to be extirpated from the Park or have not been recently re-sighted (Table 4.8-1). This comprises about 16% of HAVO's naturally occurring focal rare plant taxa. The majority of these plants occur elsewhere in the Hawaiian Islands, but one species—hōlei (*Ochrosia kilaueaensis*)—is possibly extinct. In addition, two species that were previously planted in HAVO, but not known to historically occur in HAVO, have also disappeared within the Park (Pratt, Pratt, et al. 2011).

Table 4.8-1. Focal native plant taxa that have been extirpated from the Park or have not been recently re-sighted (Pratt, Pratt, et al. 2011).

Scientific Name	Common Name	Status[1]
Adenophorus periens[2]	Palai lāʻau, pendant kihi fern	E
Argyroxiphium sandwicense ssp. sandwicense[2]	ʻAhinahina, MaunaKea silversword	E[3]
Asplenium schizophyllum[2]	–	SOC
Capparis sandwichiana	Maipilo	SOC
Joinvillea ascendens ssp. ascendens[2]	ʻOhe	C
Liparis hawaiensis[2]	ʻAwapuhi a kanaloa	SOC
Mezoneuron kavaiense	Uhiuhi	E[3]
Ochrosia kilaueaensis	Hōlei	E
Phyllostegia velutina[2]	–	E
Portulaca villosa	ʻIhi	SOC
Zanthoxylum hawaiiense	Aʻe, Hawaiʻi pricklyash	E

[1] E = endangered, C = candidate for listing, SOC = Species of Concern

[2] Species that require additional surveys

[3] Historically not known to naturally occur in HAVO.

Number of Extant Taxa

Forty-seven focal native plant taxa that are known to have naturally occurred in the Park are still extant in HAVO. Of these, 39 taxa have wild individuals. Eight focal native plant taxa only persist in the Park as plantings because wild populations that previously occurred in the Park were eliminated (Table 4.8-2). An additional five plant species are currently extant as plantings, but are not known to have naturally occurred within the Park boundaries. For some of these planted species, HAVO may be outside their natural range (Pratt, Pratt, et al. 2011).

Table 4.8-2. Focal native plant taxa that persist only as plantings in the Park.

Scientific Name	Common Name	Status[1]
Argyroxiphium sandwicense ssp. *macrocephalum*	ʻAhinahina, Haleakalā silversword,	T[2]
Clermontia peleana	ʻOhā wai, Pele's ʻōhā	E
Haplostachys haplostachya	Honohono	E[2]
Hibiscadelphus giffardianus	Hau kuahiwi	E
Hibiscus brackenridgei subsp. brackenridgei	Maʻo hau hele	E[2]
Ischaemum byrone	Hilo ischaemum	E
Kokia drynarioides	Kokiʻo	E[2]
Neraudia ovata	Maʻaloa	E
Nothocestrum breviflorum	ʻAiea	E
Ochrosia haleakalae	Hōlei	C[2]

[1] E = endangered, C = candidate for listing, SOC = Species of Concern

[2] Historically not known to naturally occur in HAVO.

Table 4.8-2 (continued). Focal native plant taxa that persist only as plantings in the Park.

Scientific Name	Common Name	Status[1]
Pritchardia affinis	Loulu	E
Schiedea diffusa subsp. macraei	–	E
Stenogyne angustifolia	–	E

[1] E = endangered, C = candidate for listing, SOC = Species of Concern

[2] Historically not known to naturally occur in HAVO.

Of the extant taxa that are known to have naturally occurred in the Park, 25 taxa (53%) are endangered, one species (2%) is threatened, two species (4%) are candidates for listing, and 19 species (40%) are SOC.

Number of Individuals/Extant Taxa

Of the extant native plant taxa that are known to have naturally occurred in the HAVO, 29 taxa (62%) are believed to have 10 or fewer wild individuals within the Park boundaries (Table 4.8-3). By contrast, only two species have more than 1,000 wild individuals within the Park: the Hawaiian catchfly and mau‘u lā‘ili (*Sisyrinchium acre*). If planted individuals are included, the number of taxa with 10 or fewer individuals decreases to nine taxa, or just over 9% of the extant focal plant taxa that are known to have naturally occurred in HAVO (Table 4.8-3).

Table 4.8-3. Extant focal native plant taxa and estimated number of wild and wild + planted individuals. Sources: Benitez et al. 2008, VanDeMark et al. 2010, Pratt et al. 2010, Pratt, VanDeMark, et al. 2011, Pratt, Pratt, et al. 2011, Pratt et al. 2012, Belfield et al. 2011, USFWS 2012a, USFWS 2012b, Sierra McDaniel, Botanist, NPS HAVO, pers. comm. (2014).

Scientific Name	Common Name	Status[1]	Estimated Number of Individuals	
			Wild	Wild + Planted
Alphitonia ponderosa	Kauila, kauwila	SOC	1–10	11–50
Anoectochilus sandvicensis	Jewel orchid	SOC	1–10	51–100
Argyroxiphium kauense	Mauna Loa silversword	E	501–1,000	>1,000
Argyroxiphium sandwicense ssp. *macrocephalum* [2]	‘ahinahina, Haleakalā silversword	T	0	1–10
Asplenium peruvianum var. *insulare*	–	E	Unknown[3]	0
Bobea timonioides	‘Ahakea	SOC	11–50	11–50
Clermontia lindseyana	‘Ohā wai, Lindsey’s ‘ōhā	E	11–50	101–500
Clermontia peleana	‘Ohā wai, Pele’s ‘ōhā	E	0	101–500
Cyanea shipmanii	Hāhā	E	0	101–500

[1] E = endangered, C = candidate for listing, T = threatened, PE = proposed endangered, SOC = Species of Concern.

[2] Historically not known to naturally occur in HAVO.

[3] Due to growth habit of this species it is not possible to determine number of individuals at each site.

Table 4.8-3 (continued). Extant focal native plant taxa and estimated number of wild and wild + planted individuals. Sources: Benitez et al. 2008, VanDeMark et al. 2010, Pratt et al. 2010, Pratt, VanDeMark, et al. 2011, Pratt, Pratt, et al. 2011, Pratt et al. 2012, Belfield et al. 2011, USFWS 2012a, USFWS 2012b, Sierra McDaniel, Botanist, NPS HAVO, pers. comm. (2014).

Scientific Name	Common Name	Status[1]	Estimated Number of Individuals	
			Wild	Wild + Planted
Cyanea stictophylla	Hāhā, haʻiwale, kanawao keʻokeʻo	E	1–10	1–10
Cyanea tritomantha	ʻAkū	E	11–50	11–50
Cyrtandra giffardii	Haʻiwale	E	11–50	51–100
Cyrtandra menziesii	Haʻiwale	SOC	51–100	51–100
Cyrtandra tintinnabula	Haʻiwale	E	11–50	11–50
Embelia pacifica	Kilioe	SOC	1–10	11–50
Eurya sandwicensis	Anini	SOC	1–10	1–10
Exocarpos gaudichaudii	Hulumoa, kaumahana	SOC	1–10	1–10
Fimbristylis hawaiiensis	Hawaiian fringed sedge	SOC	101–500	101–500
Fragaria chiloensis subsp. *sandwicensis*	ʻOhelo papa	SOC	501–1,000	501–1,000
Haplostachys haplostachya [2]	Honohono	E	0	1–10
Hibiscadelphus giffardianus	Hau kuahiwi	E	0	101–500
Hibiscus brackenridgei subsp. *brackenridgei* [2]	Maʻo hau hele	E	0	1–10
Ischaemum byrone	Hilo ischaemum	E	0	11–50
Kokia drynarioides [2]	Kokiʻo	E	0	1–10
Melicope hawaiensis	Mokihana kūkae moa, manena, alani	SOC	101–500	101–500
Melicope zahlbruckneri	Zahlbruckner's pelea, alani	E	11–50	11–50
Neraudia ovata	Maʻaloa	E	0	51–100
Phyllostegia stachyoides	–	SOC	51–100	51–100
Pittosporum hawaiiense	Hōʻawa	E	51–100	51–100
Plantago hawaiensis	Laukahi kuahiwi	E	51–100	101–500
Pleomele hawaiiensis	Hawaiʻi hala pepe	E	11–50	101–500
Polyscias sandwicensis	ʻOhe, ʻohe kukuluaeʻo, ʻohe makai	SOC	1–10	51–100
Portulaca sclerocarpa	Poʻe, ʻihi mākole	E	101–500	101–500
Pritchardia affinis	Loulu	E	0	11–50
Ranunculus hawaiensis	Makou, large-flower native buttercup	C	1–10	11–50

[1] E = endangered, C = candidate for listing, T = threatened, PE = proposed endangered, SOC = Species of Concern.

[2] Historically not known to naturally occur in HAVO.

[3] Due to growth habit of this species it is not possible to determine number of individuals at each site.

Table 4.8-3 (continued). Extant focal native plant taxa and estimated number of wild and wild + planted individuals. Sources: Benitez et al. 2008, VanDeMark et al. 2010, Pratt et al. 2010, Pratt, VanDeMark, et al. 2011, Pratt, Pratt, et al. 2011, Pratt et al. 2012, Belfield et al. 2011, USFWS 2012a, USFWS 2012b, Sierra McDaniel, Botanist, NPS HAVO, pers. comm. (2014).

Scientific Name	Common Name	Status[1]	Estimated Number of Individuals	
			Wild	Wild + Planted
Rubus macraei	‘Akala	SOC	11-–50	11–50
Sanicula sandwicensis	Snakeroot	SOC	11–50	11–50
Scaevola kilaueae	Huahekili uka,Kīlauea Naupaka, naupaka kuahiwi	SOC	101–500	101–500
Schiedea diffusa subsp. *macraei*	–	E	0	11–50
Sesbania tomentosa	‘Ohai	E	101–500	101–500
Sicyos alba	‘Anunu; white-bur cucumber	E	1–10	1–10
Sicyos macrophyllus	Large-leaved ‘ānunu, large leaf bur cucumber	C	1–10	1–10
Silene hawaiiensis	Hawaiian catchfly	T	>1,000	>1,000
Sisyrinchium acre	Mau‘u lā‘ili, mau‘u hō‘ula ‘ili	SOC	>1,000	>1,000
Spermolepis hawaiiensis	–	E	1–10	1–10
Stenogyne angustifolia	–	E	0	1–10
Stenogyne macrantha	–	SOC	11–50	11–50
Trematolobelia wimmeri	Koli‘i	SOC	101–500	101–500
Zanthoxylum dipetalum var. *dipetalum*	Kāwa‘u	SOC	51–100	51–100

[1] E = endangered, C = candidate for listing, T = threatened, PE = proposed endangered, SOC = Species of Concern.

[2] Historically not known to naturally occur in HAVO.

[3] Due to growth habit of this species it is not possible to determine number of individuals at each site.

Although continuous monitoring has not been conducted for many focal plant taxa, recent studies and surveys suggest that many species are declining in numbers despite conservation efforts in the Park. For example, Mauna Loa silversword is one of the few species with high numbers of wild individuals, with an estimated 730 individuals. However, surveys in the 1970s found more MaunaLoa silversword individuals than were recently reported (Benitez et al. 2008). Several focal plant species previously recorded in Kahuku were also not observed in the 2004 through 2006 surveys (Benitez et al. 2008), or in more recent follow-up surveys (Sierra McDaniel, Botanist, NPS HAVO, pers. comm).

Pratt et al. (2012) noted that one population of Hawaiian catchfly appeared to be declining. ‘Ahakea individuals were covered by lava during flows in the last two decades and this species has been reported as declining since 1973 (Pratt, VanDeMark, et al. 2011). Pratt, VanDeMark, et al. (2011) also saw evidence of decline of po‘e and ‘ōhai in HAVO. Recent studies of mokihana kūkae moa, Zahlbruckner's pelea, and kāwaʻu provide evidence that populations of all three of these species have decreased since earlier surveys (Pratt et al. 2010). Although some focal taxa at HAVO may be exhibiting low or declining numbers, for some species HAVO may represent the most populous and best protected site within the Hawaiian Islands (Pratt et al. 2010).

Number of Taxa Protected from Ungulates

At HAVO, many sites containing rare focal plants have been fenced to exclude ungulates, especially in the older sections of the Park (MaunaLoa, ʻŌlaʻa, Kīlauea). For example, feral pigs have been removed from four of five management units in the ʻŌlaʻa Tract, where many of the focal plants occur (Pratt, Pratt, et al. 2011). Kīpuka Kī and Kīpuka Puaulu are also free of feral ungulates. Fencing in the Kahuku Unit is being planned or currently underway. Other sites are naturally protected from ungulates by steep topography or the plant's growth habit.

Of the extant focal native plant taxa in HAVO, five taxa are reported to occur in sites that have no protection from ungulates. These taxa include Lindsey's ʻōhā (*Clermontia lindseyana*), hōʻawa (*Pittosporum hawaiiense*), makou *(Ranunculus hawaiensis*), ʻōhelo papa (*Fragaria chiloensis subsp. sandwicensis*), and snakeroot (*Sanicula sandwicensis*) (Pratt, Pratt, et al. 2011). Roughly 22 taxa are partially protected from ungulates, meaning that part of their distribution is protected, or populations are only protected from a subset of ungulates (i.e., goats, but not pigs) (Pratt, Pratt, et al. 2011, NPS 2013).

Evidence of Natural Recruitment of Plants

Few focal plant taxa that have been closely monitored have shown evidence of natural recruitment of plants in the field. Of the three species intensively monitored by VanDeMark et al. (2010) natural seedling recruitment was observed for two species: many-flowered phyllostegia and ānunu (*Sicyos alba*). Haʻiwale (*Cyrtandra tintinnabula*) also appears to have a viable, reproducing population with numerous individuals of several size classes (Waite and Pratt 2007, VanDeMark et al. 2010). The four naturally occurring focal plant taxa studied by Pratt et al. (2010) were also found to have low or non-existent seedling recruitment. All three of the focal plants monitored by Pratt, VanDeMark, et al. (2011) were determined to lack natural seedling recruitment and establishment. Of the two montane dry species studied by Pratt et al. (2012), *Phyllostegia stachyoides* showed recruitment of seedlings, while the recruitment of Hawaiian catchfly was low.

Threats and Stressors

Many Hawaiian plants are highly vulnerable because multiple stressors impact them simultaneously. Threats and stressors to focal native plants in HAVO include ungulates, invasive plants, diseases and pathogens, fires, lava flows, rodents, lack of pollinators and dispersers, and invasive invertebrates (Pratt et al. 2006).

Although ungulates have been fenced out of many areas, not all focal plants receive protection from these animals. For example, many plants occur in un-fenced areas in Kahuku, lowland areas in Kīlauea, and portions of ʻŌlaʻa. Fruit predation and bark-stripping by rodents have been observed on numerous rare plants in the Park or in other areas of Hawaiʻi (Pratt, Pratt, et al. 2011, Shiels 2010, Shiels and Drake 2011) and control of these small mammals is often difficult and expensive. Rare

Hawaiian plants are often vulnerable to introduced invertebrates, diseases, or pathogens (Dean 2006) or lack effective pollinators or native frugivores to disperse propagules (Foster and Robinson 2007). Nonnative plants can invade large areas and out-compete focal native plants or alter habitat. Fire is also a threat to many taxa, particular those within the Mid-elevation Seasonal and Coastal Lowland ecological units (NPS 2013). Finally, the small population sizes and distribution of these taxa make many susceptible to local extirpation due to volcanic eruptions, lava flows, chance demographic or environmental fluctuations (NPS 1999).

Climate change is also an important future threat to these species. Shifts in temperature and precipitation have the potential to alter these species ranges, phenology, and various ecosystem processes (Walther et al. 2002, Parmesan and Matthews 2006).

Finally, HAVO is a popular tourist attraction and high visitor rates have the potential to stress rare species without proper management. Managers at HAVO occasionally restrict access to areas containing rare plants to protect focal native taxa (Figure 4.8-2).

Figure 4.8-2. The MaunaLoa silversword exclosure occasionally closes to visitors to protect this focal native plant (Photo: Tiffany Agostini 2012).

<u>Overall Condition</u>

Data suggest that the overall condition of HAVO's focal native plant taxa is of concern. Of the 56 taxa that have been recorded to naturally occur, nine taxa have been extirpated. Many of the extant taxa have fewer than 10 wild individuals in the Park and recent studies and surveys suggest that numbers of individuals are declining for numerous taxa. Few focal native plant taxa are completely protected from ungulates and very few have been reported to have natural recruitment.

Information Gaps/Level of Confidence

Collecting data on rare species is often difficult and requires extensive resources (Niemi and McDonald 2004). Despite these challenges, the knowledge base of this indicator is relatively strong for many taxa due to recent surveys, studies, and published documents involving rare plants. The rare and endangered species handbook by Pratt, Pratt, et al. (2011) provides an exceptional summary on HAVO's focal plant taxa, including rough taxa distribution maps and occasional estimates on the number of individuals within the Park. However, some of the information is likely based on older surveys. The extent of knowledge for this indicator is ranked B.

The focused monitoring studies conducted to investigate the factors causing the rarity and decline of several taxa (VanDeMark et al. 2010, Pratt et al. 2010, Pratt, VanDeMark, et al. 2011, Pratt et al. 2012) offer valuable data on the current condition of those taxa. Similar monitoring studies on other focal plants in HAVO would be useful to help determine the condition and best management strategies for these species. A consistent monitoring scheme for focal plants would be beneficial to identify overall trends in the Park.

Some uncertainty exists regarding the estimates of individuals because many taxa have not been monitored in decades (Sierra McDaniel, Botanist, NPS HAVO, pers. comm.). Some estimates may include seedlings and recent recruits. There is a high likelihood of seasonal and annual fluctuations in numbers.

Additionally, the Kahuku unit may contain more focal species than seen in the recent survey. As stated by the authors, due to the distances between transect survey lines, large areas of the Kahuku Unit were excluded from sampling and the possibility of observing additional rare species remains (Benitez et al. 2008).

Subject Matter Experts Consulted

- Rhonda Loh, Chief of Natural Resources Management, NPS HAVO
- Sierra McDaniel, Botanist, NPS

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4.9. Wet Forest Plant Communities

Background

Hawaiian wet forests typically occur on windward aspects receiving a mean annual rainfall above 2,500 mm (98 in) (Gagné and Cuddihy 1999).Wet forests also encompass cloud forests, which may record less rainfall, but regularly receive a substantial amount of additional precipitation from fog drip due to high cloud frequency (Mueller-Dombois and Fosberg 1998). The boundary of wet forests is often difficult to delineate because wet forests often grade into mesic forests. Consequently, wet forest and transitional mesic-wet forests discussed in this section are treated as wet forest. Compared to other plant communities, these forests in the PACN represent the largest relatively intact land areas (Ainsworth et al. 2011).

The majority of HAVO's wet forests occur in the eastern region of the Park due to wetter conditions generated by orographic rainfall and fog drip. Wet forests occur in the Kīlauea section along the eastern rim of the summit caldera of Kīlauea Volcano and along the East Rift zone of Kīlauea above approximately 700 m (2,300 ft). The entire ʻŌlaʻa section is vegetated with montane wet forest plant communities. In the Kahuku section, wet forests are found above the Kaʻū Forest Reserve, on the eastern edge of the pastures between 914 and 1,524 m (3,000–5,000 ft) elevation, and in pit craters (Figure 4.9-1).

Figure 4.9-1. Unnamed pit crater with wet forest vegetation in the pastures region of the Kahuku section (NPS photo).

Measures

- Native species richness
- Percent cover of native species
- Presence and abundance of listed species/SOC
- Number and distribution of invasive target plant species
- Percent of area protected from ungulates

Two major plant communities occur in HAVO's wet forests: tree fern or hāpu‘u forests and uluhe fern forests (Pratt and Abbott 1997, NPS 2013). Tree fern forests are multi-layered and dominated by ‘ōhi‘a and a diversity of tree ferns. Uluhe fern forests are characterized by a dense mat-like cover of uluhe climbing over trees and shrubs and are common in early successional communities on younger lava flows (NPS 2013). Open wet ‘ōhi‘a forests have also been identified within HAVO (Waite and Pratt 2007).

In general, wet forests in HAVO are highly diverse compared to other plant communities. In addition to supporting many endangered, threatened, and rare plant species (Pratt et al. 2011), wet forests in HAVO contain epiphytes, as well as lichens and mosses (Cuddihy et al. 1986, Waite 2007). Wet forests also play a large role in capturing rain water and are therefore important for groundwater recharge and watershed integrity (Sailer 2006).

Wet forest plant communities at HAVO have been identified as important focal plant communities due to their "relative intactness, high species diversity, and usefulness as indicators of ecosystem change" (Ainsworth et al. 2011). As a result, these communities have been selected for future monitoring at HAVO by the PACN I&M program. Nearly 10,050 ha (24,830 ac) of wet forests will be monitored in the Park (Figure 4.9-2).

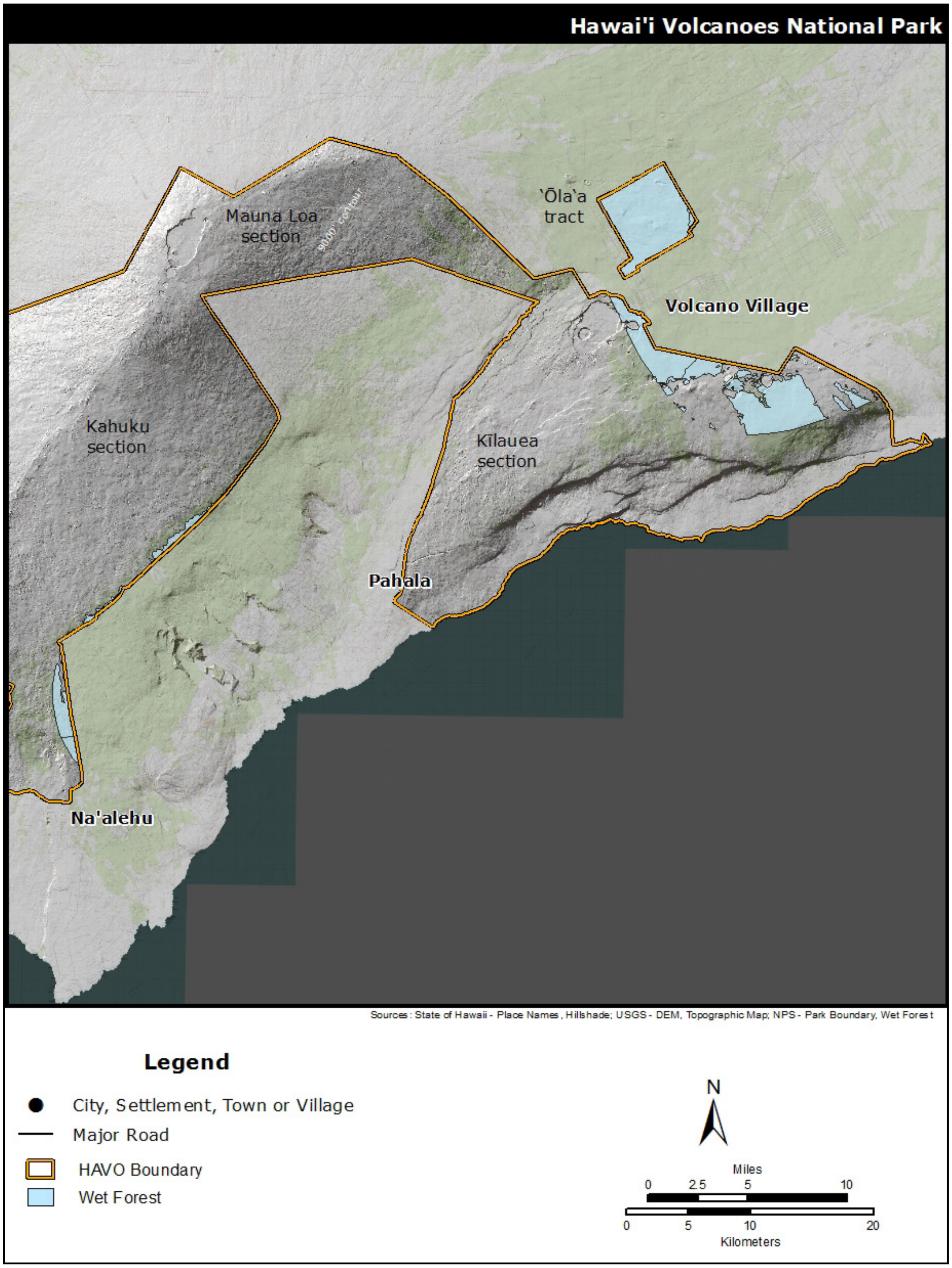

Figure 4.9-2. Wet forests in HAVO that will be sampled by the PACN I&M program from Ainsworth et al. (2011).

Reference Condition/Value

Native species richness, or the number of different native species, in Hawaiian lowland wet forests (<800 m [2,625 ft]) have been noted as being roughly the same as nonnative species richness primarily due to vulnerability of nonnative species invasions (Wagner et al. 1999, Zimmerman et al.

2008). Greater diversity occurs in the higher elevation wet forests on Hawai‘i where Mueller-Dombois and Fosberg (1998) reported 11 native tree taxa, 14 native shrub taxa, and numerous native ferns and epiphytes. The reference condition for native species richness within HAVO's wet forest plant communities is that the number of native species exceeds the number of nonnative species.

A reference condition for percent cover of native species in wet forests is not provided because a single value cannot represent an acceptable condition for all forests; however, a high percentage of native species compared to nonnative species is considered a preferable condition. The reference condition for listed species/SOC is that none of these species historically recorded in the wet forest plant communities at HAVO have been extirpated and the number of individuals remain in the range historically reported.

Two of the greatest threats to native plant communities in Hawai‘i are invasive plants and invasive ungulates. Roughly 134 plant species are considered invasive and highly disruptive to native ecosystems in HAVO (Benitez et al. 2012). Intensive invasive plant control occurs in five montane wet forest SEAs; long-term data sets are available for three of them. The reference condition for invasive species abundance in these SEAs is low abundance (<1% crown cover) or low density (100 individuals/ha). For the wet forests outside of the SEAs, a reference condition for the number and distribution of invasive species is not defined at this time. The reference condition for percent protected from ungulates is 100% exclusion.

Existing Data

The following resources were used to assess the wet forest plant communities.

- In the late 1970s, Mueller-Dombois (1977) investigated ‘ōhi‘a dieback and assessed floristic diversity and structure within the ‘Ōla‘a section and in adjacent wet forests. Four 400-m^2 (4,305-ft^2) areas were sampled in the ‘Ōla‘a tract.
- Katahira (1980) sampled vegetation along transects in the East Rift zone in the Kīlauea section in 1979 and 1980 to assess the impact of feral pigs. These data were compared with vegetation data collected in the same locations in 1975 through 1978.
- In the early 1980s, Cuddihy et al. (1986) sampled vegetation parameters at seven wet forest sites in Kīlauea's East Rift. This survey was conducted to collect baseline vegetation conditions in the event that a geothermal development begins in nearby Kahauale‘a.
- Higashino et al. (1988) provided a checklist of vascular plants observed during surveys conducted in the Park since 1944. Species found within the rainforests (i.e., wet forests) were noted.
- Between 1983 and 1985, Tunison et al. (1992) mapped select invasive plants throughout the Park. This included specific information on the montane rainforest.
- Systematic rare plants searches were conducted by Pratt and Abbott (1997) in the ‘Ōla‘a tract in 1992 through 1994. Incidental sightings were also recorded from 1995 to 1998.

- In the late 1990s, Belfield (1998) surveyed for pig activity and vegetation in three forested craters in the East Rift Zone: Pu‘u Huluhulu, Kāne Nui O Hamo, and Nāpau Trail Pit Crater. Vegetation in these craters is classified as montane rainforest.
- Loh collected vegetation data in ‘Ōla‘a in 1994 and 1997. These data are unpublished, but are summarized in Ainsworth et al. (2011).
- Loh and Tunison (1999) monitored changes in vegetation following pig removal in the ‘Ōla‘a-Koa Unit between 1990 and 1998. This 1,024-ha (2,530-ac) unit is classified as ‘ōhi‘a/hāpu‘u montane wet forest.
- In 1994, Pratt et al. (1999) collected vegetation data in the rainforests of Kīlauea’s East Rift after construction of a feral pig barrier fence and developed distribution maps of rare and invasive plant species. Results were compared to an earlier survey conducted in 1988.
- Waite and Pratt (2007) surveyed the Ōla‘a Trench, a series of craters in the remote northeastern quarter of Ōla‘a, in 2001.
- Between 2004 and 2006, Benitez et al. (2008) inventoried the vegetation within the Kahuku Unit (including the wet forests) using transects, plots, and helicopter surveys. GIS data points of invasive plants found along transects were also provided.
- Belfield et al. (2011) implemented a rare plant stabilization program throughout HAVO, which included planting 11 rare species in the Ōla‘a wet forests.
- VanDeMark et al. (2010) studied four rare plant species native to ‘Ōla‘a Forest (ha‘iwale [*Cyrtandra giffardii*], many-flowered phyllostegia, ‘ānunu [*Sicyos alba*], and ha‘iwale [*Cyrtandra tintinnabula*]). Information was collected on stand structure, mortality rates, reproductive phenology, fruit production, seed germination rates in the greenhouse, presence of soil seed bank, role of rodents as seed predators, and survival of both natural and planted seedlings. Ha‘iwale (*Cyrtandra tintinnabula*) was not intensively monitored due to its remote locality.
- Ainsworth et al. (2011) discusses the wet forests of HAVO and shows the extent of the sampling frames in these forests, which are the portions of the community that will be monitored in the future. The geographical extent of this community was determined based on median annual rainfall, potential evapotranspiration, and substrate rather than current vegetation. This report also provides summaries of unpublished vegetation data collected in wet forests in 1994, 1997, and 1998.
- Benitez et al. (2012) recorded invasive plants within the MaunaLoa, Kīlauea, and ‘Ōla‘a sections of the Park between 2000 and 2010. Distributions of 134 nonnative plants were quantified and provided in a geodatabase by projecting point features or drawing a polygon around all confirmed point locations and incidental field observations. Comparisons to previous surveys are provided to evaluate changes in distributions.
- Cole et al. (2012) monitored native and nonnative understory vegetation in the ‘Ōla‘a-Koa unit in 1994 and 16 years later in 2010. Ten plots were surveyed to determine differences between fenced (pig-free) vs. unfenced (pig-present) areas.

- Scheffler et al. (2012) measured percent cover and species richness in six monitoring plots in the ‘Ōla‘a Forest in 1997 and 2003. This study was conducted to examine pig impacts on vegetation. Data for the ‘Ōla‘a Forest are combined with data from the Pu‘u Maka‘ala Natural Area Reserve.
- In 2013, the Park released a Final Plan / Environmental Impact Statement for Protecting and Restoring Native Ecosystems by Managing Non-native Ungulates (NPS 2013), which provided the most current information on ungulate abundance in the Park.

Loh et al. (2014) discusses control of select invasive plants at three montane wet forest SEAs.

Current Condition

The various wet forests in HAVO are not homogenous, but rather divided into different management units resulting in a mosaic of different conditions. Thus, information is often broken up into the three sections containing these forests: ‘Ōla‘a, Kīlauea, and Kahuku.

Native Species Richness

In 1988, Higashino et al. (1988) reported that there were 203 native plant species and 151 nonnative plant species in the rainforests of HAVO. This survey did not include Kahuku because it was not a part of the Park at that time. Over 80% of the native species were endemic to the Hawaiian Islands. During the time of the survey, the rainforests supported the highest number of native plant species compared to any other habitat or zone within the Park. In contrast, roughly 24% of the nonnative species recorded in HAVO at that time occurred in the rainforest. Only the submontane seasonal habitat had a higher percentage of nonnative plant species (~38%) than the rainforests during the survey by Higashino et al. (1988).

‘Ōla‘a

The ‘Ōla‘a section in HAVO is often noted as having “some of the highest native plant diversity contained within the Park” (VanDeMark et al. 2010). Muller-Dombois (1977) recorded between 40 and 54 native plant species within the ‘Ōla‘a survey areas. Much fewer nonnative species (0–4 species) were detected in these areas (Table 4.9-1). The Ōla‘a survey areas had roughly similar native and nonnative species richness compared to other wet forests surveyed by Muller-Dombois in the vicinity of the Park.

Table 4.9-1. Native species and nonnative species richness during various surveys conducted in HAVO’s wet forests.

Year	Location	Native Species Richness	Nonnative Species Richness	Source
1970s	‘Ōla‘a	40–54	0–4	Mueller-Dombois 1977
1994	‘Ōla'a	18.4 (mean)[1]	3.7(mean)*	Ainsworth et al. 2011
1997	‘Ōla‘a	24.1 (mean)[1]	3.3(mean)*	Ainsworth et al. 2011
1998	‘Ōla‘a	22.2 (mean)[1]	4.3(mean)*	Ainsworth et al. 2011
2001	‘Ōla‘a	97	34	Waite and Pratt 2007

* Mean Species Richness in 10 x 10 m plots; all other data are total number of species found across the area.

Table 4.9-1 (continued). Native species and nonnative species richness during various surveys conducted in HAVO's wet forests.

Year	Location	Native Species Richness	Nonnative Species Richness	Source
2010	ʻŌlaʻa	33	7	Cole et al. 2012
1980s	Kīlauea	61–89	14–31	Cuddihy et al. 1986
1990s	Kīlauea	88	21	Belfield 1998
1994	Kīlauea	>35	48	Pratt et al. 1999

* Mean Species Richness in 10 x 10 m plots; all other data are total number of species found across the area.

In 1994, mean native species richness determined in 10 x 10 m plots in ʻŌlaʻa was 18.4, while mean nonnative species richness was 3.7. Three years later mean native and nonnative species richness were 24.1 and 3.3, respectively (Table 4.9-1). In 1998, mean native species richness in ʻŌlaʻa decreased to 22.2 and nonnative species richness increased to 4.3 (Ainsworth et al. 2011).

In the Ōlaʻa Trench, native species (97 species) were more rich than nonnative species (34 species) (Table 4.9-1). Native species comprised 74% of all species observed in the trench. The upper canopy is largely dominated by native plants, while the ground cover is primarily nonnative species (Waite and Pratt 2007).

Most recently, Cole et al. (2012) documented 33 native species in the ʻŌlaʻa-Koa unit an areas where nonnative pigs had been excluded for 16 years (Table 4.9-1). These species represented nearly 83% of the species found in the survey. Roughly 18 woody native species and 15 native ferns or herbs were recorded. Natives dominated the overstory vegetation in the unit (Cole et al. 2012).

Kīlauea

Within the seven wet forest sites surveyed by Cuddihy et al. (1986), native species richness ranged from 61 to 89 (mean of 83.4). Between 14 and 31 nonnative species were documented at the sites (Table 4.9-1). In the late 1990s, Belfield (1998) found 88 native plants in the three East Rift rainforest craters: Puʻu Huluhulu, Kāne Nui O Hamo, and Nāpua Trail Pit Crater (Table 4.9-1). Nonnative species comprised less than 20% of the flora in these areas (Belfield 1998). Forty-seven nonnative species were found by Pratt et al. (1999) in the East Rift area in 1994 (Table 4.9-1). Although the total number of native plants was not reported, at least 35 were noted in the report.

Kahuku

The number of native and nonnative species documented within Kahuku's wet forest is not known. However, native plants comprised 41% of the total flora at Kahuku (Benitez et al. 2008).

Percent Cover of Native Species

ʻŌlaʻa

In the ʻŌlaʻa-Koa unit, Loh and Tunison (1999) reported that native understory cover increased by 48% and nonnative understory cover increased 190% between 1991 and 1998. Cover changes differed between the upper strata (1<2 m) and lower strata (<1 m) within the understory vegetation (Figure 4.9-3). Each year, native cover was higher than nonnative cover (Loh and Tunison 1999).

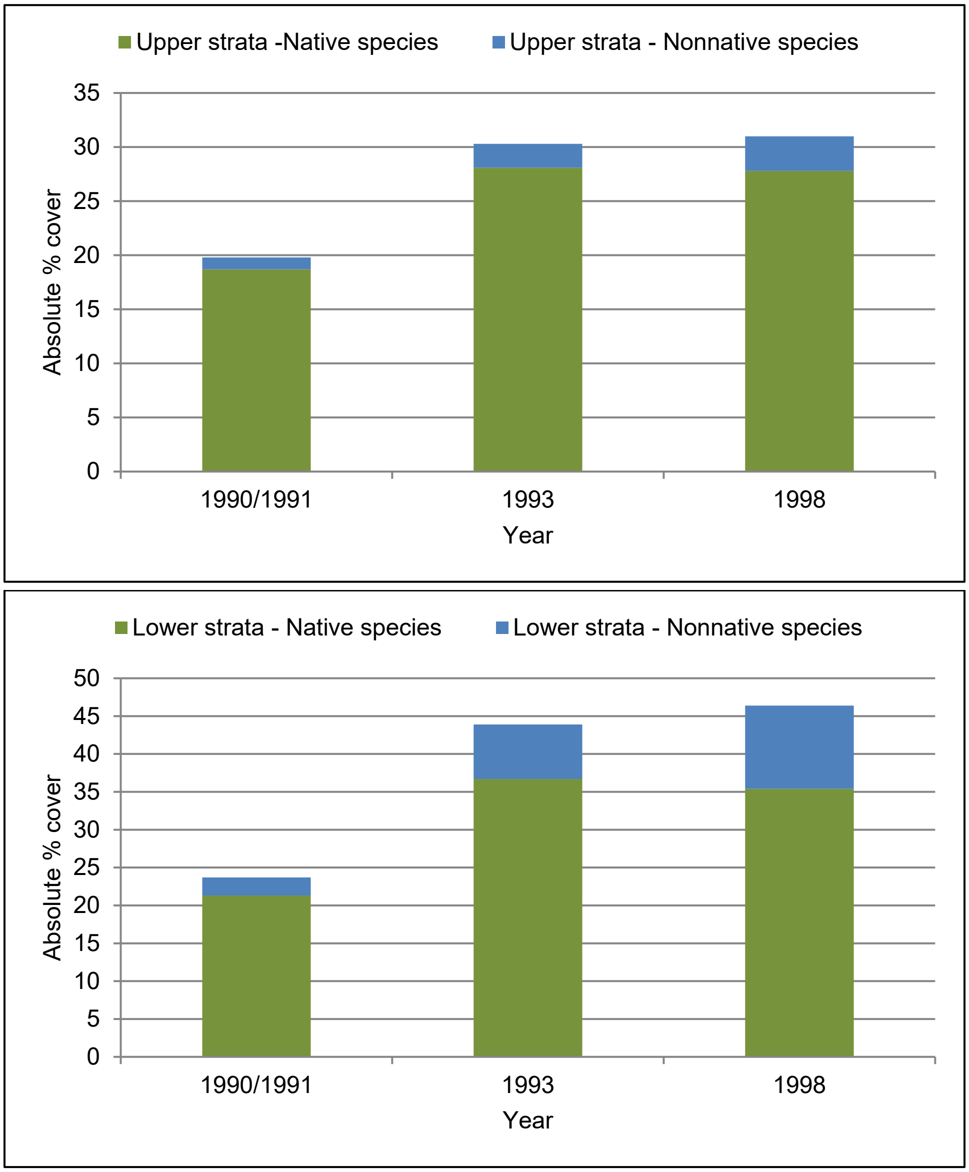

Figure 4.9-3. Absolute percent cover of native and nonnative species in the upper strata (above) and lower strata (below) understory vegetation in the ʻŌlaʻa-Koa unit between 1990 and 1998 according to Loh and Tunison (1999).

During the survey by Cole et al. (2012) in the ʻŌlaʻa-Koa unit (~1.5 km [0.9 mi] from the Loh and Tunison 1999 site), native herbaceous species were reported to have a higher cover than nonnative herbaceous species in the pig-free and pig-present sites in 1994. By 2010, native herbaceous cover remained higher than nonnative cover in the pig-free sites, but nonnative cover was higher that the native in the pig-present sites (Figure 4.9-4) (Cole et al. 2012). In contrast, Cole et al. (2012) found that the mean density of epiphytic or ground-rooted understory woody plants was not different between native or nonnative species in 1994 or 2010.

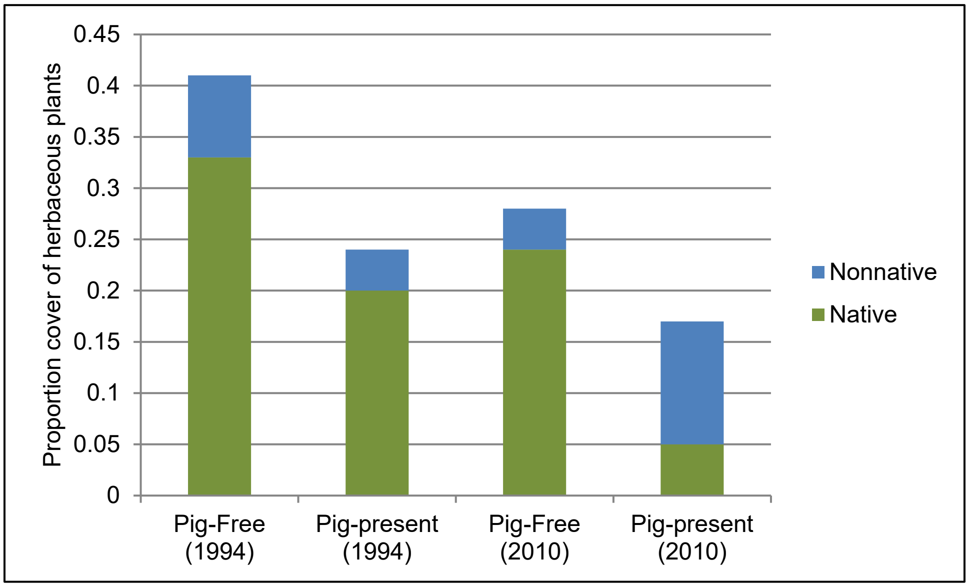

Figure 4.9-4. Proportion of cover of native and nonnative herbaceous species in pig-free and pig-present sites in 1994 and 2010 from Cole et al. (2012).

Kīlauea

Between 1979 and 1980, Katahira (1980) reported cover of several native species inside a pig-free exclosure in the East Rift zone. Cover of ʻamaʻu (*Sadleria pallida*), hāpuʻu, and ʻōhā wai (*Clermontia parviflora*) was 47.8%, 6%, and 3.4%, respectively. These estimates were higher than those reported in the same area in 1975 when pigs were still present. Invasive species cover in the exclosure was less, with most species having less than 0.3% cover (Katahira 1980).

Also within the East Rift, Cuddihy et al. (1986) reported native species cover estimates ranging from 14% to 50%, while the nonnative species cover ranged from 0.9% to 4% (Cuddihy et al. 1986). This study found that although woody plant species diversity was low, the frequency of native woody plants is relatively high (Cuddihy et al. 1986).

In the interior plots in the East Rift wet forest craters (Puʻu Huluhulu, Kāne Nui O Hamo, and Nāpua Trail Pit Crater), nonnative plant species rarely exceeded 1% of ground cover. Bryophyte, ground, and shrub layers cover was determined to be significantly higher in the craters than in forests outside (Belfield 1998).

Kahuku

Percent cover of native and nonnative species in Kahuku's wet forest is not provided in Benitez et al. (2008). However, in the wet forests above Kaʻū Forest Reserve, the canopy was noted as closed (60%) and dominated by ʻōhiʻa and the groundcover was greater than 60% and dominated by native ferns and sedges (Benitez et al. 2008).

Presence and Abundance of Listed Species/SOC

Of the 63 listed plant species or SOC that have identified habitat in HAVO, 26 species (41%) occur in wet forests. Currently, 21 exist as either planted or naturally occurring individuals in the Park while 5 species are believed to be extirpated or have not been recently re-sighted. The endangered palai lāʻau (*Adenophorus periens*) was previously found in ʻŌlaʻa and Kāne Nui o Hamo, but has not been recently observed. The endangered *Phyllostegia velutina* has also not been seen in recent years, although it was previously recorded at ʻŌlaʻa. *Asplenium schizophyllum* (no common name) and ʻawapuhi a kanaloa (*Liparis hawaiensis*) have not been recently re-sighted. The candidate ʻohe (*Joinvillea ascendens* subsp. *ascendens*) has not been documented in HAVO's wet forests since the 1980s (Pratt and Abbott 1997, Pratt et al. 2011).

Three species (Pele's ʻōhā [*Clermontia peleana* ubsp. *peleana*], hāhā [*Cyanea shipmanii*] and *Schiedea diffusa* subsp. *macraei* [no common name]) only exist as plantings in HAVO's wet forests (Table 4.9-2) (Pratt et al. 2011). The average survivorship of rare plantings in the ʻŌlaʻa wet forests was 21% and survival is expected to decline further over time (Belfield et al. 2011).

Table 4.9-2. Listed plant species and SOC documented within HAVO's wet forest plant communities. E = endangered, PE = proposed endangered, C = candidate for listing, SOC = Species of Concern.

Scientific Name	Common Name	Status	Occurrence
Adenophorus periens	Palai lāʻau, pendant kihi fern	E	Extirpated
Anoectochilus sandvicensis	Jewel orchid	SOC	Natural and planted
Argyroxiphium kauense	Mauna Loa silversword	E	Natural and planted
Asplenium schizophyllum	–	SOC	Extirpated
Bobea timonioides	ʻAhakea	SOC	Natural and planted
Clermontia lindseyana	ʻOhā wai, Lindsey's ʻōhā	E	Natural and planted
Clermontia peleana	ʻOhā wai, Pele's ʻōhā	E	Planting only
Cyanea shipmanii	Hāhā	E	Planted only
Cyanea stictophylla	Hāhā, haʻiwale, kanawao keʻokeʻo	E	Natural and planted
Cyanea tritomantha	ʻAkū	E	Natural and planted
Cyrtandra giffardii	Haʻiwale	E	Natural only
Cyrtandra menziesii	Haʻiwale	SOC	Natural and planted
Cyrtandra tintinnabula	Haʻiwale	E	Natural only
Embelia pacifica	Kilioe	SOC	Natural and planted
Eurya sandwicensis	Anini	SOC	Natural and planted
Joinvillea ascendens ssp. ascendens	ʻOhe	C	Extirpated
Liparis hawaiensis	ʻAwapuhi a kanaloa	SOC	Extirpated
Phyllostegia floribunda	Many-flowered phyllostegia	E	Natural and planted
Phyllostegia velutina	–	E	Extirpated
Pittosporum hawaiiense	Hōʻawa	E	Natural and planted

Table 4.9-2 (continued). Listed plant species and SOC documented within HAVO's wet forest plant communities. E = endangered, PE = proposed endangered, C = candidate for listing, SOC = Species of Concern.

Scientific Name	Common Name	Status	Occurrence
Pritchardia lanigera	–	E	Planting only
Rubus macraei	‘Akala	SOC	Natural only
Schiedea diffusa subsp. macraei	–	E	Planting only
Sicyos alba	‘Anunu; white-bur cucumber	E	Natural only
Stenogyne macrantha	–	SOC	Natural and planted
Trematolobelia wimmeri	Koli‘i	SOC	Natural and planted

Information regarding whether the numbers of extant listed species and/or SOC are declining or increasing in the wet forest plant communities is varied. *Cyrtandra tintinnabula* appears to have a viable, reproducing population with numerous individuals of several size classes (Waite and Pratt 2007, VanDeMark et al. 2010). Recent surveys of *Cyrtandra giffardii* indicate the species has a stable population (VanDeMark et al. 2010). On the other hand, the jewel orchid (*Anoectochilus sandvicensis*) has disappeared from several sites where it was previously found in the East Rift, but is still extant in ‘Ōla‘a (Pratt et al. 2011). Kilioe (*Embelia pacifica*) has not been re-sighted in its former habitat on the East Rift, but restoration efforts are planned for this species in the area (Pratt et al. 2011).

Lindsey's ‘ōhā, ‘ākala (*Rubus macraei*), *Cyrtandra menziesii*, and hāhā (*Cyanea stictophylla*) were only recently located at Kahuku (Benitez et al. 2008) and therefore a trend cannot be determined for these species.

Surveys in HAVO's wet forests are primarily localized. Additional intensive and broader surveys are needed to confirm if species are extirpated from certain areas, particularly for smaller species.

Number and Distribution of Invasive Target Plant Species

Out of the roughly 134 invasive target plant species that are monitored at HAVO, at least 57 species occur or previously occurred in the wet forests at HAVO (Tunison et al. 1992, Benitez et al. 2008, Benitez et al. 2011). Of these, nearly 10 invasive plant species are presumed extirpated due to control efforts including gorse (*Ulex europaeus*) and pipinella (*Sechium edule*) (Benitez et al. 2012). The most widely distributed invasive plants in the wet forests include Japanese anemone (*Anemone hupehensis*), kāhili ginger (*Hedychium gardnerianum*), banana poka, knotweed, strawberry guava, Florida prickly blackberry, yellow raspberry (*Rubus ellipticus*), thimbleberry (*Rubus rosifolius*), palm grass (*Setaria palmifolia)*, and cane tibouchina (Benitez et al. 2012). Meadow ricegrass (*Ehrharta stipoides*) and purple granadilla (*Passiflora edulis*) are also present in the Kīlauea and ‘Ōla‘a forests, but are not considered significant weeds in ‘Ōla‘a (David Benitez, Ecologist, NPS HAVO, pers. comm. 2014). Cole et al. (2012) found that while some wet forest nonnative invasive plants may be more abundant in pig-present sites than pig-free sites (e.g., palm grass), other invasive plants (i.e., strawberry guava) have a higher density in pig-free sites.

Five montane wet forest SEAs (Thurston, ‘Ōla‘a small tract, ‘Ōla‘a-Koa, Ag and Pu‘u units) are intensively managed for invasive plants. Long-term treatment data are available for three of the SEAs. The number of invasive plants per hectare has remained relatively low (<1% crown cover abundance) in the ‘Ōla‘a small tract since management began in 1985 (Loh et al. 2014). The number of invasive individuals in Thurston decreased to low levels between 1985 and1990 (Figure 4.9-5). In contrast, infestation levels have remained relatively high in ‘Ōla‘a Koa unit (973 individuals/ha during the most recent monitoring) (Loh et al. 2014).

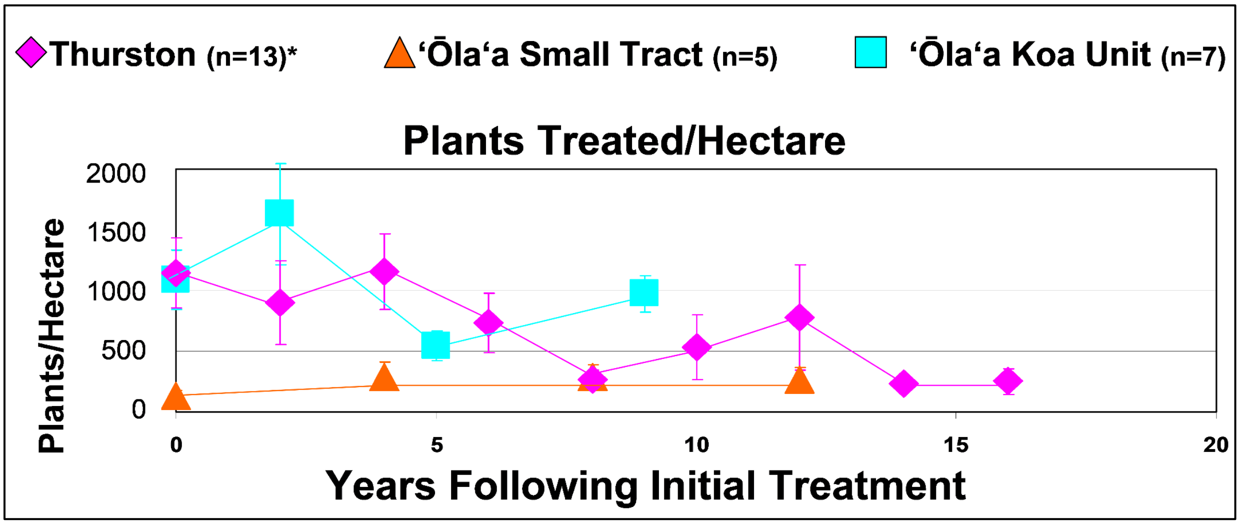

Figure 4.9-5. Number of invasive plants per hectare treated in the three montane wet forest SEAs (Thurston 1985–1990, ‘Ōla‘a Small Tract 1985–1993, ‘Ōla‘a Koa 1998–1999) from Loh et al. (2014).

Figures 4.9-6 and 4.9-7 illustrate the distribution of the 11 invasive target plant species recorded in the Kahuku wet forest transects from Benitez et al. (2008). An additional suite of weedy species have been identified in Kahuku’s wet forests including bull thistle (*Cirsium vulgare*), hill raspberry (*Rubus niveus*), Japanese mat rush (*Juncus effusus*), a pine species (*Pinus* sp.), rattail grass or African dropseed (*Sporobolus africanus*), sweet granadilla (*Passiflora ligularis*), and sourbush (*Pluchea carolinensis*) (Benitez et al. 2008). These are considered invasive, as well and are being considered for inclusion into the list of target weeds. In the eastern survey region above the Ka‘ū Forest Reserve, meadow ricegrass and Japanese mat rush were the most abundant invasive species (Figure 4.9-6), but cover was usually sparse (<1% cover) (Benitez et al. 2008). Many more invasive plants were present in the eastern edge of the pastures region as shown in Figure 4.9-7. Strawberry guava and faya tree were also present, but not detected on transects. Strawberry guava was present in lower elevation forest just west of the Kā‘u Forest Reserve, and faya tree above the reserve.

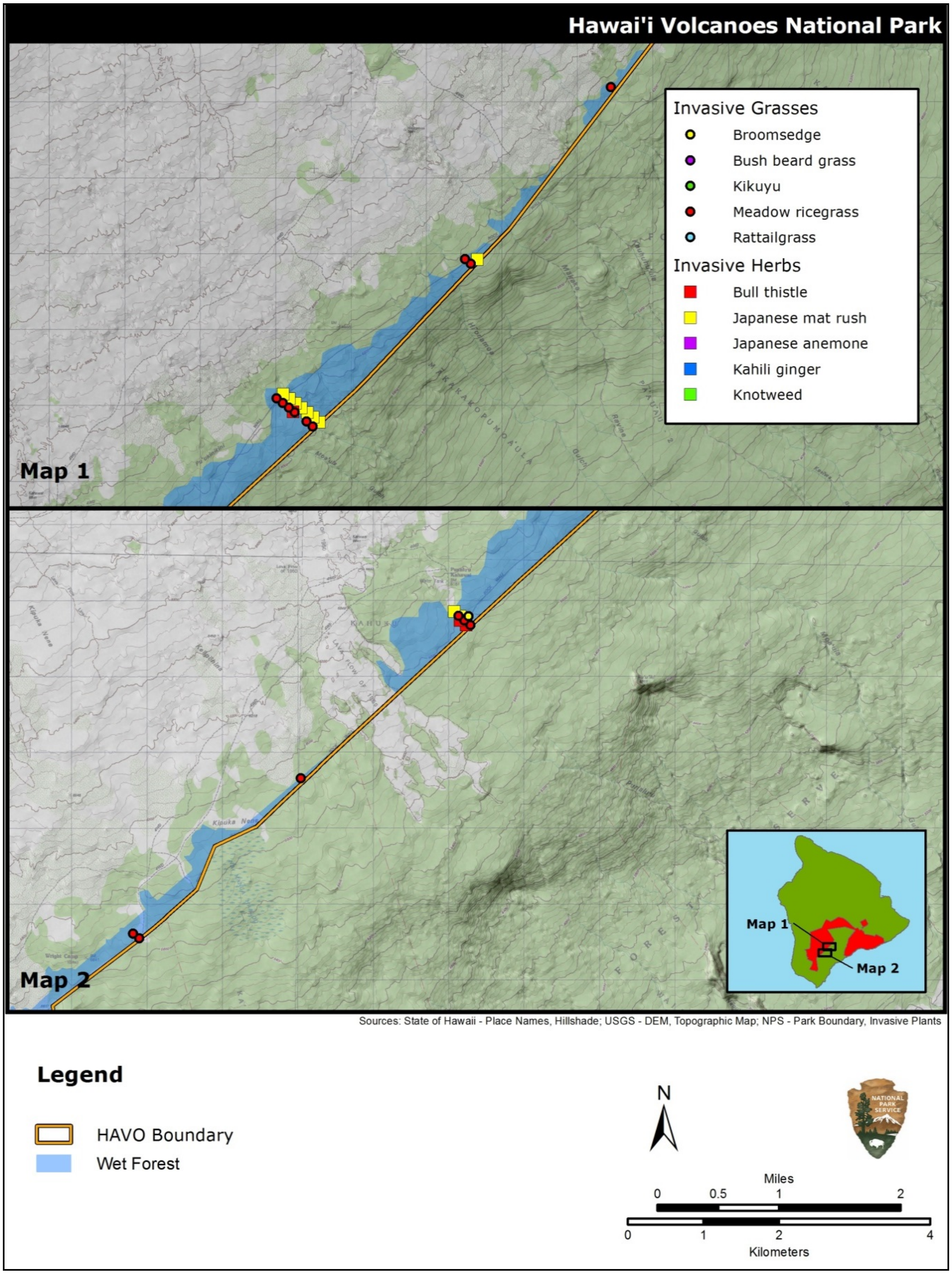

Figure 4.9-6. Point locations of invasive target plants and other invasive plant species recorded in the Kahuku wet forest above the Kaʻū Forest Reserve from Benitez et al. (2008). Note: faya tree was present but not detected on transects.

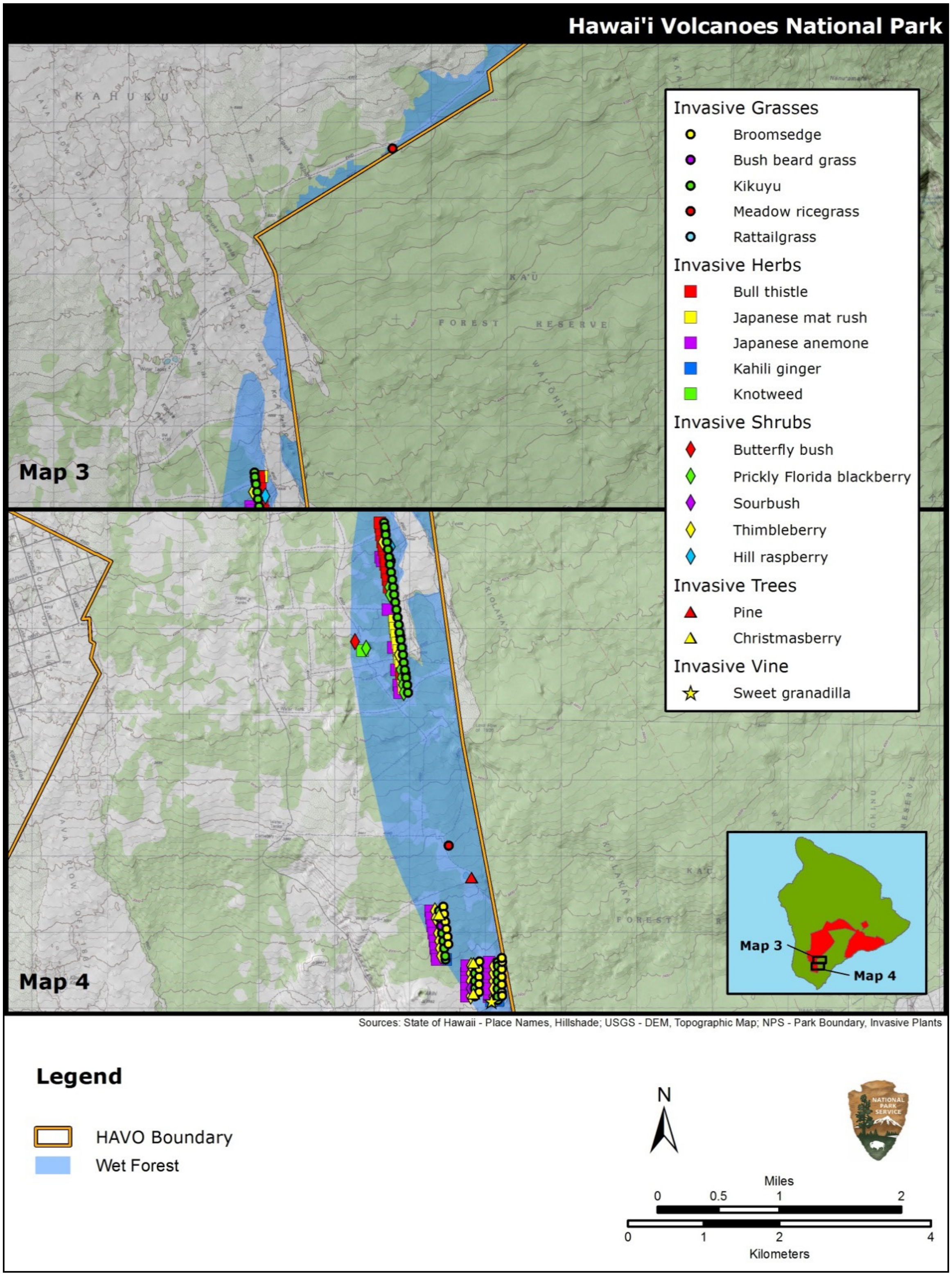

Figure 4.9-7. Point locations of invasive target plants and other invasive plant species recorded in the wet forests in the eastern edge of the pastures region in Kahuku from Benitez et al. (2008). Note: Strawberry guava was present but not detected along transects in Map 4, and faya tree was present but not detected along transects in Map 3.

Percent of Area Protected From Ungulates

Roughly half of the ʻŌlaʻa section is currently fenced into five units, and pigs are successfully excluded from four of the units (769-ha or 1,900-ac). Efforts are ongoing to remove pigs from the fifth unit (see Section 4.4, Figure 4.4-3).

Since the acquisition of the Kahuku section in 2003, boundary fences and cross fences are being constructed and ungulate control implemented with additional fences planned through 2018 to exclude all ungulates from large areas of Kahuku (see map Figure 4.4.2). Until these fences are completed, wet forest in Kahuku are unprotected from ungulates.

Threats and Stressors

Wet forest plant communities in HAVO are primarily threatened by invasive species. Ungulates have significant, cascading adverse impacts on native plants by trampling, grazing, and consuming a variety of plant material. Wet forests are particularly susceptible to pigs due to abundance of resources (i.e., food and water) in these communities (Cuddihy and Stone 1990). Invasive plants also represent an important threat to wet forests at HAVO and are able to establish and out-compete many native species. Rodents are also known to consume and damage rare and listed wet forest species, such as ʻakū (*Cyanea tritomantha*) (Pratt and Abbot 1997).

Fires are relatively rare in wet forests at HAVO; however, fires have occurred in uluhe-dominated areas after dry periods (NPS 2013). Eruptions from nearby volcanically active areas can impact plant cover and health due to lava flows, falling cinders or sulfur dioxide fumes (Cuddihy et al. 1986). Finally, climate change has the potential to stress HAVO's wet forest plant communities due to changes in precipitation and temperature, particularly for plants such as epiphytes that rely on atmospheric inputs (Nadkarni and Solano 2002).

Overall Condition

The wet forests at HAVO contain a high diversity of native species compared to nonnative species. The distribution of invasive species, however, is extensive in many wet forest areas and average number of invasive plant remains high in the ʻŌlaʻa-Koa SEA. Five listed species or SOC formerly recorded in HAVO's wet forests have not been recently sighted and are believed to be extirpated and many high value areas remain unfenced and exposed to ungulates. It is difficult to determine the condition of Kahuku's wet forests due to the lack of specific data for these communities and lack of historical knowledge for these areas. However, the entire area is not fully fenced, and until fencing and ungulate removal is completed continued degradation by ungulates can be anticipated. While small pockets of intact and protected wet forests occur, the overall condition of these forest plant communities in HAVO is considered of concern.

Information Gaps/Level of Confidence

Wet forests tend to be less accessible than other forest types and often require more time and resources due to a higher density of plants. Despite these challenges, more plant surveys have been conducted in HAVO's wet forests than other plant communities. Many surveys were designed to investigate vegetation changes following ungulate removal in the ʻŌlaʻa and Kīlauea sections or to survey rare plants.

Although numerous surveys have been previously conducted in the wet forests at HAVO, these projects utilized different methodologies, data analysis protocols, and observers, making comparisons and accurate compilations of the data difficult. Ainsworth et al. (2011) calculated percent precision for the mean plant community parameters collected in studies in HAVO's wet forests. The precision of the mean for native, nonnative, and total species richness was relatively high, while other parameters varied. Additionally, studies are often lumped with other forest types (typically mesic) or wet forests outside of the Park. Some of the surveys also have minimal replication which can be problematic in areas with potentially high heterogeneity, such as HAVO's wet forests (Scheffler et al. 2012).

Although several of the wet forest surveys collected quantitative data for more than 1 year, these surveys are focused on specific sites rather than within wet forests Park-wide; however, a long-term systematic approach to monitoring plants within the wet forests is currently being developed and monitoring within HAVO's these forests will be conducted every 5 years (Ainsworth et al. 2011). Altogether the extent of the knowledge base for HAVO's wet forests is ranked as A.

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4.10. Subalpine Plant Communities

Background

Subalpine plant communities occur between 1,700 and 3,000 m (5,577–9,843 ft) elevation on East Maui and Hawai‘i Island. These communities lie within or above the trade wind zone inversion layer and therefore tend to have dry to mesic conditions. Low-lying clouds and fog drip also contribute to the moisture regime (Gagné and Cuddihy 1999).

Three dominant subalpine vegetation communities have been identified at HAVO: shrublands, woodlands, and mesic grasslands. Shrublands are the most widespread, covering about 1,733 ha (4,283 ac) of the Park (Ainsworth et al. 2011). This community is characterized by scattered, low-growing ‘ōhi‘a, with an understory of native shrubs and grasses (Benitez et al. 2008). Shrublands occur in both the Kahuku and MaunaLoa sections. In the MaunaLoa section, patches of subalpine shrubland occur from the top of MaunaLoa Strip Road to the alpine boundary at about approximately 3,000 m (9,843 ft) elevation. The northwestern and eastern portions of the Kahuku section also support subalpine shrublands (Benitez et al. 2008).

In the Mauna Loa section, the most notable subalpine shrublands occur within two well-vegetated kīpuka: Kīpuka Kulalio and Kīpuka Mauna‘iu. These kīpuka extend into the lower elevation portion of the subalpine zone and lie on older pāhoehoe lava flows dated between 1,500 and 4,000 years old (Stone and Pratt 2002). Extensive fencing and planting efforts have been implemented within these kīpuka (Belfield et al. 2011).

Woodlands occur on older substrates. These open areas have sparsely scattered ‘ōhi‘a and māmane. Some rare plants occur in Kahuku’s subalpine woodlands, particularly in the remote eastern portion (Benitez et al. 2008).

The subalpine mesic grassland is dominated by an endemic bunchgrass Deschampsia nubigena. The native kīlau fern (Pteridium aquilinum var. decompositum) is one of the more common species within the grassland, although native grasses, sedges and shrubs may also be present. The grassland occurs in small patches within the MaunaLoa Strip and to a greater extent in Kahuku above the Kā‘u Forest Reserve. The Deschampsia nubigena mesic grassland is considered globally imperiled by the Hawai‘i Natural Heritage Program, with between 6 and 20 occurrences known only on the northeastern slopes of MaunaLoa and the northeastern slopes of East Maui (Pratt et al. 2011).

The subalpine shrublands at HAVO are one of the five focal plant communities monitored in PACN parks. These communities were chosen based on relative intactness, high species diversity, prevalence across Pacific Island parks, uniqueness to their respective areas, and usefulness as indicators of environmental change (Ainsworth et al. 2011).

HAVO is the only location within MaunaLoa where the subalpine vegetation is legally protected. Many other subalpine areas on Hawai‘i Island have been converted to pasture (Stone and Pratt 2002).

Compared to other areas of the Park, relatively few invasive plants have invaded subalpine plant communities. It has also been noted that HAVO's subalpine shrublands may be of research interest because changes in the treeline of these communities may indicate shifting climatic conditions due to changes in the inversion layer (Ainsworth et al. 2011).

Measures

- Native species richness
- Presence and abundance of listed species/SOC
- Number and distribution of invasive target plant species
- Percent of area protected from ungulates

<u>Reference Condition/Value</u>
A reference condition for native species richness within the subalpine plant communities is that the number of native species exceeds the number of nonnative species. The reference condition for listed species/SOC is that none of these species historically recorded in the subalpine plant communities at HAVO have been extirpated and the number of individuals remain in the range historically reported.

Two of the greatest threats to native plant communities in Hawaiʻi are invasive plants and invasive ungulates. Roughly 134 plant species are considered invasive and highly disruptive to native ecosystems in HAVO (Benitez et al. 2012). A reference condition for the number and distribution of invasive species within the subalpine plant communities is not defined at this time. The reference condition for percent protected from ungulates is 100% exclusion.

<u>Existing Data</u>
The following resources were used to assess this indicator.

- Higashino et al. (1988) provided a checklist of vascular plants observed during surveys conducted since 1944. Species found within the subalpine habitat, defined as primarily shrublands with scattered trees, were noted.
- Loh et al. (2000) reported the results of mullein monitoring and control efforts which were conducted in the Park between 1994 and 1999. This included mullein found within the subalpine shrublands.
- Belfield and Pratt (2002) surveyed rare plants in the MaunaLoa Strip, including a small portion of the subalpine zone.
- Between 2004 and 2006, Benitez et al. (2008) inventoried the vegetation within the Kahuku Unit (including the subalpine communities) using transects, plots, and helicopter surveys. GIS data points of invasive plants found within the subalpine were also provided.
- Belfield et al. (2011) implemented a rare plant stabilization program throughout HAVO, which included outplanting common and uncommon species at Kīpuka Kulalio.
- Pratt et al. (2011) provided distribution maps and descriptions of rare and listed plants within the Park, including species in the subalpine shrublands. This report also discusses the distribution and threats to the *Deschampsia nubigena* grassland.

- Ainsworth et al. (2011) discusses the subalpine shrublands of HAVO and shows the extent of the subalpine shrubland sampling frames, which are the portions of the community that will be monitored in the future. The geographical extent of this community was determined by substrate and climatic criteria, as well as accessibility, rather than existing plant community boundaries.
- Benitez et al. (2012) recorded invasive plants at 10- to 50-m intervals throughout the Park, indicating the presence of identifiable individuals as observed from trails, roads, and fences. Some comparisons between previous surveys are provided to evaluate changes in invasive distributions.
- In 2013, the Park released a Final Plan / Environmental Impact Statement for Protecting and Restoring Native Ecosystems by Managing Non-native Ungulates (NPS 2013), which provided the most current information on ungulate abundance in the Park.

Current Condition

Native Species Richness

Higashino et al. (1988) identified 130 plant species in the subalpine zone within the MaunaLoa section. Of these, less than half (63 species) were native Hawaiian species. However, the subalpine zone had a relatively low number of nonnative species (67 species) compared to other ecological zones identified in the Park by Higashino et al. (1988). The only other environment with fewer native species was the alpine environment (Higashino et al. 1988).

Fewer native plant species are reported to occur in the Kahuku subalpine section compared to the MaunaLoa section due to centuries of browsing and trampling by mouflon sheep and other ungulates (Stone and Pratt 2002, NPS 2013). However, species-rich forest fragments were reported in Kahuku's subalpine plant communities during recent surveys (Benitez et al. 2008).

Presence and Abundance of Listed Species/SOC

Eleven listed species or SOC currently occur in HAVO's subalpine plant communities (Table 4.10-1). Three of these only exist as outplants: Haleakalā silversword (*Argyroxiphium sandwicense* ssp. *macrocephalum*), makou, and *Stenogyne angustifolia*. MaunaKea silversword (*Argyroxiphium sandwicense* ssp. *sandwicense*) was formerly planted in the subalpine. This species is not known to historically occur on MaunaLoa, and plantings were either removed or died (Pratt et al. 2011).

Table 4.10-1. Listed plant species and SOC documented within HAVO's subalpine plant communities. E = endangered, C = candidate for listing, SOC = Species of Concern.

Scientific Name	Common Name	Status	Occurrence
Argyroxiphium kauense	Mauna Loa silversword	E	Natural and planted
Argyroxiphium sandwicense ssp. macrocephalum	'Ahinahina, Haleakalā silversword	T	Planted only*
Argyroxiphium sandwicense ssp. sandwicense	'Ahinahina, MaunaKea silversword	E	Historical planting*

* Historically not known to naturally occur in HAVO.

Table 4.10-1 (continued). Listed plant species and SOC documented within HAVO's subalpine plant communities. E = endangered, C = candidate for listing, SOC = Species of Concern.

Scientific Name	Common Name	Status	Occurrence
Asplenium peruvianum var. insulare	–	E	Natural only
Fragaria chiloensis subsp. sandwicensis	ʻOhelo papa	SOC	Natural only
Plantago hawaiensis	Laukahi kuahiwi	E	Natural and planted
Ranunculus hawaiensis	Makou, large-flower native buttercup	C	Planted
Rubus macraei	ʻAkala	SOC	Natural only
Sanicula sandwicensis	Snakeroot	SOC	Natural only
Silene hawaiiensis	Hawaiian catchfly	T	Natural and planted
Sisyrinchium acre	Mauʻu lāʻili, mauʻu hōʻula ʻili	SOC	Natural only
Stenogyne angustifolia	–	E	Planted only

* Historically not known to naturally occur in HAVO.

Information regarding whether the numbers of listed species and/or SOC are declining or increasing in the subalpine communities is varied. Snakeroot was only recently located at Kahuku and therefore a trend cannot be determined. An extensive outplanting effort for the endangered MaunaLoa silversword has been implemented in both Kahuku and the MaunaLoa Strip, with over 15,000 individuals planted inside protected fenced units in the Park (NPS 2013). Belfield and Pratt (2002) reported that populations of Hawaiian catchfly have decreased since historically observed, while populations of laukahi kuahiwi (*Plantago hawaiensis*) were stable. For the remaining species, data on the number of individuals compared to historical estimates are not available or inconclusive.

Number and Distribution of Invasive Target Plant Species

Out of the roughly 134 invasive target plant species that are monitored at HAVO, only seven species (5%) are currently known in the subalpine shrublands (Benitez et al. 2008, Benitez et al. 2012). This is a relatively small number of species compared to other areas of the Park. The most abundant invasive plant in the subalpine is mullein, which has been estimated to infest over 1,000 ha (2,471 ac) in the MaunaLoa Strip (Loh et al. 2000).

Figure 4.10-1 shows the range of invasive plants in the MaunaLoa subalpine shrublands from Benitez et al. (2012). Only two invasive species occur here: mullein and knotweed.

Figure 4.10-2 is a map of the seven invasive target plant species recorded in the Kahuku subalpine shrubland transects from Benitez et al. (2008). Mullein is common along the northwestern and western portions of the Kahuku Unit between 1,760 and 2,500 m (5,774–8,200 ft) elevation (Benitez et al. 2008). In the northwest, it was observed in 88% of transect stations and 75% of vegetation plots. In the west, it was seen in two kīpuka and on flow edges. Mullein is also abundant along roadsides in the nearby Hawaiian Ocean View Estates (Benitez et al. 2008).

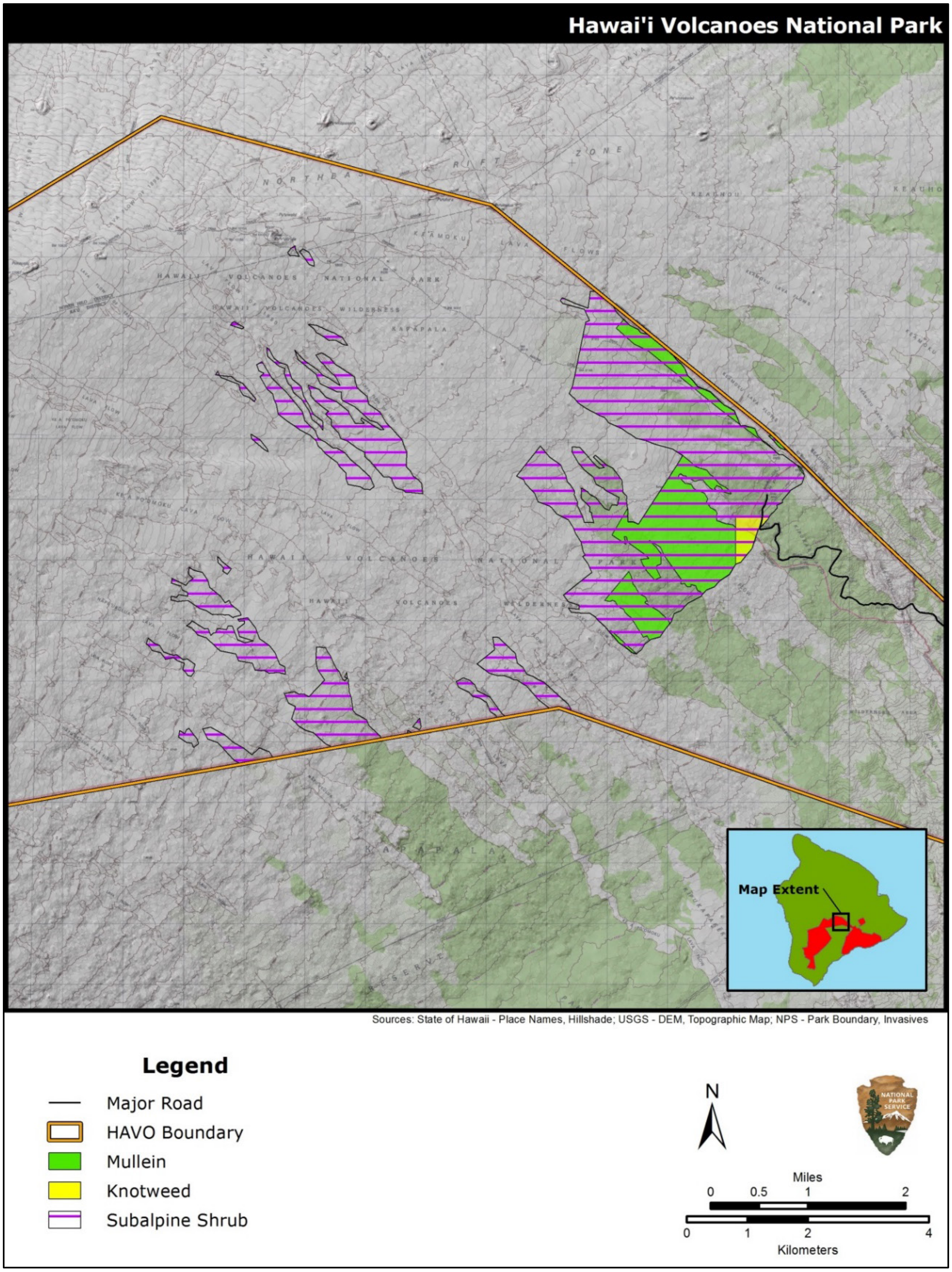

Figure 4.10-1. Distribution of invasive target plants in the Mauna Loa subalpine shrublands from Benitez et al. (2012).

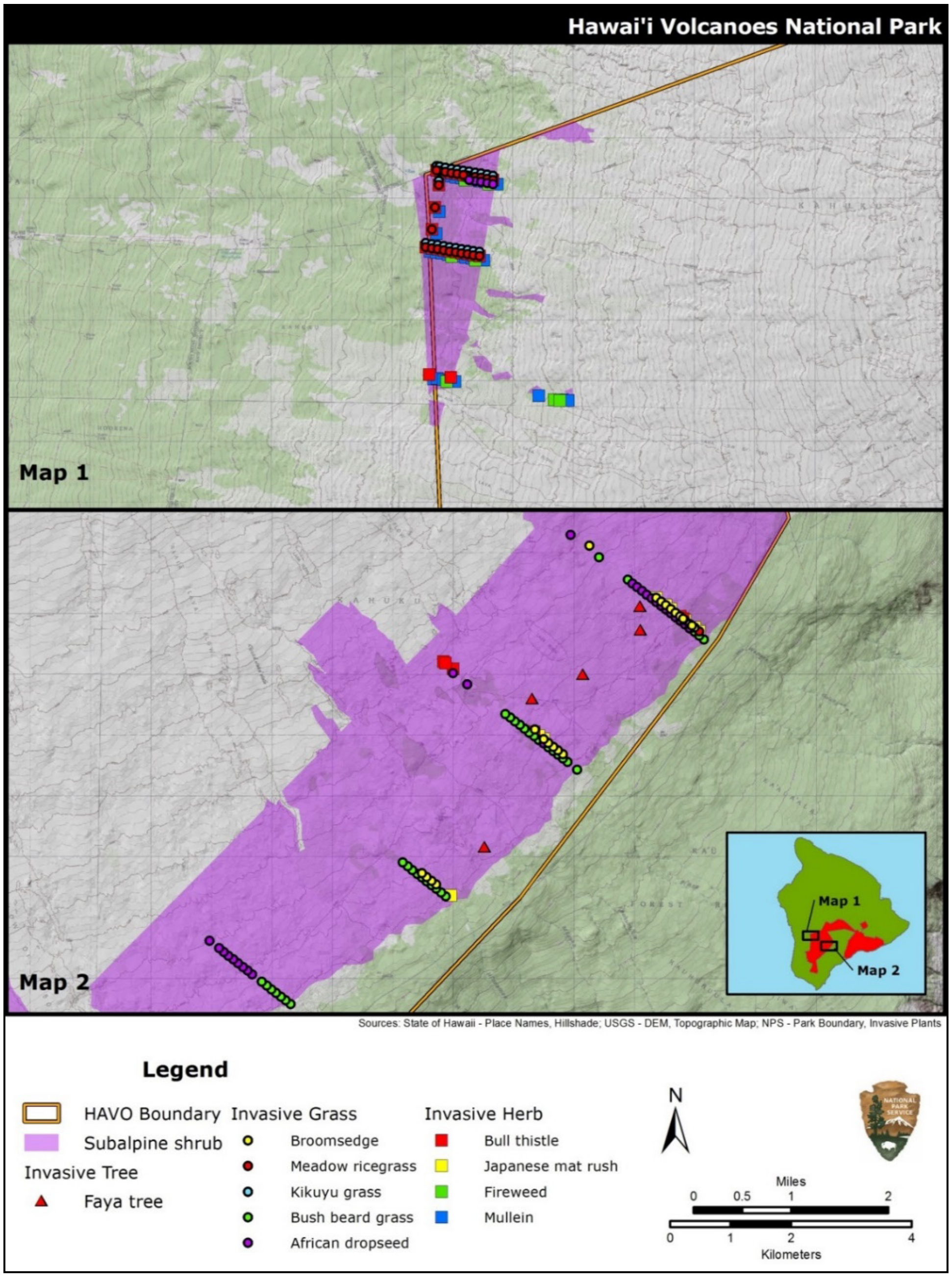

Figure 4.10-2. Point locations of invasive target plants and other invasive plant species recorded in the Kahuku subalpine shrublands from Benitez et al. (2008).

Three other invasive plants are noted in Kahuku's subalpine shrublands that are not currently on the Park's target invasive plant list. These include African dropseed (*Sporobolus africanus*), bull thistle, and Japanese mat rush (Benitez et al. 2008).

<u>Percent of Area Protected From Ungulates</u>

The entire MaunaLoa subalpine was fenced in 1992 and is continually managed for ungulates. All pigs, sheep, and goats formerly within the MaunaLoa Subalpine SEA have been eradicated.

In contrast, only a small portion of the Kahuku subalpine is currently protected from ungulates. Cattle, goats, and pigs occur in small numbers. Sheep and mouflon sheep are more abundant in Kahuku, but control efforts are reducing the number of these ungulates (NPS 2013).

Threats and Stressors

Compared to the other plant communities within HAVO, the subalpine environment is subjected to less threats and stressors. The rocky substrates have limited disturbance by ungulates, particularly in the Mauna Loa Strip. The majority of the area is fenced and managed to control ungulates, although animals are still present in Kahuku's subalpine. The impact of fire is also low (NPS 2013). Mauna Loa is an active volcano and lava flows could lead to loss of plant communities. Relatively few invasive plants have established. However, mullein has the potential to expand its range in Kahuku and the Mauna Loa Strip. Nonnative slugs have been identified as a potential threat to some rare plants in the subalpine plant communities (Pratt et al. 2011). Furthermore, climate change has the potential to impact these communities.

Overall Condition

Overall, the current condition of the subalpine plant communities is considered moderate. Existing data show that some listed species and SOC are declining and protection from ungulates is not complete. Although comparatively few nonnative species have been recorded in many of the subalpine plant communities, the number of nonnative species is greater than the number of native species. The rare *Deschampsia nubigena* mesic grassland is present in HAVO; however, it has been damaged by ungulates (Pratt et al. 2011). The most extensive and intact example of this grassland in Hawaiʻi occurs in Kalapawili on the upper windward slopes of East Maui in Haleakalā National Park (Jacobi 1981, Gagné and Cuddihy 1999, Pratt et al. 2011). A reliable trend for this indicator cannot be determined at this time; however, the condition of these communities in Kahuku is expected to improve as a result of future efforts to reduce feral ungulates.

Information Gaps/Level of Confidence

The extent of knowledge for this indicator is ranked B. Relatively few surveys specific for the subalpine plant communities have been conducted and long-term or repeat data are not available. Information on native species richness and the abundance of listed species or SOC is largely based on older surveys, with the exception of Kahuku. Detailed and consistent vegetation sampling plots will be monitored in the Kahuku and Mauna Loa subalpine shrublands at HAVO in the future (Ainsworth et al. 2011, Ainsworth et al. 2012).

The extent of the subalpine shrublands in HAVO is based on the sampling frames identified in Ainsworth et al. (2011). These areas are limited to safely accessible areas. It is unknown how much area meets the substrate and climatic criteria for subalpine shrublands, but is considered inaccessible. It is unlikely that earlier surveys, such as Higashino et al (1998), classified subalpine shrublands using the same criteria, therefore, the exact survey areas will likely differ.

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4.11. Mānele/ Koa/ ʻŌhiʻa Montane Mesic Forest Plant Communities

Background

Although the MaunaLoa Strip (the corridor that connects the Kīlauea Caldera to the summit of MaunaLoa) is located within the montane seasonal unit and has a summer-dry climate, portions of the area support rare mānele/koa/ʻōhiʻa mesic forest plant communities. The most diverse and intact mānele/koa/ʻōhiʻa montane mesic forests at HAVO occur within two kīpuka: Kīpuka Puaulu and Kīpuka Kī (Figure 4.11-1).

Kīpuka Puaulu, which occurs between 1,200 and 1,280 m (3,937–4,200 ft) elevation, is roughly 100 ha (247 ac) in size. Kīpuka Kī is approximately 90 ha (222 ac) in size and ranges in elevation from 1,210 to 1,350 m (3,970–4,430 ft) (Pratt et al. 2010). The flows underlying these kīpuka are older and unique compared to surrounding flows, consisting mostly of deep ash deposits from volcanic eruptions between 4,000 and 8,500 years old rather than weathered lava (Gagné and Cuddihy 1999, Pratt et al. 2010, Belfield et al. 2011). Additional mānele/koa/ʻōhiʻa forest fragments occur along MaunaLoa Strip Road and on patches of deep ash along the boundary with Keauhou Ranch (Belfield et al. 2011).

The mānele/koa/ʻōhiʻa forest is considered critically imperiled globally by the Hawaiʻi Natural Heritage Program, with fewer than six occurrences known in the Hawaiian Islands (Pratt et al. 2011). Mānele/koa/ʻōhiʻa forest is characteristic of Kīpuka Puaulu and Kīpuka Kī. Invasive plant control and ungulate exclusion have been conducted in these kīpuka for several decades (Belfield et al. 2011). Additional locations containing remnants of this forest type have been identified and are currently the focus of intensive restoration efforts (e.g., planting, weeding). Additionally, a number of endangered and rare plant species are found in this forest type (Pratt et al. 2010, Pratt et al. 2011).

Although HAVO's mānele/koa/ʻōhiʻa forests are considered unique within the Pacific Island region, these forests were not selected as one of the five focal communities that will be monitored within the PACN due to budget constraints (Ainsworth et al. 2011). However, HAVO staff continually manage Kīpuka Puaulu and Kīpuka Kī as SEAs and restoration projects have been conducted in the mānele/koa/ʻōhiʻa forests throughout HAVO (Belfield et al. 2011).

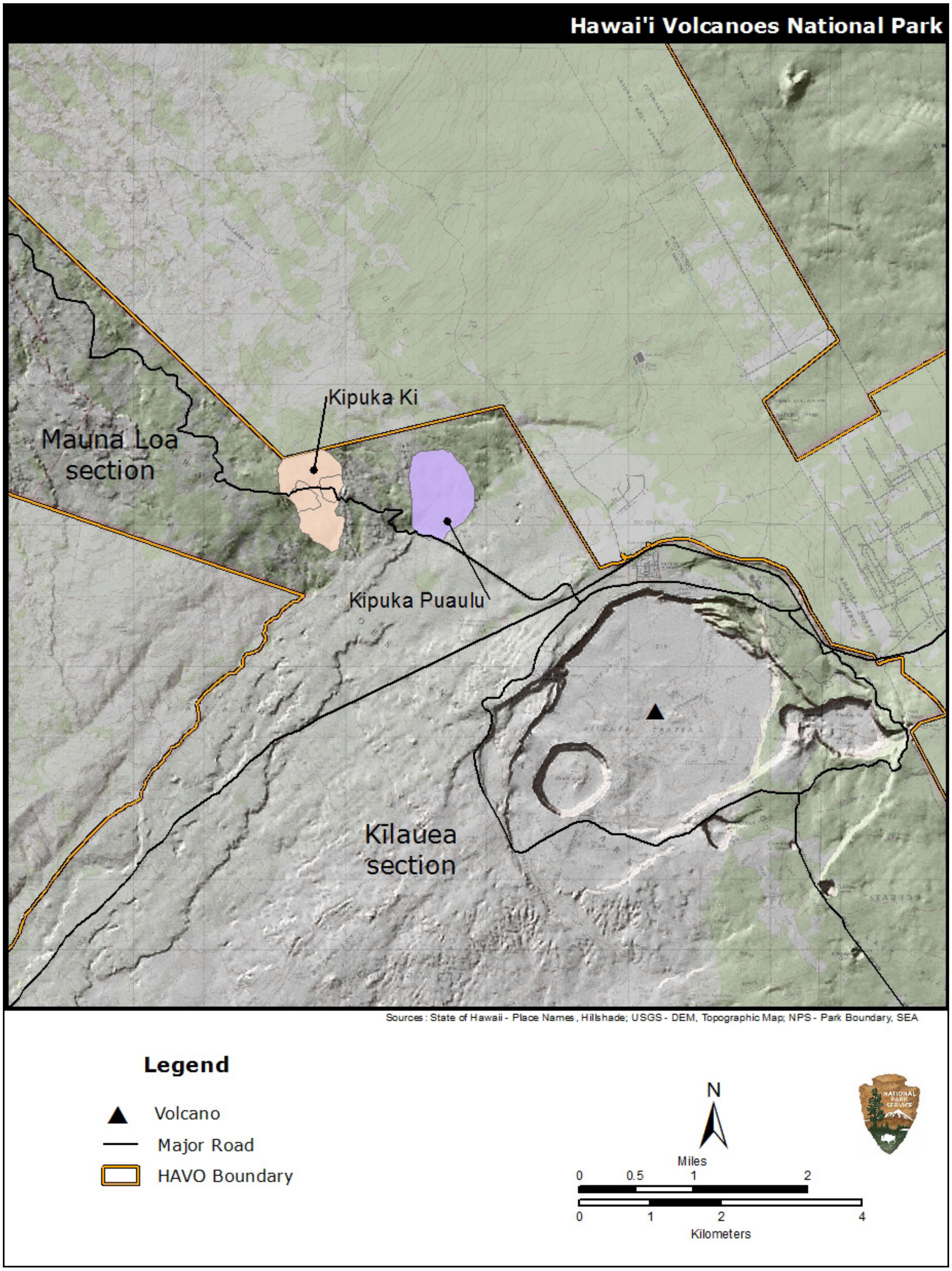

Figure 4.11-1. Kīpuka Puaulu and Kīpuka Kī, which are recognized as the most diverse and intact mānele/koa/ʻōhiʻa mesic forests at HAVO. Note: smaller mānele/koa/ʻōhiʻa forest remnants do not appear (Loh et al. 2014).

Measures

- Native species richness
- Presence and abundance of listed species/SOC
- Number and distribution of invasive target plant species
- Percent of area protected from ungulates

<u>Reference Condition/Value</u>

Few very relatively intact examples of the koa/ʻōhiʻa/mānele forest community remain in the state. The largest and least degraded examples of this community occur at Kīpuka Puaulu and Kīpuka Kī in HAVO (Gagné and Cuddihy 1999). Outside of HAVO, remnants occur in Puʻuwaʻawaʻa and Kapāpala Ranch (Pratt et al. 2011). Therefore, Kīpuka Puaulu and Kīpuka Kī are considered the reference site of this community. The reference condition for native species richness is the range of naturally growing native species observed at these kīpuka during the surveys conducted between 1963 and 1965 (Mueller-Dombois and Lamoureux 1967).

The reference condition for listed species/SOC is that none of these species historically recorded in the mānele/koa/ʻōhiʻa montane mesic forests at HAVO have been extirpated and the number of individuals remain in the range historically reported.

Two of the greatest threats to native plant communities in Hawaiʻi are invasive plants and invasive ungulates. Roughly 134 plant species are considered invasive and highly disruptive to native ecosystems in HAVO (Benitez et al. 2012). Intensive invasive plant control occurs in Kīpuka Puaulu and Kīpuka Kī because these areas are managed as SEAs; thus, the reference condition for invasive species abundance in these kīpuka is low abundance (<1% crown cover) or low density (one individual per hectare). For the montane mesic forests outside of the SEAs, a reference condition for the number and distribution of invasive species is not defined at this time. The reference condition for percent protected from ungulates is 100% exclusion.

<u>Existing Data</u>

The following literature and datasets were reviewed and used to evaluate the condition of this indicator.

- Between 1963 and 1965, Mueller-Dombois and Lamoureux (1967) surveyed Kīpuka Puaulu and Kīpuka Kī in order to describe the flora of these areas and their relationships to soil characteristics. The number of native species observed at each site is provided.
- Changes in invasive plant infestations in Kīpuka Puaulu due to the adoption of the SEA approach to weed management are summarized in Tunison and Stone (1992).
- Pratt et al. (2010) studied five rare or endangered plant species in Kīpuka Puaulu and Kīpuka Kī during a 2-year period to identify limiting factors of these species. The species included hau kuahiwi, mokihanakūkae moa, Zahlbruckner's pelea, kāwaʻu, and large-leaved ʻānunu.
- Rare and common native plants were planted in the montane mesic forest in the early 2000s by Belfield et al. (2011). This report also discusses the history of management in these areas.

- Pratt et al. (2011) discuss the condition and distribution of the critically imperiled mānele/koa/ʻōhiʻa forest community, as well as specific rare and listed plants within HAVO's montane mesic forests.
- Benitez et al. (2012) described invasive plants within the MaunaLoa, Kīlauea, and ʻŌlaʻa sections of the Park, including the mānele/koa/ʻōhiʻa forests, between 2000 and 2010. Distributions of 134 nonnative plants were quantified and provided in a geodatabase by projecting point features or drawing a polygon around all confirmed point locations and incidental field observations. Some comparisons between previous surveys are provided to evaluate changes in invasive distributions.
- In 2013, the Park released a *Final Plan / Environmental Impact Statement for Protecting and Restoring Native Ecosystems by Managing Non-native Ungulates* (NPS 2013), which provided the most current information on ungulate abundance in the Park, including this forest type.
- Loh et al. (2014) discuss control of select invasive plants at the Kīpuka Puaulu and Kīpuka Kī SEAs between 1985 and 2007.

<u>Current Condition</u>

Native Species Richness

The mānele/koa/ʻōhiʻa forests within Kīpuka Puaulu and Kīpuka Kī are considered "one of the most botanically diverse forest communities of HAVO" (Pratt et al. 2011). The native woody plant flora, in particular, supports the richest vascular plant assemblage per hectare (Belfield et al. 2011). The canopy in these kīpuka is dominated by three tall native trees; however, the understory contains a diversity of common and uncommon native trees, as well as native herbs and ferns. High native species richness in these kīpuka has been attributed to the ability to support plants typically more characteristic of other moisture regimes, as well as the forests' latter stage of succession (Belfield et al. 2011).

During the survey conducted in 1963 through 1965, 52 naturally occurring native species were recorded in the kīpuka. A greater number of naturally occurring native species was recorded in Kīpuka Puaulu (48 native species) compared to Kīpuka Kī (30 native species). Native species comprised 52% and 48% of the total flora at Kīpuka Puaulu and Kīpuka Kī, respectively (Mueller-Dombois and Lamoureux 1967).

Currently, at least 39 native plant species are known to occur within Kīpuka Kī and Kīpuka Puaulu (Benitez et al. 2008, Pratt et al. 2010, Belfield et al. 2011, Pratt et al. 2011). However, some of these only exist as plantings. Twenty-two native plant species were planted in the montane mesic forests in the early 2000s (Belfield et al. 2011).

<u>Presence and Abundance of Listed Species/SOC</u>

Kīpuka Puaulu and Kīpuka Kī provide important refuge for listed or rare plant species. Twelve listed species or SOC currently occur in these two kīpuka (Table 4.11-1). Five of these species only exist as plantings. Several of these rare species are restricted to the mesic environment.

Table 4.11-1. Listed species and SOC currently or previously recorded in Kīpuka Puaulu and Kīpuka Kī. E = endangered, C = candidate for listing, SOC = Species of Concern.

Scientific Name	Common Name	Status	Occurrence
Alphitonia ponderosa	Kauila, kauwila	SOC	Planted only
Clermontia lindseyana	‘Ohā wai, Lindsey’s ‘ōhā	E	Natural and planted
Embelia pacifica	Kilioe	SOC	Natural and planted
Hibiscadelphus giffardianus	Kau kuahiwi	E	Planted only
Melicope hawaiensis	Mokihana kūkae moa, manena, alani	SOC	Natural and planted
Melicope zahlbruckneri	Alani, Zahlbruckner’s pelea	E	Natural and planted
Neraudia ovata	Ma‘aloa	E	Planted only
Nothocestrum breviflorum	‘Aiea	E	Planted only
Ochrosia haleakalae	Hōlei	C	Planted only*
Ochrosia kilaueaensis	Hōlei	E	Extirpated
Phyllostegia stachyoides	–	SOC	Natural and planted
Sicyos macrophyllus	‘Anunu, large-leaved ‘ānunu, large leaf bur cucumber	C	Natural and planted
Zanthoxylum dipetalum var. dipetalum	Kāwa‘u	SOC	Natural and planted
Zanthoxylum hawaiiense	A‘e, Hawai‘i pricklyash	E	Extirpated

* Historically not known to naturally occur in HAVO.

Two listed species that were previously found in Kīpuka Puaulu have been extirpated from the Park (Pratt et al. 2011). Hōlei (*Ochrosia kilaueaensis*) has not been observed since 1927 and a‘e (*Zanthoxylum hawaiiense*) was last reported in 1921 (Pratt et al. 2011).

Phyllostegia stachyoides no longer occurs in Kīpuka Puaulu (Pratt et al. 2011). The study by Pratt et al. (2010) found that the current population of three species in the montane mesic forests (*mokihana kūkae moa, Zahlbruckner’s pelea, and kāwa‘u*) are declining compared to data collected 15 years before. Indicators of a declining population structure for these species include fewer mature trees, decrease in tree diameter, and lack of reproduction (Pratt et al. 2011). For the remaining species, data on the number of individuals compared to historical estimates are not available or inconclusive.

<u>Number and Distribution of Invasive Target Plant Species</u>
Of the 134 invasive plants currently managed throughout the Park, about 22 species (over 16%) are known to occur within Kīpuka Puaulu and Kīpuka Kī. The broad estimated ranges of these species within Kīpuka Puaulu and Kīpuka Kī are shown in Table 4.11-2 (Benitez et al. 2012). The species abundance or density within each range was not documented, but varied considerably among species (e.g., a few individuals of faya tree to significant patches of meadow rice grass).

Table 4.11-2. Invasive plants and estimated range within Kīpuka Puaulu and Kīpuka Kī. Derived from GIS data from Benitez et al. (2012).

Scientific Name	Common Name	Range
Andropogon virginicus	Broomsedge	186 ha (459 ac)
Anemone hupehensis	Japanese anemone	2 point locations
Asclepias physocarpa	Balloon plant	186 ha (459 ac)
Buddleia asiatica	Butterfly bush	114 ha
Commelina diffusa	Honohono grass	3 point locations
Ehrharta stipoides	Meadow rice grass	186 ha (459 ac)
Hedychium gardnerianum	Kāhili ginger	112 ha (277 ac)
Melinis minutiflora	Molasses grass	143 ha (354 ac)
Morella faya	Faya tree	186 ha (459 ac)
Passiflora edulis	Purple granadilla	91 ha (225 ac)
Pennisetum clandestinum	Kikuyu grass	186 ha (459 ac)
Persicaria capitata	Knotweed	186 ha (459 ac)
Plumbago auriculata	Plumbago	1 point location
Psidium cattleianum	Strawberry guava	186 ha (459 ac)
Psidium guajava	Common guava	76 ha (187 ac)
Rubus argutus	Florida prickly blackberry	186 ha (459 ac)
Rubus rosifolius	Thimbleberry	186 ha (459 ac)
Schinus terebinthifolius	Christmasberry	91 ha (225 ac)
Schizachyrium condensatum	Bush beard grass	186 ha (459 ac)
Solanum pseudocapsicum	Jerusalem cherry	186 ha (459 ac)
Soliva sessilis	Soliva	1 point location
Tropaeolum majus	Common nasturtium	168 int locations

Portions of both Kīpuka Puaulu and Kīpuka Kī are intensively managed for invasive plants using the SEA approach. Nonnative plant control began in Kīpuka Puaulu in the mid-1980s and in 1990 for Kīpuka Kī (Belfield et al. 2011). Three invasive plants formerly occurred in the two montane mesic kīpuka, but have been eradicated as a result of management efforts. These include Chinese melon (*Benicasa hispida*), common fig (*Ficus carica*), and octopus tree (*Schefflera actinophylla*) (Benitez et al. 2012).

The amount of infested area of invasive species in Kīpuka Puaulu and Kīpuka Kī has decreased since the late 1980s due to invasive plant control in the SEAs (Tunison and Stone 1992, Loh et al. 2014). In 1986, roughly 40 invasive individuals representing kāhili ginger, Jerusalem cherry (*Solanum pseudocapsicum*), strawberry guava, faya tree, and Florida prickly blackberry were treated per hectare in Kīpuka Puaulu (Figure 4.11-2). This number has decreased to below 5 individuals/ha (Loh et al. 2014). Information on Kīpuka Kī is not provided.

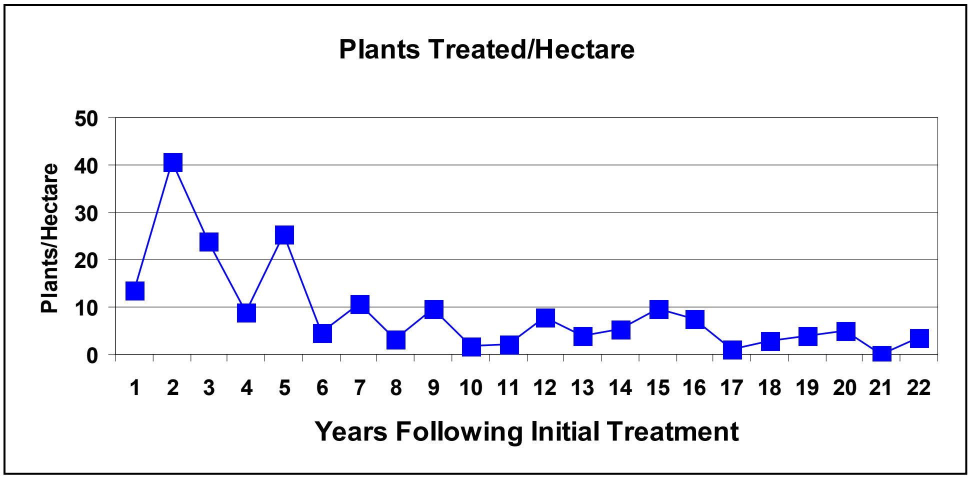

Figure 4.11-2. Number of invasive plants (kāhili ginger, Jerusalem cherry, strawberry guava, faya tree, and Florida prickly blackberry) treated in Kīpuka Puaulu between 1985 and 2007 from Loh et al. (2014).

<u>Percent of Area Protected From Ungulates</u>

Kīpuka Puaulu has been ungulate-free since 1968. Ungulates were removed from Kīpuka Kī and other remnants of mānele/koa/ʻōhiʻa forest in the MaunaLoa Strip by the late 1980s (Pratt et al. 2010, Belfield et al. 2011).

<u>Threats and Stressors</u>

Invasive plants represent an important threat to native species in the mānele/koa/ʻōhiʻa forests, despite ongoing control efforts. Rodents are also known to consume and damage seeds and saplings of rare and listed species in these forests (Pratt et al. 2010). MaunaLoa is an active volcano and lava flows could lead to loss of plant communities. Finally, this mesic forest community is vulnerable to fire. The Broomsedge Burn, which burned in 2000, came within 50 m (164 ft) of the Kīpuka Puaulu SEA (Loh et al. 2007).

<u>Overall Condition</u>

As stated above, Kīpuka Puaulu and Kīpuka Kī are considered the best examples of the critically imperiled koa/ʻōhiʻa/mānele forest within the state (Gagné and Cuddihy 1999) and these kīpuka contain a high diversity of native species. Invasive species are controlled to low densities and ungulates have been excluded. However, two endangered species have been extirpated from the kīpuka and evidence suggests that populations of other listed species and SOC are declining. It is difficult to determine the condition of the other smaller koa/ʻōhiʻa/mānele forests due to the lack of specific data for these areas. All of these forests are fenced. Due to difference in the condition across the Park, the overall condition of the mānele/koa/ʻōhiʻa montane mesic forest plant communities in HAVO is considered of moderate concern.

Information Gaps/Level of Confidence

For Kīpuka Puaulu and Kīpuka Kī, quantitative data are available for multiple measures over multiple years. This is likely due to the high botanical diversity in these areas. In contrast, very limited data are available for the other mānele/koa/ʻōhiʻa forests in the Park. Due to the availability of historic and recent data, yet lack of data outside of Kīpuka Puaulu and Kīpuka Kī, the extent of the knowledge base of this indicator is ranked as B.

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4.12. Coastal Strand Communities

Background

Coastal strand communities occur in the strip of land along the shoreline that is strongly influenced by the sea. The halophytic flora of these communities is adapted to salt spray, saline soil, strong winds, low moisture, high rates of evaporation, and shoreline processes. As a result of these harsh conditions, the vegetation is often low growing or mat forming. Coastal strand species are dispersed by wind and water and are typically incapable of migration outside of the coastal zone (Mueller-Dombois and Fosberg 1998, Gagne and Cuddihy 1990).

Compared to other plant communities in Hawaiʻi, coastal strand communities have a smaller percentage of endemic species. However, the flora of this community is relatively diverse given its limited size and several rare and listed species occur (Gagne and Cuddihy 1990, Warshauer et al. 2009).

At HAVO, coastal strand communities occur along the 53 km (33 mi) of coastline within the coastal habitat ecological unit. The inland extent of these communities can reach up to 150 m (492 ft) from the shore. Coastal strand communities are typically narrow in areas above high cliffs and extend farther inland (mauka) in low bluff or beach areas. The upper fringe merges with coastal lowland vegetation. Substrate in the coastal strand communities varies in age and composition from pāhoehoe and ʻaʻā flows to sandy beaches (Kozar et al. 2007, Belfield et al. 2011).

Small, disjunct areas of well-developed coastal strand vegetation occur at HAVO, mostly on older substrates (Belfield et al. 2011). Notable areas with strand communities in HAVO include Hōlei Sea Arch, Kaʻena Point, Kealakomo, Kaʻaha, Kaluē, Halapē, Keauhou, ʻĀpua Point, and Kahue Point (Table 4.12-1, Figure 4.12-1). The largest remaining coastal strand habitat in the Park occurs at ʻĀpua Point (Loh et al. 2014). Restoration efforts have been implemented at HAVO to augment and stabilize common and uncommon native plants (Belfield et al. 2011). The coastal strand community is not included within the focal plant communities monitored in HAVO (Ainsworth et al. 2011); however, rare and listed Hawaiian plants are present within this community.

Table 4.12-1. Notable coastal strand sites at HAVO.

Name	Type
ʻĀpua Point	low bluff
Halapē	low cobble/sandy beach
Hōlei Sea Arch	high bluff
Ka Laeʻapuki	covered by lava flow
Kaʻena Point	high bluff
Kealakomo	low bluff

Table 4.12-1 (continued). Notable coastal strand sites at HAVO.

Name	Type
Kahue	low bluff
Ka‘aha	low bluff
Kaluē	low bluff
Keauhou Landing	low sandy beach
Waha‘ula	covered by lava flow

The majority of the coastal areas in the Hawaiian Islands have been severely disturbed and degraded by previous human activities (Warshauer et al. 2009). Many of these areas continue to undergo development. The coastal strand communities at HAVO are protected from these impacts; however, potential remains for abrupt changes due to natural causes, such as subsidence, tsunamis, and lava flows.

Measures

- Native species richness
- Presence and abundance of listed species/SOC
- Number and distribution of invasive target plant species
- Percent of area protected from ungulates

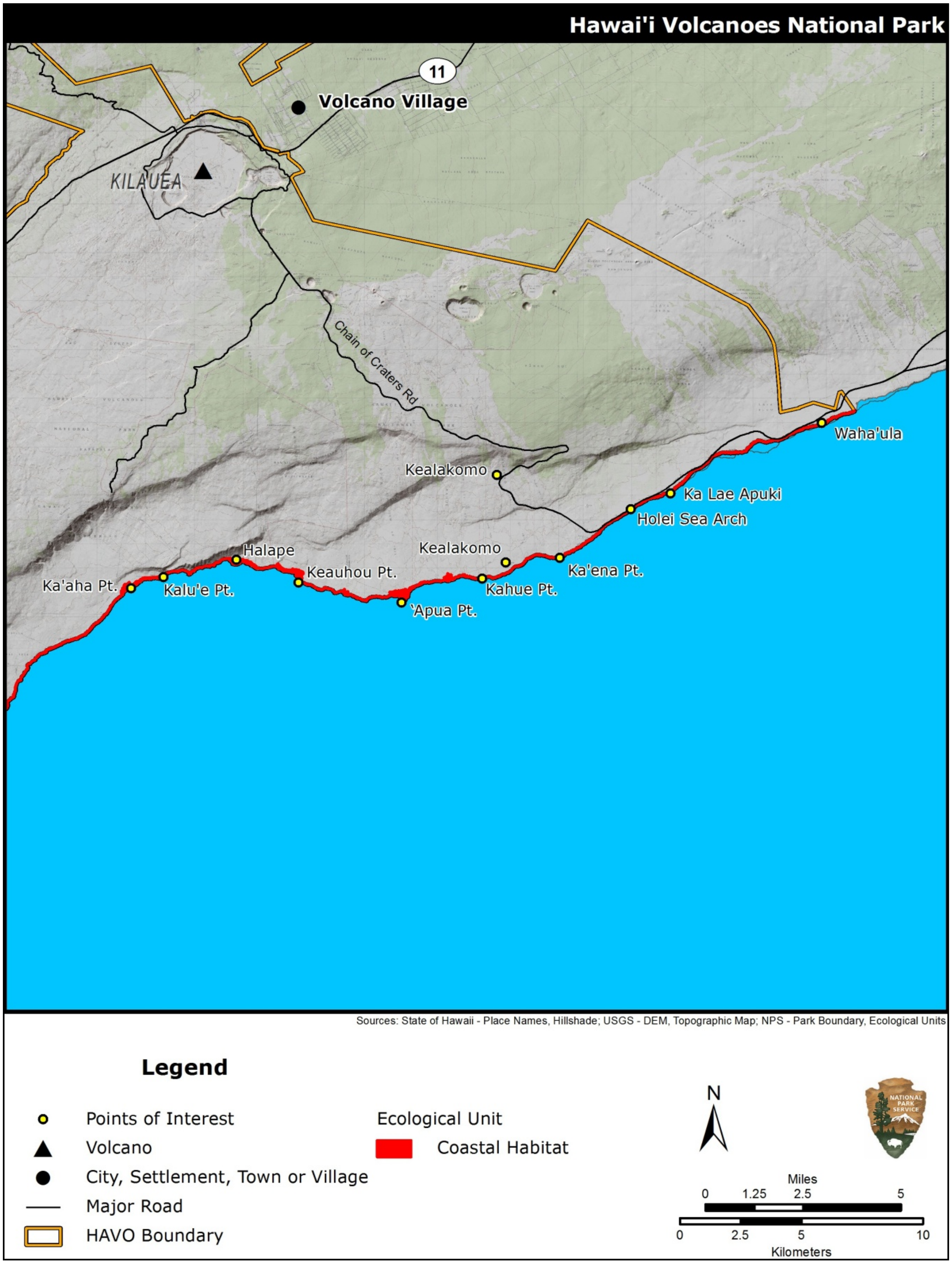

Figure 4.12-1. Coastal Habitat Ecological Unit and notable coastal strand sites (Belfield et al. 2011).

Reference Condition/Value

Very few coastal areas throughout the Hawaiian Islands contain diverse, intact, and extensive native strand communities. Warshauer et al. (2009) reviewed coastal sites in the state and identified several notable sites with "high species diversity and/or populations of rare plant species" that also had "an established connection with contiguous lowland vegetation" (Warshauer et al. 2009). None of these sites occur on the Island of Hawaiʻi.

Warshauer et al. (2009) reported that the most species-rich coastal sites occurred on Maui and Molokaʻi (between 30 and 32 species) and very few coastal sites contained over 20 native plant species. The reference condition for native species richness at HAVO is 20 native species. The reference condition for listed species/SOC is that none of these species historically recorded in the coastal strand communities at HAVO have been extirpated and the number of individuals remain in the range historically reported.

Two of the greatest threats to native plant communities in Hawaiʻi are invasive plants and invasive ungulates. Roughly 134 plant species are considered invasive and highly disruptive to native ecosystems in HAVO (Benitez et al. 2012). A reference condition for the number and distribution of invasive species within the coastal strand is not defined at this time. The reference condition for percent protected from ungulates is 100% exclusion.

Existing Data

Very few surveys and studies focus specifically on the coastal strand communities throughout HAVO; however, data from these communities have been collected during larger, Park-wide surveys and restoration projects. Additional researchers have made notes on the strand vegetation during their surveys of other coastal resources. The following resources were used to asses this indicator.

- In 1980, Smith proposed a restoration program for three coastal strand sites: Halapē, Keauhou, and ʻĀpua Point. The report includes descriptions of the existing vegetation types within the sites, a list of all species observed, and cover estimates (Smith 1980).
- Higashino et al. (1988) provided a checklist of vascular plants seen throughout HAVO during surveys conducted since 1944. Species found within the coastal lowland zone (including strand, grassland, shrublands, etc.) were noted.
- Chai et al. (1989) noted vegetation during a study of anchialine pools, some of which occur within the coastal strand.
- Tunison et al. (1992) mapped select invasive plants throughout the Park between 1983 and 1985. This included a survey of the coastal shoreline of the Park between the western boundary and the MaunaUlu flow.
- Kozar et al. (2007) discussed vegetation at coastal sites while surveying for seabirds and shorebirds along the coast.
- More recently, Belfield et al. (2011) implemented a rare plant stabilization program throughout HAVO, which included outplanting common and uncommon species at seven coastal strand sites: Ka Laeʻapuki (now covered by recent lava flows), Hōlei Sea Arch,

Kaʻena Point, Kealakomo, Kahue, Kaʻaha-Kaluē, and Keauhou Landing. This project noted plant species and existing conditions at the sites and monitored outplanted species and seeding activities. The goal was to create diverse, self-perpetuating native strand plant communities comprised of characteristic shrubs and vines.

- Pratt, VanDeMark, et al. (2011) examined the status and limiting factors of ʻōhai at ʻĀpua Point. The research assessed several factors including stand structure, mortality rates, reproductive phenology, fruit production, and the soil seed bank.
- Pratt, Pratt, et al. (2011) provided distribution maps and descriptions of rare and listed plants within the Park, including the coastal zone.
- Benitez et al. (2012) recorded invasive plants throughout the Park, indicating the presence of identifiable individuals as observed from trails, roads, and fences. Additionally, a 50 × 50-m (164 ft) GIS grid was developed to map particular species along open areas. Some comparisons between previous surveys are provided to evaluate changes in invasive distributions.
- NPS's I&M Program collected pilot data at HAVO's anchialine pools between 2008 and 2010. The I&M Anchialine Pool Monitoring access database (NPS 2011) contains information on plant cover in the vicinity of the pools.
- In 2012, NPS delineated the coastal habitat unit to recognize areas with coastal strand vegetation and coastal wildlife habitat. Specific areas of coastal strand were indicated. The method for delineating these areas is unknown.
- In 2013, the Park released a Final Plan / Environmental Impact Statement for Protecting and Restoring Native Ecosystems by Managing Non-native Ungulates (NPS 2013), which provided the most current information on ungulate abundance in the Park.

Loh et al. (2014) discuss invasive plant control at the ʻĀpua Point SEA.

Current Condition

Native Species Richness

An estimated 29 native strand species occur within the coastal strand communities at HAVO (Smith 1980, Higashino et al. 1988, Chai et al. 1989, Belfield et al. 2011, NPS 2011, Pratt, Pratt, et al. 2011). Two native species—Hilo ischaemum (*Ischaemum byrone*) and loulu (*Pritchardia affinis*)—only occur as rare plantings. Four native species have been extirpated from the coastal strand (Table 4.12-2) (Belfield et al. 2011).

As shown in Figure 4.12-2, Smith (1980) reported 14 native plant species at ʻĀpua Point and Halapē and 16 native plant species at Keauhou. Common native strand vegetation at HAVO include the naupaka shrub, mauʻu ʻakiʻaki sedge, pōhuehue, ʻilima (*Sida fallax*), and pili grass.

Table 4.12-2. Status of plant species documented in coastal strand communities.

Plant Category	# of Species
Native plant species[1]	29
Federally/State Listed	3
SOC	1
Extirpated species	4
Nonnative plant species	45
HAVO invasive targets[2]	12

[1] Includes indigenous and endemic species.

[2] Source: Benitez et al. 2012.

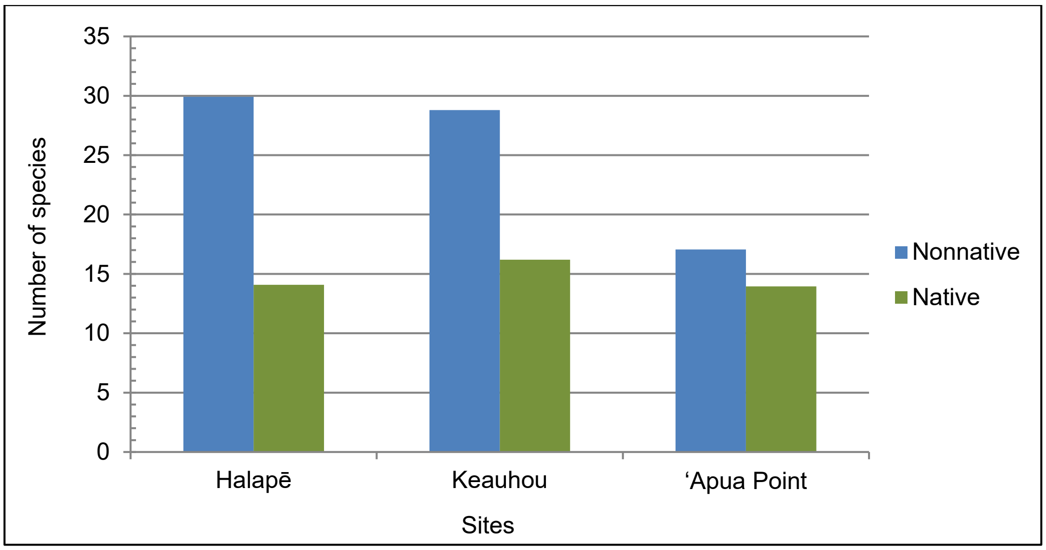

Figure 4.12-2. Number of native vs. nonnative plant species observed at three coastal sites by Smith (1980).

In contrast, at least 45 nonnative species have been reported from the coastal strand communities (Smith 1980, Chai et al. 1989). Common nonnatives include sourbush, lantana, and coconut. In 1980, Smith found that there was a higher percentage of nonnative species than native species in the coastal areas at 'Āpua Point, Halapē, and Keauhou. 'Āpua Point had the highest proportion of native species, with ~45% native species. A comprehensive list of all nonnative plants specifically within the coastal strand communities does not exist.

Presence and Abundance of Listed Species/SOC

Three listed species currently occur or were previously recorded in the coastal strand: 'ōhai, Hilo ischaemum, and loulu. Additionally, three SOC have been reported in the coastal strand communities: 'ihi (*Portulaca villosa*), maiapilo (*Capparis sandwichiana*), and Hawaiian fringed sedge (*Fimbristylis hawaiiensis*). 'Ihi and maiapilo are believed to be extirpated. Recent restoration efforts for these species were unsuccessful (Belfield et al. 2011). As stated above, Hilo ischaemum and loulu only occur as rare plantings.

‘Ōhai and Hawaiian fringed sedge are the only naturally extant listed species/SOC within the coastal strand communities at HAVO. The ‘Ōhai Lowland Dry Shrubland is considered a rare plant community (Figure 4.12-3). It is present at fewer than 10 occurrences within the Park (Pratt, et al. 2011). Within the coastal strand, ‘ōhai occurs at Kū‘ē‘ē, ‘Āpua Point, and Ka‘aha and has been planted at other coastal sites (Pratt, Pratt, et al. 2011). A recent study by Pratt, VanDeMark, et al. (2011) indicates that ‘ōhai at ‘Āpua Point is declining in numbers.

Figure 4.12-3. ‘Ōhai Lowland Dry Shrubland (Photo: Linda Pratt 2011).

Hawaiian fringed sedge occurs along the HAVO coastline from Ka Lae‘apuki to Kū‘ē‘ē, and at Pu‘u Loa and Ka‘ena Point. The species was recently monitored for a 5-year period at Pu‘u Loa and Ka‘ena Point (Pratt, Pratt, et al. 2011), but abundance estimates and trends were not reported.

Number and Distribution of Invasive Target Plant Species

Out of the roughly 134 invasive target plants that are monitored at HAVO, about 11 species (8%) are currently known in the coastal strand communities (Table 4.12-3) (Benitez et al. 2012). Species common in the coastal strand include balloon plant, koa haole, lantana, molasses grass, and thatching grass. Black-eyed Susan (*Abrus precatorius*) was previously noted in the coastal zone, but eliminated due to lava flows and control efforts (Benitez et al. 2012). Maunaloa vine (*Canavalia cathartica*), which was previously controlled is not currently listed on HAVO’s target list, and occurs at ‘Āpua Point (Loh et al. 2014).

Table 4.12-3. Target invasive plant species documented within HAVO's coastal strand communities during previous surveys. Distribution is listed within the coastal lowland zone, which may extend beyond coastal strand. An "X" indicates that the species was identified as being inside the park for that study.

Scientific Name	Common Name	Higashino et al. 1988	Tunison et al. 1992	Benitez et al. 2012
Asclepias physocarpa	Balloon plant	X	–	X
Abrus precatorius	Black-eyed Susan	X	–	–
Ricinus communis	Castorbean	X	X	X
Schinus terebinthifolius	Christmasberry	X	–	X
Phoenix dactylifera	Date palm	X	–	X
Cenchrus setaceus	Fountain grass	X	X	X
Urochloa maxima	Guinea grass	X	–	X
Prosopsis pallida	Kiawe	X	X	X
Leucaena leucocephala	Koa haole	X	X	X
Lantana camara	Lantana	X	–	X
Melinis minutiflora	Molasses grass	X	–	X
Hyparrhenia rufa	Thatching grass	X	–	X

Percent of Area Protected From Ungulates

Goats, cattle, mouflon, and sheep have been excluded from HAVO's coastal zone (NPS 2013). The eastern portion of the coastal zone is not fenced, but the area is protected by vast fields of recent lava flows. Pig occurrences are rare along the shoreline and in coastal strand communities (Rhonda Loh, Chief of Natural Resources Management, NPS HAVO, pers. comm. 2014).

Threats and Stressors

Similar to other coastal areas on Hawaiʻi Island, the coastal zone at HAVO is continually threatened by invasive species. Invasive plants compete with native plants for limited resources. Ants and rodents are known to adversely impact coastal plants. For example, rats are known seed predators of ʻōhai and ants have been observed impacting interactions with native pollinators (Hopper 2002). Reduction in natural pollinators has been noted to inhibit reproduction of some coastal plants (Pratt, Pratt, et al. 2011). Additionally, if active lava flows cease on the east end of Kīlauea, there is potential for ungulate ingress (NPS 2013).

Furthermore, the coastal strand communities at HAVO are continuously subject to abrupt and dramatic changes due to the active geology of the Park. Subsidence, tsunamis, earthquakes, and lava flows have impacted or removed species and communities in the coastal strand. Finally, this plant community is threatened by tidal inundation and sea level rise associated with climate change.

Overall Condition

According to Belfield et al. (2011), the coastal strand is one of the most degraded and simplified native ecosystems in HAVO. Only small, fragmented areas of intact and well-developed coastal strand vegetation occur. These are located on older substrates in low bluff or beach environments.

Native species richness at the more intact sites is relatively low, potentially due to the new substrates that have not undergone much succession. Listed species and SOC have been extirpated in the coastal strand or only occur as plantings, and the only extant endangered species appears to be declining. The coastal strand communities are also threatened by various invasive plants. Thus, this indicator does not meet all or most of the reference conditions, ranking it as Moderate with an unknown trend.

Information Gaps/Level of Confidence
Data within the coastal strand communities consists mostly of non-repeatable plant inventories and monitoring of outplants. There is a general lack of quantitative information (i.e., cover, density, frequency) within this specific plant community. Additionally, previous inventories appear to have lumped coastal lowland occurrences and distributions with coastal strand, making separation between these areas difficult. Overall, the data for this indicator is ranked B.

Monitoring of the coastal strand areas has not been listed as a priority at HAVO; however, a more systematic monitoring of the quantitative and qualitative attributes of the plant species would provide more detail about the coastal strand communities. An analysis of the trend of this community type could be obtained by comparing to prior information, for example, from Smith in 1980. More specific details on diseases, pathogens, and predators could also be noted.

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4.13. Landbirds

Background

Only 42 of the once 113 species of native landbirds existed at the time of first human contact persist in the Hawaiian Islands (Pyle 2002). Thirty of the remaining species are listed as federally threatened or endangered and 10 of them have not been seen in the last 40 years, (Judge et al. 2011) and could be extinct. Fourteen native landbird species are present on the Island of Hawaiʻi, all of which 14 are endemic to the Hawaiʻi Islands and 8 (more than 50%) are listed as threatened or endangered. Some species, such as the Hawaiian hawk or ʻio (*Buteo solitarius*) and the Hawaiian goose or nēnē (*Branta sandvicensis*), are found in predominantly native as well as disturbed habitats.

However, many of the forest bird species are confined to native forests, particularly montane forests above the mosquito line, or the highest elevation at which mosquitos are currently found, due to their susceptibility to avian malaria (Atkinson and LaPointe 2009). Available mosquito-free montane habitat is anticipated to further narrow with the increasing effects of climate change. These montane species also face predation pressure from introduced mammals and habitat destruction due to feral ungulates. At the same time, many landbirds, such as the ʻōmaʻo, are dispersers of native seeds (Wakelee and Fancy 1999), and may be important to the restoration of native forests. Many of the nectar feeding native landbirds such as the ʻapapane (*Himatione sanguinea*), ʻiʻiwi (*Vestiaria coccinea*) (Figure 4.13-1), and ʻamakihi (*Hemignathus virens*), are important for the pollination of native plants such as ʻōhiʻa (Carpenter 1976).

Figure 4.13-1. ʻIʻiwi (*Vestiaria coccinea*) are one of the native nectar feeding landbirds at HAVO (Photo: Jaap Eijzenga 2010).

Because HAVO encompasses diverse habitats and spans a large elevational range, many listed and native landbird species are able to persist within HAVO. However, even these areas are not sufficient to provide year-round range for most native landbirds.

Measures

- Number of native landbird species present
- Number of endangered or threatened landbird species present
- Population trends of landbirds

Reference Condition/Value

The number of native species present and the number of endangered or threatened species present in HAVO relative to the number that are currently extant on Hawaiʻi Island is used to determine 1) how intact the native landbird assemblages are within HAVO habitats, and 2) if specific endangered or threatened species are able to find suitable habitat in HAVO to use or expand into.

No reference condition (i.e., a target percentage) is defined for either measure above, but a high percentage (e.g., of more than 50% or a majority), would indicate that HAVO provides significant habitat for the native landbird assemblages found in or around the Island of Hawaiʻi or contains a high proportion of listed landbird species.

The availability of long-term monitoring data sets enables an assessment of the population trends of native landbirds within HAVO. The most recent trend analyses by Judge et al. (2011) had the power to identify a 50% change in the population over 25 years. Changes in population density, or trends, were defined as increasing, decreasing, stable, or an inconclusive result. The reference condition for population trends for landbird species is a stable population trend.

The *Draft Revised Recovery Plan for the Nēnē* states as one of the recovery criteria that self-sustaining populations need to exist on Hawaiʻi, Maui Nui, and Kauaʻi (USFWS 2004). Self-sustaining is defined as "maintaining (or increasing) established population levels without additional releases of captive-bred nēnē, although habitat manipulation, such as predator control or pasture management, may need to be continued" (USFWS 2004). Thus, the reference condition for nēnē at HAVO is also a stable population trend.

Existing Data

The following literature sources were used to assess landbirds.

- The PACN annual report by Judge et al. (2011) documents the status of three endangered native Hawaiian honeycreepers—ʻakiapolaʻau (*Hemignathus munroi*), Hawaiʻi creeper (*Oreomystis mana*), and Hawaiʻi ʻakepa (*Loxops coccineus*)—and five additional native species—Hawaiʻi ʻelepaio (*Chasiempis sandwichensis*), ʻōmaʻo (*Myadestes obscurus*), Hawaiʻi ʻamakihi (*H.v. virens*), ʻiʻiwi, and ʻapapane—in lands adjacent to and within HAVO in 2010 (Figure 4.13-2). Change in population densities between the 2010 survey and the most recent survey (either 1994 or 2005 from Gorresen et al. [2005] and Tweed et al. [2007]) were compared to determine if populations were increasing, decreasing, stable, or inconclusive. Data from prior studies such as the landmark Hawaii Forest Bird Survey (HFBS) (Scott et al. 1986), which included certain forested portions of HAVO, were also included in the report when available. Since 1986, forest bird surveys have also been conducted by Kamehameha Schools, the State of Hawaiʻi Division of Forestry and Wildlife, NPS, USGS, and USFWS and these data were also included when present.

- In addition to the PACN landbird survey, a lowland bird inventory was conducted at HAVO in 2005 using area searches and line transects (Turner et al. 2006) (Figure 4.13-2) comprising woodlands, barren, and shrubland/grassland habitat. The goal was to document at least 90% of bird species present, estimate relative abundance and distribution, and to provide a baseline for future monitoring.
- Data for the distribution of the ʻio are from Gorresen et al. (2008) and Pratt et al. (2011).
- Nēnē distribution data and fledgling success were obtained from Pratt et al. (2011) and the HAVO annual reports (NPS 2000, 2001, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012).

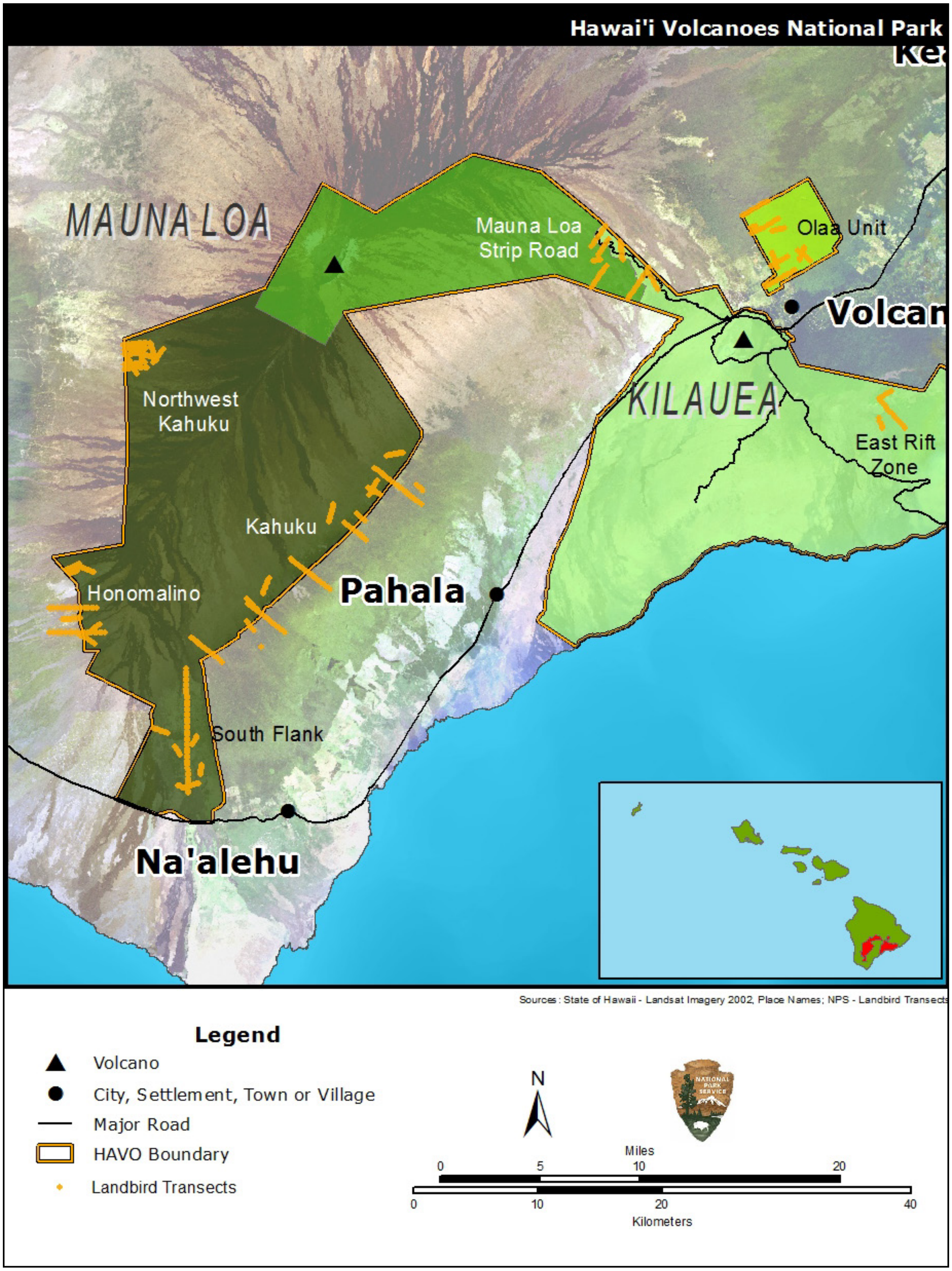

Figure 4.13-2. PACN landbird monitoring tracts at HAVO from Judge et al. (2011).

Current Condition

Number of Native Landbird Species Present

Of the 14 native landbirds recorded on the Island of Hawai‘i, 11 species (79%) are present within HAVO (Table 4.13-1). Absent species include the endangered palila (*Loxioides bailleui*), which is currently only found on the slopes of MaunaKea; the Hawaiian crow (*Corvus hawaiiensis*), which is extinct in the wild; and the ‘ō‘ū (*Psittirostra psittacea*), which is possibly already extinct. Thus, all landbird species for which suitable habitat is available and can be found within the geographic region of HAVO are present within the Park (Table 4.13-1) and the assemblage of landbird species on the Island of Hawai‘i is well represented at HAVO. Of the 29 species of landbirds detected in the 2010 forest bird survey by Judge et al. (2011), two-thirds were nonnative (19 species) and 10 species were native.

Table 4.13-1. Landbird species found on the Island of Hawai‘i (adapted from Pyle 2002 and Pyle and Pyle 2002) and presence within HAVO. E = endangered. An “X” indicates that the species was identified as being inside the park for that study.

			Presence in Surveys of HAVO		
Species Name	**Common Name**	**Status**	**Lowland[1]**	**Forest Bird[2]**	**All Combined**
Hemignathus munroi	‘akiapola‘au	E	–	X	X
Himatione sanguinea	‘apapane	–	X	X	X
Loxops coccineus	Hawaii ‘akepa	E	–	X	X
Hemignathus virens	Hawaii ‘amakihi	–	X	X	X
Oreomystis mana	Hawaii creeper	E	–	X	X
Chasiempis sandwichensis	Hawaii ‘elepaio	–	–	X	X
Corvus hawaiiensis	Hawaiian crow	E	–	–	–
Branta sandvicensis	Hawaiian goose (nēnē)	E	X	X	X
Buteo solitarius	Hawaiian hawk (‘io)	T	X	X	X
Asio flammeus sandwichensis	Hawaiian owl	–	X	–	X
Vestiaria coccinea	‘i‘iwi	–	–	X	X
Myadestes obscurus	‘ōma‘o	–	X	X	X
Psittirostra psittacea	ou	E	–	–	–
Loxioides bailleui	palila	E	–	–	–
Total	**14**	–	**6**	**10**	**11**

[1] Turner et al (2006)

[2] Judge et al. (2011)

Number of Endangered or Threatened Landbird Species Present

Approximately half (45% or 5 out of 11) of the native landbirds detected by Judge et al. (2011) were endangered species. This includes the nēnē, ʻio, ʻakiapolaʻau, Hawaiʻi creeper, and Hawaii ʻakepa. HAVO provides habitat for a large number of the threatened and endangered bird species found on Hawaiʻi Island. The nēnē and ʻio are further discussed in detail below.

Population Trends of Landbirds

In general, Judge et al. (2011) reported that forest bird abundance was greater for the 2010 survey than almost all previous surveys. Enough data to determine population trends were collected for five native species from trends analysis. The trends for these species are largely positive (Table 4.13-2a). The native ʻapapane and Hawaii ʻamakihi were detected throughout the tracts, had the highest relative abundances of native bird species and were generally on the increase at most of the sites (Table 4.13-2b, 4.13-3). The presence of ʻapapane throughout all tracts is likely an indicator of resistance to avian malaria, which has restricted the range of many other native forest bird species, such as ʻiʻiwi (Woodworth et al. 2005).

The ʻōmaʻo, ʻiʻiwi, and Hawaiʻi ʻelepaio were detected in modest densities in most tracts (Tables 4.13-2, 4.13-3). A possible range expansion was detected for the ʻōmaʻo. The ʻōmaʻo was considered extirpated from the southwest flank of MaunaLoa since the 1970s, but was detected in the high elevation tracts (northwest Kahuku and Papa) of the region in the 2010 surveys (Tables 4.13-2, 4.13-3). However, the ʻōmaʻo have declined in the ʻŌlaʻa tract (Table 4.13-2).

At HAVO, ʻiʻiwi were restricted to elevations above 1,500 m (4,900 ft) where the disease vector-mosquito (*Culex quinquefasciatus*) for avian malaria is absent. ʻIʻiwi were present at low densities relative to most species and also declined in the northwest Kahuku tract (Tables 4.13-2 and 4.13-3).

Hawaiʻi ʻelepaio were most abundant in the moderately dry native montane forest of the MaunaLoa Strip tract, but were absent or detected in low densities in all other tracts (Tables 4.13-1, 4.13-2, and 4.13-3). Hawaiʻi ʻelepaio trend data are inconclusive in all tracts. As surveys of the leeward and mid-elevation windward tracts on Hawaiʻi Island (outside of HAVO) have shown a decline in ʻelepaio densities (Gorresen et al. 2005, Camp et al. 2009), ʻelepaio densities in HAVO warrant further monitoring in order to detect a potential population decline. ʻElepaio were also absent in the lowlands of HAVO in the recent lowland bird inventory (Turner et al. 2006), while previously present in the 1980s.

The Hawaiʻi Forest Bird Survey surveys in 1976 (Kaʻū) and 1978 (Kona) found that the Kahuku unit contained important populations of three endangered forest bird species: ʻakiapolaʻau, Hawaii ʻakepa, and Hawaii creeper. The Park acquired the Kahuku unit in 2003. A subsequent bird survey reported these three species (Tweed et al. 2007) in the area. In 2010, ʻakiapolaʻau, Hawaiʻi ʻakepa, and Hawaiʻi creeper were recorded in low numbers (4, 20, and 26 individuals, respectively) (Judge et al. 2011) (Table 4.13-1), and primarily in the mature montane and subalpine forests of the Kahuku tract above 1,300 m (4,300 ft) elevation. During the 2010 survey, Hawaiʻi creeper was the most abundant endangered species in the Kahuku tract and was even detected in small numbers in the Honomalino and Papa tracts for the first time since the Hawaiʻi Forest Bird Survey began.

Table 4.13-2a. Landbird survey trend data summarized from Judge et al. (2011). 6t ↑ - increasing trend ↓ - decreasing trend. ? – Trend inconclusive.

Scientific Name	Common Name	With Trends							
		East Rift Zone	Honomalino	Kahuku	MaunaLoa South Flank	MaunaLoa Strip	North-west Kahuku	ʻŌlaʻa	Papa
Himatione sanguinea	ʻapapane	↑	↑	↑	↑	↑	?	↑	↑
Hemignathus virens	Hawaii ʻamakihi	?	↑	↑	↑	↑	↑	?	↑
Chasiempis sandwichensis	Hawaii ʻelepaio	–	?	?	–	?	?	?	–
Vestiaria coccinea	ʻiʻiwi	–	?	?	–	?	↓	?	ND
Myadestes obscurus	ʻōmaʻo	↑	–	?	?	↑	ND	↓	ND

Table 4.13-2b. Landbird survey absence/presence data summarized from Judge et al. (2011). D – Detected by Judge et al. (2011) but insufficient data for trend analysis. ND – new detections within unit. X – Detected only by Tweed et al. (2007).

Scientific Name	Common Name	With Trends							
		East Rift Zone	Honomalino	Kahuku	MaunaLoa South Flank	MaunaLoa Strip	North-west Kahuku	ʻŌlaʻa	Papa
ʻakiapolaʻau	*Hemignathus munroi*	–	–	D	–	–	–	–	–
Hawaii ʻakepa	*Loxops coccineus*	–	–	D	D	–	–	–	–
Hawaii creeper[2]	*Oreomystis mana*	–	D	D	–	–	–	–	D
Nēnē*[1]	*Branta sanvicensis*	–	–	D	–	–	–	–	–
ʻIo[1]	*Buteo solitarius*	–	D	–	X	D	X	D	–
Total native species	–	**3**	**6**	**9**	**5**	**6**	**6**	**6**	**5**

[1] Please see individual write-ups for the ʻio and nēnē for additional information on distribution.

[2] Possible range expansion.

Table 4.13-3. Landbird densities (birds/ha ± SE) and abundances from Judge et al. (2011).

Common Name	East Rift Zone	Honomalino	Kahuku	MaunaLoa South Flank	MaunaLoa Strip	North-west Kahuku	‘Ōla‘a	Papa	Total Abundance
‘Apapane	19.53 ± 2.13	18.24 ± 1.81	30.99 ± 2.65	9.77 ± 1.50	10.14 ± 1.24	3.57 ± 0.58	13.14 ± 1.52	12.36 ± 2.60	523,140 ± 44,362 (451,080–627,840)
Hawaii ‘amakihi	0.93 ± 0.56	19.71 ± 2.57	5.49 ± 0.73	11.88 ± 1.57	8.35 ± 1.21	15.40 ± 2.15	0.10 ± 0.06	13.55 ± 2.47	195,070 ± 23,545 (156,870–248,360)
Hawaii ‘elepaio	0.00	0.18 ± 0.08	0.19 ± 0.07	0.00	1.53 ± 0.36	0.20 ± 0.08	0.20 ± 0.09	0.00	7,901 ± 1,774 (5,009–11,828)
‘I‘iwi	0.00	0.45 ± 0.16	1.37 ± 0.29	0.00	0.64 ± 0.21	0.03 ± 0.03	0.33 ± 0.16	0.23 ± 0.23	18,804 ± 3,676 (12,230–27,197)
‘Oma‘o	2.37 ± 0.33	0	1.10 ± 0.13	0.35 ± 0.10	0.32 ± 0.07	0.16 ± 0.05	0.34 ± 0.10	0.50 ± 0.22	21,160 ± 1,911 (17,419–24,786)

In terms of native landbird diversity, the Kahuku tract had the highest number of native forest bird species (Table 4.13-3). The transects in this tract are adjacent to the Ka‘ū Forest Reserve, and together the Kahuku tract and Ka‘ū Forest Reserve comprise among the largest stands of mature native forest on the island providing important habitat for the three documented endangered landbird species. Native species percent occurrence was highest in mesic and wet climate zones (Table 4.13-4). Forest restoration and ungulate removal should help facilitate recovery of endangered forest bird species and continued monitoring will assist in identifying shifts in populations and habitat critical for native species survival.

Table 4.13-4. Native species occurrence within climate zones from Judge et al. (2011). AKIP= ‘akiapola‘au; APAP=‘apapane; HAAK=Hawaii ‘akepa; HAAM=Hawaii ‘amakihi; HAEL=Hawaii ‘elepaio; HAGO=Hawaiian goose (or nēnē); HCRE=Hawaii creeper; HWAH=Hawaiian hawk (or ‘io).

Species Code	Total Number of Species Detentions	Very Dry	Moderately Dry	Seasonal Mesic	Moist Mesic	Moderately Wet
AKIP	4	0.00	0.00	0.00	50.00%	50.00%
APAP	4358	3.53%	2.25%	25.59%	43.14%	25.39%
HAAK	20	0.00	0.00	5.00%	60.00%	35.00%
HAAM	2286	17.76%	11.07%	37.31%	29.33%	4.64%
HAEL	104	2.88%	6.73%	66.35%	2.88%	21.15%
HAGO	2	0.00	0.00	100.00	0.00	0.00
HCRE	26	0.00	0.00	19.23%	23.08%	57.69%
HWAH	9	0.00	0.00	55.56%	11.11%	33.33%
IWI	173	0.00	0.58%	26.59%	18.50%	54.34%
OMAO	292	4.79%	1.03%	11.64%	36.99%	45.55%

The most widely observed native species in the lowlands of HAVO was the Hawai‘i ‘‘amakihi (Turner et al. 2006) (Figure 4.13-3). ‘Amakihi were the most abundant of native birds in the Park lowlands and were found as low as 620 m (2,030 ft) in shrubland/grassland and woodlands. ‘Ōma‘o, nēnē, and ‘apapane were also observed. Native bird species were predominantly observed in woodland habitats. The Hawai‘i ‘elepaio and Hawaiian short-eared owl, or pueo (*Asio flammeus sandwichensis*) were not detected by Tweed et al. (2007) but were detected in the previous survey and in similar habitat (Table 4.13-1). Detected in the late 1970’s (Conant 1980), the pueo is currently thought to be no longer resident in the Park, although visiting birds may be expected (Pratt et al. 2011). The reason for this apparent extirpation is unknown.

Figure 4.13-3. Distribution of native birds in the lowlands of HAVO from Turner et al. (2006).

Nēnē are widely distributed throughout the Park from the coast to 2,700 m (8,858 ft) and utilize a variety of habitats including sparse woodlands, native shrubland, and grasslands and remnant pastures (Pratt et al. 2011, Hess 2012, Banko 1999) (Figure 4.13-4). While nēnē are non-migratory, they do move seasonally in response to rainfall and forage availability. The HAVO flock moves generally moves from low to mid elevation nesting and molting areas to slightly higher, wetter flocking areas. During the summer flocking season, much of the HAVO flock moves daily between roosting sites in the park and foraging sites on adjacent lands. The Kahuku section, above 1,524 m (5,000 ft), is a popular summer flocking site for scores of nēnē from other distinct populations across the island. Two recent telemetry studies have provided further detail on nēnē use of the Park. Radio tracking of nēnē in 2008, 2009 and 2010 identified several previously unknown flocking areas and specific forage sites within HAVO (NPS 2010, 2011, 2012) which potentially can be incorporated into the management regimes. Satellite tracking from 2009 – 2011 improved the park's understanding of nēnē use of the Kahuku section and clarified the links between the park and nēnē from other populations across the island (Kathleen Misajon, Wildlife Biologist, NPS HAVO, pers. comm. 2014).

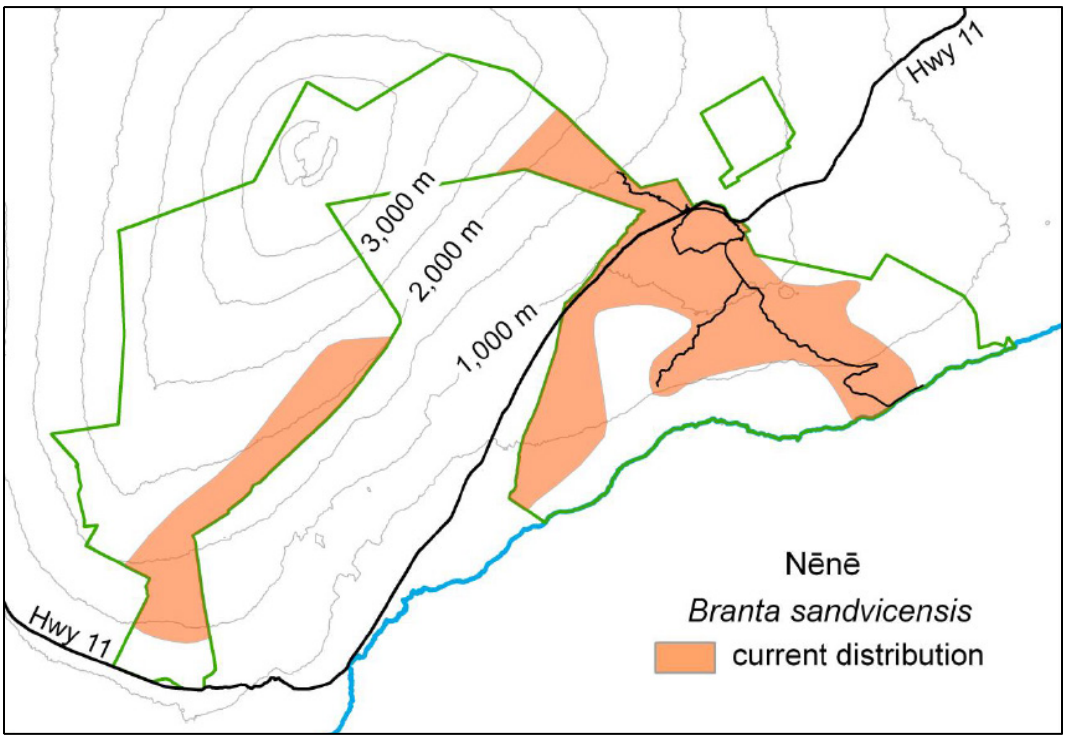

Figure 4.13-4. Distribution of nēnē at HAVO (from Pratt et al. 2011).

Management of the Hawaiian goose includes predator control for rats, mongooses, cats, pigs, and occasionally dogs during the breeding season, predator exclusionary fencing, habitat improvement, banding and subsequent re-sighting, reproductive success monitoring, and supplemental feeding in brooding areas when forage resources are inadequate. These measures have contributed to the steady increase in the park's population from the most recent low of 142 birds in 2001 to the current high of 245 birds in 2012. However, adult mortality still occurs and can be attributed to various causes including but not limited to: predation by small mammals, vehicle strikes, and occasional golf ball strikes in the adjacent Volcano Golf Course and Country Club (Rave et al. 2005).

While the nēnē population in HAVO appears to be stable or increasing, the species has been identified as "conservation reliant" which implies they will require active management into perpetuity (Underwood 2013). To this end, the park continues seasonal predator control in targeted areas and manages several exclusionary fences protecting nesting, brooding and molting habitat. Over 400 acres of key habitat was fenced in 2001 to protect breeding birds from feral pigs. The first small mammal exclosure was constructed in 2004 in the ‘Āinahou area; the second was completed in 2012 and will provide additional breeding habitat for birds currently using the Kilauea summit and lower MaunaLoa areas (Kathleen Misajon, Wildlife Biologist, NPS HAVO, pers. comm. 2014).

Fledging success of nēnē (from known number of hatchlings to fledglings) in 1994 through 1996 at HAVO was documented at 14.3% when 42 goslings resulted in 6 fledglings (Hu 1998). The number of goslings that fledged between 2003 and 2011 has increased since the 1990s, with a fledging success ranging between 45 and 60% (Table 4.13-5).

Table 4.13-5. Fledging success of nēnē at HAVO from 1994–1996 (Hu 1998) and 2009–2011 (NPS 2002-2012 unpublished data). Blanks indicate no data. 60 captive reared individuals were released between 2001 (36 individuals) and 2008. 1) Nests: all identified nesting attempts: nests located, pairs observed with goslings, females with brood patches. 2) Goslings: number of goslings observed, does not include any estimate of goslings from nests not located. 3) Fledged: number of goslings observed that survived to fledge. 4) Fledging Success is derived from number of goslings surviving to fledge from total number of goslings observed. The percentage does not account for goslings that hatched and died without being observed. 5) Reproductive Success is the percentage of breeding pairs that fledged one or more goslings.All reproductive data was lumped for this table regardless of management actions applied during the breeding period (e.g. some pairs may have nested and brooded in open topped pens benefitting from predator protection and supplemental feed and water).

Year	Nests	Goslings	Fledged	Fledging success	Reproductive success	Population size
1994-1996	–	42	6	14.3%	–	–
2000	–	–	–	–	–	142
2001	–	–	18	–	–	161
2002	30	25	15	60.0%	21%	149
2003	29	28	15	54.0%	31%	144
2004	31	29	13	45.0%	27%	148
2005	46	44	23	52.0%	27%	160
2006	44	59	38	64.0%	34%	182
2007	42	50	32	64.0%	40%	200
2008	48	48	25	52.0%	24%	211
2009	38	38	17	45.0%	35%	214
2010	49	56	31	55.0%	31%	207
2011	54	54	32	59.0%	37%	222
2012	47	80	33	41.0%	43%	247

The ‘io can be expected in forested areas within HAVO. Figure 4.13-5 shows the current breeding range distribution of the ‘io (Gorresen et al. 2008) on Hawai‘i Island based on habitat and known sightings. Expected densities of ‘io at HAVO range from 0 to 1.5 birds/km^2 (Figure 4.13-5) (Gorresen et al. 2008).

The ‘io is most likely to be found along the Ka‘ū boundary of the Kahuku section, and is expected in low densities in parts of the Kīlauea section and MaunaLoa section. The ‘io appears to be persisting as a stable, viable population of about 3,000 individuals throughout forest and adjacent areas for all of Hawai‘i Island (Gorresen et al. 2008). At HAVO, the numbers are expected to remain stable without any special management, and their prospects for long-term survival are anticipated to be good (Pratt et al. 2011).

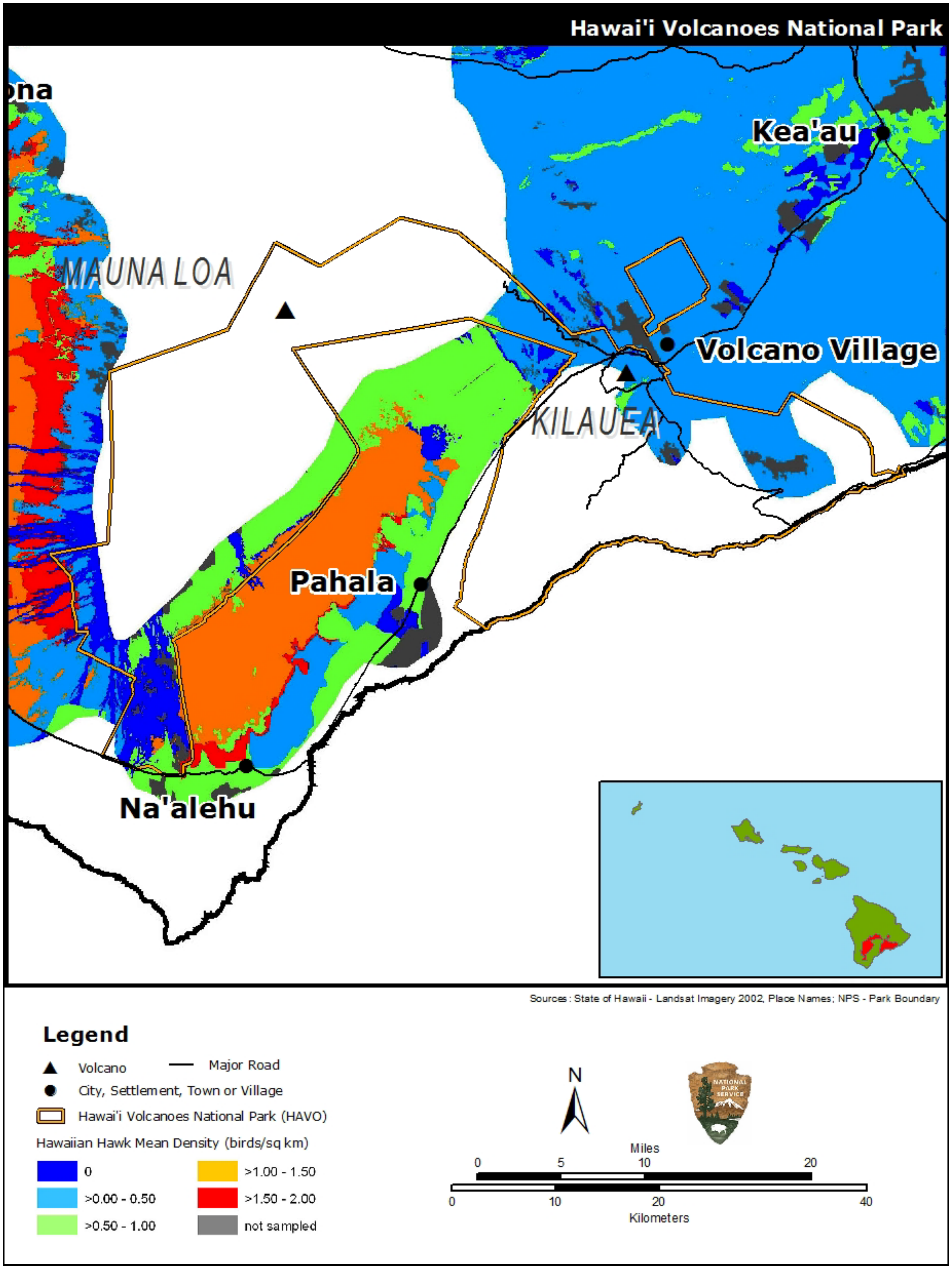

Figure 4.13-5. Breeding range and estimated density of the ‘io within HAVO (data from Gorresen et al. 2008).

Threats and Stressors

Many of the native landbirds are threatened by the degradation of native habitat by invasive plants and introduced ungulates; predation of adults, chicks, and eggs by introduced small mammals (rats, cats, mongooses); and introduced diseases such as avian malaria (Mitchell et al. 2005). Endangered species such as ‘akepa, ‘akiapola‘au, and Hawaii creeper are currently confined to habitats above 1,350 m (4,500 ft) where mosquitoes are absent, suggesting a susceptibility to avian malaria. Temperature increases forecasted by climate change models are predicted to further restrict available habitat (Benning et al. 2002).

Overall Condition

The overall condition landbirds within HAVO is considered moderate with a stable trend. For common or well-monitored species, populations appear to be persisting and, in some cases, increasing (e.g. nēnē, ‘apapane, Hawaii ‘amakihi). While no species of landbirds have been found to be declining throughout the Park, several species are decreasing in specific areas. ‘Elepaio were not detected in lowland sites during surveys on Kīlauea in 2005, while previously detected in the 1980s. ‘Elepaio population trends are also inconclusive in all other tracts, and the species warrant further monitoring. ‘I‘iwi are declining in the north-west Kahuku tract and show inconclusive trends in other areas of the park. Because this is a species that moves in and out of HAVO and is quite sensitive to avian malaria, its condition in the context of a larger area of the island also should be considered, particularly when park-based data are too limited to discern trends. ‘Ōma‘o are declining in the ‘Ōla‘a tract but have shown an increase and possible range expansion in other locations. Although more widespread detections in the latest surveys may be a sign of range expansion in the Kahuku area for Hawai'i creeper, it is important to note that population trends for rarer species are not available.

Information Gaps/Level of Confidence

Due to regular monitoring of landbirds within and around HAVO, confidence in the status and trends in densities of landbirds is high. Lowland birds should be monitored at intervals to assess persistence and trends in densities of native species, as well as to detect additional alien invasions that may pose a threat to persisting native bird populations. ‘Elepaio densities in HAVO warrant further monitoring in order to detect a potential population decline and identify and manage threats. The extent of knowledge for landbirds is ranked B (status knowledge) as trend data are only available for a subset of landbirds.

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4.14. Seabirds

Background

Many seabirds that were once common in the main Hawaiian Islands now breed only on the predator-free Northwestern Hawaiian Islands. Despite the presence of predators, several species of seabirds still nest or roost along the coast in the main Hawaiian Islands and include the white-tailed tropicbird (*Phaethon lepturus*), wedge-tailed shearwater (*Puffinus pacificus*), red-tailed tropicbird (*Phaethon rubricauda*), great frigatebird (*Fregata minor*), red-footed booby (*Sula sula*), black noddy (*Anous minutus*), and brown noddy (*Anous stolidus*). In addition, three species of seabirds are known or presumed to nest inland on Hawaiʻi Island: the endemic Hawaiian petrel (*Pterodroma sandwichensisi*), endemic Newell's shearwater (*Puffinus auricularis newelli*), and the indigenous band-rumped storm petrel (*Oceanodroma castro*).

The once-significant breeding populations of Hawaiian petrels were reduced to only very small numbers by the end of the twentieth century (Richardson and Woodside 1954, Banko 1980a, Conant 1980). The species now nests primarily on Maui and Kauaʻi. HAVO currently encompasses the largest active Hawaiian petrel colony on Hawaiʻi Island. Abundant Newell's shearwater breeding colonies were once known historically from Hawaiʻi, Maui, Molokai, and Kauaʻi (Banko 1980b). The main population now breeds on Kauaʻi (Banko 1980b) and continues to decline due to anthropogenic threats. Small remnant populations are thought to persist on other islands including Hawaiʻi Island (Ainley et al. 1997, Conant 1980, Reynolds and Ritchotte 1997). Remnant colonies of the threatened Newell's shearwater potentially occur in mid-elevation rain forests (700–1,000 m [2,300–3,300 ft] elevation) in the East Rift Zone of Kīlauea.

No nests of band-rumped storm-petrels have been found on Hawaiʻi Island, but breeding colonies are suspected in remote locations (Slotterback 2002, NPS unpublished data). The Hawaiian petrel is the only seabird species for which specific management measures are implemented at HAVO. Predator control occurs annually at known Hawaiian petrel colonies and along potential access routes within HAVO during nesting season. However, not all known nesting areas are managed in any given year (NPS 2010, 2011, 2012). The park is in the process of constructing 5.5 mi of cat exclusionary fencing around the most active petrel colony. Upon completion, this fence will protect over 600 ac of petrel nesting habitat. All known colonies are in need of active management for their continued persistence.

Measures

- Number of native seabird species present
- Number of inland breeding seabird species present
- Nesting success of Hawaiian petrels

<u>Reference Condition/Value</u>

Overall, current seabird diversity and numbers across the Hawaiian Islands are much less than pre-contact. Many species have been extirpated. Consequently, reference conditions or values using the present numbers and species on the Islands will not reflect the substantial loss of multiple seabird species and seabird biomass that have occurred in the past.

For this assessment, the number of native seabirds present at HAVO (breeding and non-breeding) relative to the number of species that are present on or in the nearshore waters of the Island of Hawai‘i are compared to determine 1) the extent of seabird use of coastal areas of HAVO, and 2) the importance of waters off-shore of HAVO to seabirds as feeding and as staging areas. The number of seabird species breeding inland, relative to the number that could potentially breed, is used as 1) a measure of HAVO's importance in providing suitable breeding habitat, and 2) a means to determine HAVO's significance in conserving these threatened, endangered, or candidate species.

No reference value (i.e., a target percentage) is defined for either measure above, but a high percentage for either measure (e.g., of more than 50% or a majority) would indicate that HAVO contains significant breeding habitat for the seabird assemblages found in or around the Island of Hawai‘i.

The nesting success of Hawaiian petrels (number of active nests that successfully fledge a chick) in recent years within HAVO is compared to the nesting success on Haleakala Crater, Maui within Haleakala National Park (HALE). The nesting success of Hawaiian petrels at HALE is used as a reference condition because HALE has the largest nesting Hawaiian petrel colony in the Hawaiian Islands (Simons 1985). This colony has been actively managed for several decades, and management has resulted in a significant increase in Hawaiian petrel nesting success (Hodges and Nagata 2001) and increases in the size of the breeding population (Cathleen Bailey, Supervisory Wildlife Biologist, NPS HALE, pers. comm. 2014).

Existing Data

The following literature sources were used to assess the indicator.

- Kozar et al. (2007) describe a seabird survey conducted along 48 km (30 mi) of coastline within HAVO in March 2005. The report also includes incidental observations from 2003 to 2005. The bird species (including migratory birds) were documented and the shorelines described in detail. Data of non-migratory seabirds were obtained from this report for this section.
- The report by Swift and Burt-Toland (2009) summarizes the first systematic surveys for procellariiform seabirds in HAVO. It includes results of targeted ground searches and auditory and nightvision surveys conducted in 2005, as well as sporadic surveys and incidental observations by HAVO crews for the years 2001 to 2005. The report also summarizes results of radar surveys conducted in 2002, as well as a short review of three published radar studies (1994–2002).
- Banko (1980b) reported Newell's shearwaters in the vicinity of HAVO in 1970 and 1975.
- Reynolds and Ritchotte (1997) found evidence of Newell's shearwaters nesting in the Puna district adjacent to HAVO.

Hawaiian petrel nesting and fledgling success were obtained from the HAVO annual reports (NPS 2007, 2008, 2009, 2010, 2011, 2012).

Current Condition

Number of Native Seabird Species Present

Of the 12 seabird species documented during surveys on the Island of Hawai‘i and in its nearshore waters (Table 4.14-1), eight species (67% of species) are present within HAVO or have been observed in the nearshore waters off HAVO. Five out of the eight species (63%) breed or possibly breed within HAVO. Although not detected during surveys, the Frigatebird and Bulwer's petrel have been observed in the park by NPS staff (Darcy Hu, Ecologist, NPS HAVO pers. comm. 2014). A summary of seabirds present in HAVO and their breeding status is presented in Tables 4.14-1 and 4.14-2 below. An additional six species that may have bred in the park in pre-contact and pre-Western contact time periods are missing. Given the high number of seabird species present and/or breeding at HAVO, the coastal and inland areas of HAVO are important to seabirds for roosting, foraging, and breeding.

During the coastline survey by Kozar et al. (2007), four species of seabirds were detected: the black noddy, sooty tern (*Onychoprion fuscata*), white-tailed tropicbird, and red-tailed tropicbird. Black noddies were found primarily along high ocean cliffs, especially those with archways eroded by ocean wave action. Black noddies were observed roosting in these areas and are also likely to nest there (Kozar et al. 2007) (Figure 4.14-1, Table 4.14-2). Three additional seabird species were detected aurally: white-tailed tropicbirds and sooty terns were heard at night at NaPu‘u o NaElemakule, and red-tailed tropicbirds were heard at dusk at ‘Āpua Point (Kozar et al. 2007). White-tailed tropic birds nest within HAVO, notably within Halema‘uma‘u crater (Pyle and Pyle 2009). Nesting status of Red-tailed tropicbirds in the park is unknown; however, a freshly dead adult found near a pit crater in the Ka'u Desert in the early 2000s (Darcy Hu, Ecologist, NPS HAVO pers. comm.) is further evidence of their presence. In addition, the carcass of one wedge-tailed shearwater, which died of unknown causes, was collected along the top of lava cliffs near Nali‘ikakani Point in southwestern HAVO by Kozar et al. (2007). Swift and Burt-Toland (2009) suggest that wedge-tailed shearwaters do not nest at HAVO because the young lava substrate makes it impossible for this species to dig its nest burrows. However, the park may have locations with substrate suitable for nesting wedge-tailed shearwaters, particularly where coastal vegetation is restored to stabilize the soil, and/or in areas containing rock crevices suitable for nesting (R. Swift pers. comm. Feb 17, 2016).

Table 4.14-1. Seabird species found on the Island of Hawaiʻi (adapted from Pyle 2002) and detected during surveys within HAVO. C = candidate species, E = endangered, T = threatened * only evidence from one carcass. An "X" indicates that the species was identified as being inside the park for that study.

Species Name	Common Name	Status	Presence detected during surveys in HAVO			
			Kozar et al (2007)	Turner et al (2006)	Swift and Burt-Toland (2009)	All Combined
Oceanodroma castro	Band-rumped storm-petrel	C	–	–	X	X
Anous minutus	Black noddy	–	X	X	–	X
Sula leucogaster	Brown booby	–	–	–	–	–
Bulweria bulwerii	Bulwer's petrel	–	–	–	–	–
Fregata minor	Great frigatebird	–	–	–	–	–
Pterodroma sandwichensis	Hawaiian petrel	E	X	–	X	X
Phoebastria immutabilis	Laysan albatross	–	–	–	–	–
Puffinus newelli	Newell's shearwater	T	X	–	X	X
Phaethon rubricauda	Red-tailed tropicbird	–	X	–	–	X
Sternafuscata	Sooty tern	–	X	–	–	X
Puffinus pacificus	Wedge-tailed shearwater	–	X*	–	–	X
Phaethon lepturus	White-tailed tropicbird	–	X	X	–	X
Total	**12**	**–**	**7**	**2**	**3**	**8**

Table 4.14-2. Species of seabirds documented at HAVO and their breeding status.

Scientific Name	Common Name	Locations at HAVO	Status at HAVO
Oceanodroma castro	Band-rumped storm-petrel	Kahuku section, MaunaLoa section	Likely to be breeding
Anous minutus	Black noddy	coastal	Roosting, likely to be breeding
Bulweria bulwerii	Bulwer's petrel	coastal	Possibly breeding
Fregata minor palmerstoni	Great frigatebird	coastal	Not breeding
Pterodroma sandwichensis	Hawaiian petrel	coastal (staging offshore), Kahuku section, MaunaLoa section	Breeding
Puffinus newelli	Newell's shearwater	coastal (staging offshore), Kīlauea section?	Possibly breeding
Phaethon rubricauda	Red-tailed tropicbird	coastal	Unknown
Onychoprion fuscata	Sooty tern	coastal	Not breeding
Puffinus pacificus	Wedge-tailed shearwater	coastal	Unknown
Phaethon lepturus	White-tailed tropicbird	coastal; Kīlauea section	Breeding
Total No. of Species	**10**	**–**	**–**

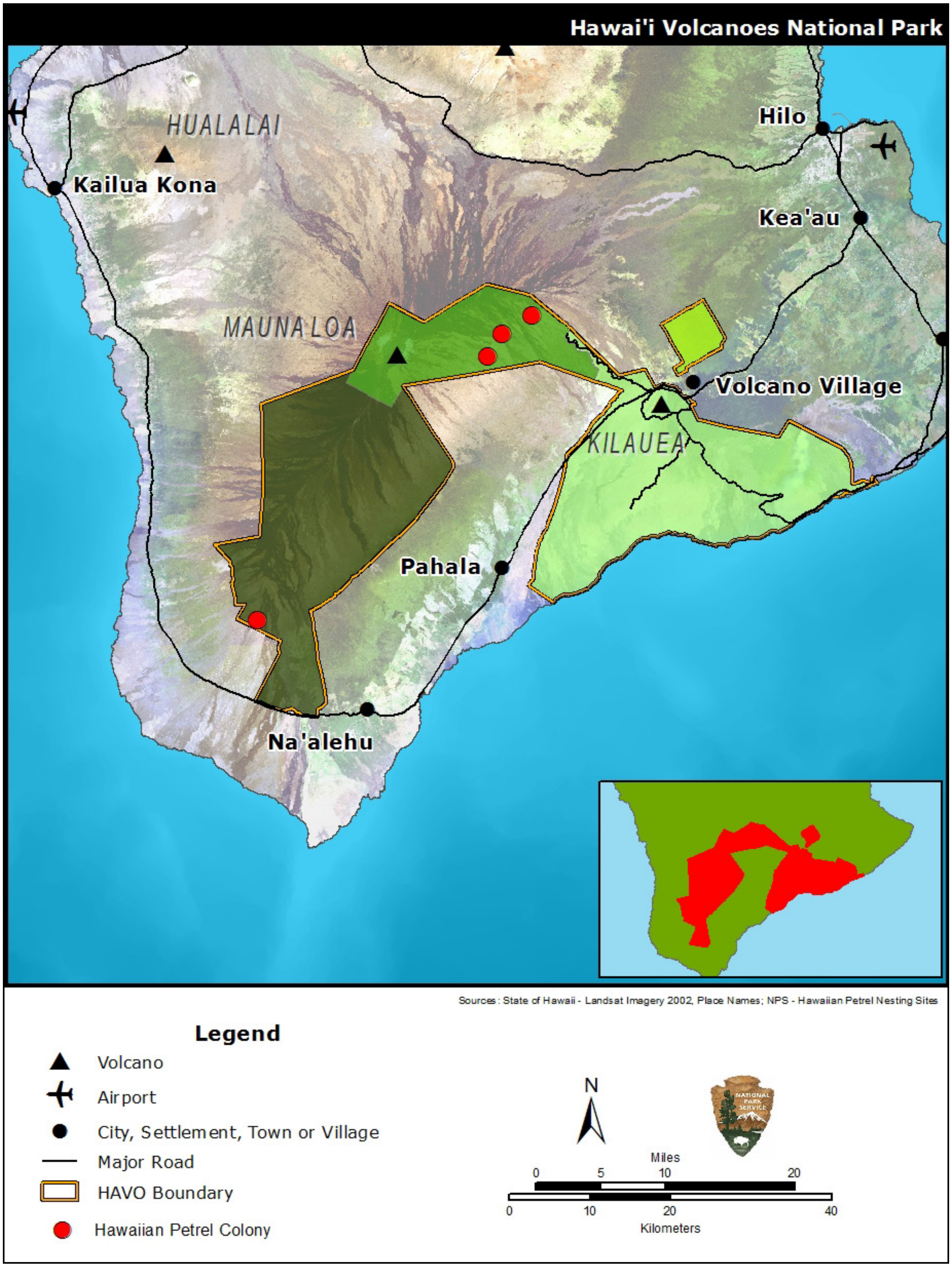

Figure 4.14-1. Known Hawaiian petrel colonies within HAVO from Swift and Burt-Toland (2009).

Although not detected during surveys, the great frigatebird and Bulwer's petrel have been documented or reported in the park by NPS staff. Bulwer's petrels were recorded from Ke'a'oi, the small islet off Halapē (Baldwin 1946 *in* Pyle and Pyle 2009). Park staff reported seeing small, dark birds in crevices on the islet in the late 1990s that likely were this species (L Schuster, Chief of Cultural Resources, NPS HAVO, pers. comm. ~2013). A great frigatebird was grounded near the Volcano House in 2007. The individual was recovered by park staff and transported to the coastal bluff, where it joined a second great frigatebird upon taking off (Kathleen Misajon, Wildlife Biologist, HAVO pers.comm. 2014).

Current or previous presence elsewhere suggests additional species that may have bred within the park previously (pre-contact through pre-Western contact time periods). Christmas shearwaters (*Puffinus nativitatis*), masked boobies (*Sula dactylatra*), red-footed boobies (*Sula sula*), and brown noddies (*Anous stolidus*) now nest on offshore islets and/or other Main Hawaiian Islands (Fefer et al. 1983, Hawaii Audubon Society 2005). On Hawai'i Island at archaeological sites outside the park, remains of Christmas shearwaters and sooty storm-petrels (*Oceanodroma tristrami*) were found at coastal elevations, and Bonin petrels (*Pterodroma hypoleuca*) were documented both coastally and at upland sites (Nakamura 1999). Bonin petrel remains also were found in excavations conducted by the late Alan Ziegler at Waha'ulu, within the park (Laura Schuster, Chief of Cultural Resources, NPS HAVO, pers. comm. ~2013). Although gray-backed terns (*Onychoprion lunata*) also nest in low numbers on a few islets, this species and the congeneric sooty tern may have confined their nesting to offshore islets within the Main Hawaiian Islands, based on the lack of subfossil remains at main island sites (Olson and James 1982). Thus, conservatively, the park may have had an additional six seabird species that now are absent.

Number of Inland Breeding Seabird Species Present

All three of the possible inland nesting seabirds on the Island of Hawai'i (the endangered Hawaiian petrel, the threatened Newell's shearwater, and the proposed band-rumped storm-petrel) are present within HAVO and are either known to breed or are suspected to breed within the park (Swift and Burt-Toland 2009). Hawaiian petrels and possibly band-rumped storm-petrels breed in the Kahuku section and on the southeast flank of MaunaLoa (MaunaLoa Section), and Newell's shearwaters may breed in lowland forests along the East Rift Zone of Kīlauea (Kīlauea Section; Swift and Burt-Toland 2009) (Table 4.14-2). Thus, the lowland forest and subalpine scrubland of HAVO are likely important for the continued persistence of inland nesting seabird species on the Island of Hawai'i. However, it is important to note that for at least the Hawaiian petrel and the band-rumped storm-petrel, breeding currently only occurs at the highest margins of their former ranges: Based on subfossils and bones, both species likely occupied lower elevation habitats (Olson and James 1982, Nakamura 1999). Similarly, archaeological and paleontological records of Newell's shearwaters from coastal sites at South Point and Waiahukini in Ka'u (Nakamura 1999) and elsewhere in the Main Hawaiian Islands (Olson and James 1982) suggest this species also nested in additional habitat types and at lower elevations, a conclusion bolstered by results of a cross-fostering experiment at Kilauea Point on Kaua'i (Byrd et al. 1984, Pyle and Pyle 2009). Therefore, the park may offer opportunities for management and recolonization for all three species, including at locations beyond currently known or suspected breeding sites and in a wider variety of habitats. These three procellariiform seabirds are discussed in further detail below.

Multiple Hawaiian petrel nesting locations are known in HAVO (Figure 4.14-1), and the park encompasses the majority of known active Hawaiian petrel colonies on the island. Three notable colonies occur on the southeast flank of MaunaLoa in the subalpine region of the MaunaLoa section. Two of the three colonies are monitored and managed seasonally, while the third receives irregular monitoring and possibly some benefit from management of the other areas (Rhonda Loh, Chief of Natural Resources Management, NPS HAVO, pers. comm. 2014). In the Kahuku section, nests were scattered across a band from 8,000-10,000 ft on the south-east rift of MaunaLoa, and numerous Hawaiian petrel calls also were documented during surveys conducted in these areas (Swift and Burt-Toland 2009, Judge et al *in prep*) (Figure and 4.14-2a and b). Two active nests were found during surveys of a portion of the lower area in 2014, although all Kahuku sites currently are unmanaged (K. Misajon, Wildlife Biologist, NPS HAVO, pers. comm. 2014).

While band-rumped storm-petrels are considered the rarest breeding seabird in Hawai‘i (Banko et al. 1991, Slotterback 2002), vocalizations of band-rumped storm-petrels transiting through the area were heard regularly along the southeast flank of MaunaLoa (MaunaLoa section) and within the Kahuku section during surveys (Figure 4.14-2). No band-rumped storm-petrel nests have been documented in the park. However, since 1994, at least eight band-rumped storm-petrel carcasses were identified, and one individual was caught in a mist net on MaunaLoa between 2,400 and 2,700 m (7,800–9,000 ft.) (HAVO RM unpubl. data). Collectively, these data suggest that band-rumped storm-petrels still breed on MaunaLoa, possibly along HAVO’s Keauhou boundary and higher up along the Southwest Rift Zone on MaunaLoa, and possibly in close proximity to nesting Hawaiian petrels.

No Newell’s shearwaters were confirmed during the surveys by Swift and Burt-Toland (2009), although they sighted approximately 40 procellariiforms massing offshore of Ka’aha at dusk, possibly prior to flying inland, as is the pattern for this species off Kaua'i. Additionally, several incidental auditory detections by HAVO staff suggest that Newell’s shearwaters still occur in the Park and may be prospecting for nest sites at low to mid elevation locations such the forest of the Kīlauea East Rift Zone (Kīlauea section) at 700 to 900 m (2,300–3,000 ft), or inland of coastal sites such as Ka’aha and ‘Āpua Point (Swift and Burt-Toland 2009). Historical observations include bird calls and carcasses from 1972 of a small breeding colony at Makaopuhi Crater (Banko 1980b). Banko (1980b) also reported Newell’s shearwaters in the vicinity of HAVO offshore of Kalapana in 1970 and 1975. More recently, Reynolds and Ritchotte (1997) found evidence of Newell’s shearwaters nesting in forested pit craters in the Punadistrict adjacent to HAVO. These observations led the authors to conclude that Newell’s shearwaters may still nest in HAVO. The authors suggest that it may be possible for Newell’s shearwaters to re-colonize lowland areas in the Park if measures such as predator control and restoration of native vegetation are implemented.

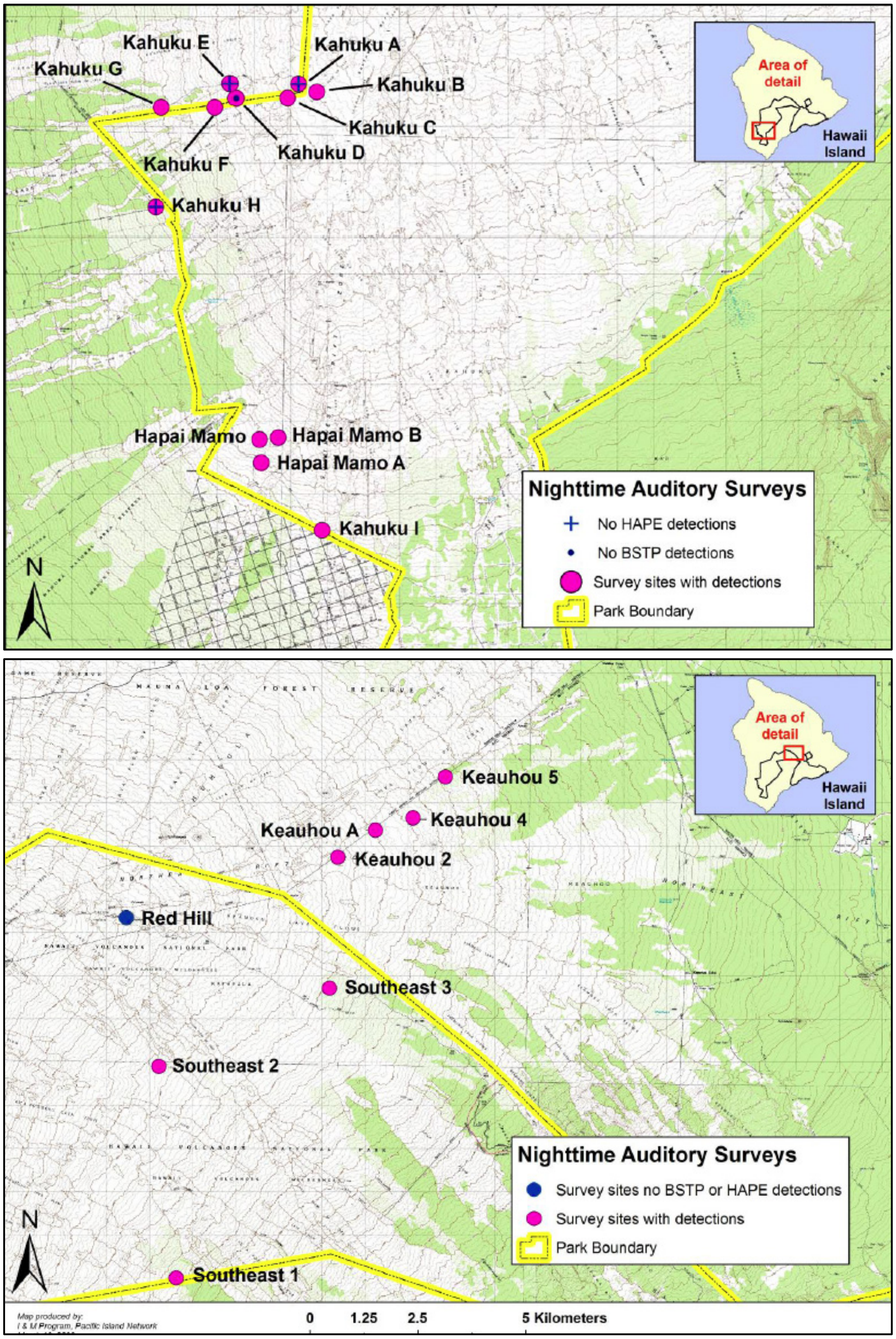

Figure 4.14-2. Survey locations with Hawaiian petrel (HAPE) and band-rumped storm petrel (BSTP) detections from Swift and Burt-Toland (2009).

Nesting Success of Hawaiian Petrels

Predator control occurs annually at HAVO during the seabird nesting season, though not all nesting areas may be managed in any given year (NPS 2010, 2011, 2012). Nesting success (percent of active burrows that fledge a chick) from 2006 to 2010 ranged from 12% to 68% (average of 39%) at HAVO (Table 4.14-3) (NPS 2007, 2008, 2009, 2010, 2011, 2012). These numbers are similar to or greater than nesting success documented at HALE on Maui in areas where predator control is occurring (range 17% to 57%, average of 42% success) (Hodges 1994, Hodges and Nagata 2001) (Table 14.13-3). This level of nesting success at HALE has resulted in an increasing Hawaiian petrel colony there (Cathleen Bailey, Supervisory Wildlife Biologist, NPS HALE, pers. comm. 2014), and it is therefore inferred that the Hawaiian petrel population at HAVO, with the given management, is similarly stable. However, because reproductive success alone is not a reliable indicator of population growth trends, management targets also should be assessed using nest density estimates.

Table 4.14-3. Nesting success of Hawaiian petrels at HAVO from 2006 to 2010 from HAVO Annual Reports (NPS 2010, 2011, 2012). From Hodges and Nagata (2001).

Year	Burrows Checked	Active Nests	Fledged	Fledging Success at HAVO	Fledging Success at HALE (1982, 1990–1996)
2006	–	74	18	24.3%	–
2007	–	59	7	11.9%	–
2008	135	58	28	48.3%	–
2009	93	50	34	68.0%	–
2010	94	54	24	44.4%	–
Average	**–**	**–**	**–**	**39.3%%**	**42%**

In addition, a predator-proof fence currently under construction (scheduled for completion in 2016) will enclose one of the nesting colonies and is anticipated to result in further increases in nesting success and increased density within the nesting colony. Significant increases have been documented among other seabird species at Ka‘na Point on O‘ahu following fence installation in 2011 (Young et al. 2013). The park’s goal of documenting stable or increasing colonies in the two monitored sites in the park is an important recovery action for a species with low overall numbers of known nesting pairs within the park, colonies that are genetically and behaviorally distinct from those on other islands, a worldwide abundance that is orders of magnitude lower than pre-contact populations, and which remains endangered (Simons and Hodges 1998, Judge 2011, Welch et al. 2012).

Threats and Stressors

Declines in ground-nesting seabirds are attributed mainly to the loss of nesting habitat; habitat degradation; predation of eggs, chicks, and adults by introduced mammals (e.g., dogs, mongooses, cats, rats, and pigs) at nesting sites; and fallout of juvenile birds associated with disorientation from urban lighting (Ainley et al. 1997, Mitchell et al. 2005, Hays and Conant 2007). Bird strikes on powerlines and other obstacles may be another substantial source of mortality in some locations (Duffy 2010). Mongooses are abundant in low elevations and can prey on seabird species which nest coastally or at low elevations (e.g., wedge-tailed shearwaters and Newell’s shearwaters). Feral cats range from sea level to subalpine areas and are major threats to ground-nesting birds at high elevations (Simons 1983, Natividad Hodges 1994, Winter 2003). Seabird fallout due to light attraction is less of an issue on the Island of Hawai‘i due to the more rural nature of the island and Hawai‘i County's Outdoor Lighting Ordinance, which requires shielded low pressure sodium lamps for all ground illumination (Hawai‘i County Code, Ch 14, Article 9). This minimizes the upward light pollution and greatly reduces the risk of fallout to seabirds. Also, the park has enacted protocols to ensure its own lighting remains appropriate, particularly on Kilauea summit, which is visible from at least some of the colonies on MaunaLoa.

Overall Condition

The overall condition of seabirds based on their presence/absence within HAVO is considered moderate with a stable trend. It is not confirmed if Newell's shearwaters and band-rumped storm petrels breed within the Park, and if they do, these species currently are not being managed. However, for the Hawaiian petrel and coastal seabirds the populations appear to be persisting. Based on nesting success at HAVO and inference from HALE data, the Hawaiian petrel is considered stable. However, these birds, and any other procellariiform seabirds are dependent upon active management at their nesting colonies for their continued persistence.

Information Gaps/Level of Confidence

Due to regular monitoring, confidence in the knowledge base for the Hawaiian petrels is high. Due to lack of confirmed nesting sites, the status of Newell's shearwater and band-rumped storm petrels is largely still unknown. Surveys for Newell's shearwaters and band-rumped storm petrels should continue in areas where breeding is suspected to occur.

Incidental sightings of ground-nesting seabirds by HAVO field staff working on various projects and by Hawksbill Turtle Project volunteers could increase if more of these individuals received training on identification of seabird vocalizations. This would increase knowledge of the distribution of seabirds within HAVO, particularly along the coastline.

The extent of knowledge for seabirds is ranked B (status knowledge) as the presence of listed species such as Newell's shearwater and band-rumped storm petrels is largely still unknown.

Subject Matter Experts Consulted

- Cathleen Bailey. Supervisory Wildlife Biologist. NPS HALE.

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4.15. Hawaiian Hoary Bats

Background

The Hawaiian hoary bat or ope‘ape‘a (*Lasiurus cinereus semotus*) is the only native land mammal present in the Hawaiian archipelago. It is a sub-species of the hoary bat (*Lasiurus cinereus*), which occurs across much of North America and South America. The Hawaiian hoary bat was listed as an endangered species in 1970 by the USFWS after a perceived decline in abundance (USFWS 1970); however, much of this subspecies' natural history continues to be poorly understood.

The species has been recorded on Kaua‘i, O‘ahu, Moloka‘i, Maui, and Hawai‘i, but no historical population estimates or information exist for this subspecies. Population estimates for all islands in the state in the recent past have ranged from hundreds to a few thousand bats (Menard 2001). It is thought that the Islands of Kaua‘i and Hawai‘i support the largest populations (Mitchell et al. 2005). Methods to estimate population size of solitary-roosting bat species such as the Hawaiian hoary bat do not yet exist (Mitchell et al. 2005).

The Hawaiian hoary bat is a solitary tree-roosting species that most often roosts in foliose trees with significant structure (Frank Bonaccorso, Research Wildlife Biologist, USGS, pers. comm. 2014). Bats have been recorded roosting in native and nonnative vegetation from 1 to 9 m (3–29 ft) above ground level. Native roost trees include ‘ōhi‘a, hala (*Pandanus tectorius*), pūkiawe (*Leptecophylla tameiameiae*), and fern clumps (Mitchell et al. 2005, USDA unpublished data).

It is suspected that breeding primarily occurs between April and August. Lactating females have been documented from June to August, indicating that this is the period when non-volant young are most likely to be present. Breeding has only been documented on the Islands of Hawai‘i and Kaua‘i (Baldwin 1950, Kepler and Scott 1990, Menard 2001). Seasonal changes in the abundance of Hawaiian hoary bat at different elevations indicate that altitudinal movements occur on the Island of Hawai‘i. During the breeding period, Hawaiian hoary bat occurrences increase in the lowlands and decrease at high-elevation habitats. In the winter, bat occurrences increase in high-elevation areas (above 1,525 m [5,000 ft]) especially from January through March (Menard 2001, Bonaccorso 2011).

A preliminary study of a small sample of Hawaiian hoary bats (n = 18) on the Island of Hawai‘i has shown that Hawaiian hoary bats are wide ranging. The estimated short term (1–2 weeks) core range habitat sizes of a male was 34.1 ha (84.3 ac; n = 14) and 16.7 ha (41.2 ac; n = 11) for a female bat (Frank Bonaccorso, Research Wildlife Biologist, USGS, pers. comm. ~2013). The size of home ranges and core areas varied widely between individuals. Core areas included feeding ranges that were actively defended, especially by males, against conspecifics.

The Hawaiian hoary bat begins foraging either just before or after sunset depending on the time of year (USFWS 1998, Mitchell et al. 2005). Bats typically feed along a line of trees, forest edge, or road and a typical feeding range stretches around 275 m (300 yds). Bats will spend 20 to 30 minutes hunting in a feeding range before moving on to another (Bonaccorso 2011). Water courses and edges (e.g., coastlines and forest/pasture boundaries) also appear to be important foraging areas (Grindal et al. 1999, Francl et al. 2004, Brooks and Ford 2005, Morris 2008, Menzel et al. 2002).

The wide range of elevations and habitats available within HAVO are likely to encompass the altitudinal migrations of the Hawaiian hoary bat, and also provide feeding, roosting, and breeding opportunities. HAVO is likely the only national park in the state of Hawaiʻi that provides large enough areas of suitable habitat over a large enough altitudinal range that can accommodate the entire life cycle of the Hawaiian hoary bat.

Measures

- Presence/absence of bats
- Bat activity rates

Reference Condition/Value

As bats forage along tree lines and forest edges and roost in foliose trees, the reference condition for bats at HAVO is documented presence in forested habitats based on acoustic data.

Acoustic data are also used to document bat activity rates. Acoustic data on the Hawaiian hoary bat have only been systematically collected in recent years. Measures of bat activity can provide "information about locations within a sampling area that are being continuously used by bats, used and later abandoned, or perhaps never used," and also may elucidate seasonal and nightly activity patterns at the sites (Fraser and HaySmith 2009). However, bat activity cannot be related to estimates of population size or density, since available acoustic equipment cannot differentiate between multiple passes by a single bat and single passes by multiple bats (Fraser and HaySmith 2009).The level of Hawaiian hoary bat activity that would be indicative of foraging or breeding at suitable habitat or threshold activity levels providing supporting evidence of healthy population sizes remain undetermined. Therefore, no reference condition for bat activity rates exists at this time. The data collected in the preliminary study at HAVO can be used as a baseline and compared to data collected at the same sample locations in subsequent years. These data can be compared to determine if changes in bat utilization of the different areas of the Park have changed. A significant decrease in bat activity at the higher activity areas of the Park would be cause for concern.

Acoustic monitoring methods of the Hawaiian hoary bat have improved over the last 5 years, with refinements to monitoring protocols, equipment used, and metrics reported. The changes in methodology over a short period of time makes comparisons between studies throughout the islands difficult until sampling methods are standardized between different research teams.

Existing Data

PACN developed a monitoring protocol for the Hawaiian hoary bat at selected national parks in Hawaiʻi to determine status and trends of Hawaiian hoary bat activity in these parks (Fraser and HaySmith 2009). Between July and September 2007, pilot data for HAVO were collected by staff from the PACN at six randomly generated points along Hilina Pali Road and 12 points along Mauna Loa Road. In 2008, HAVO was divided into two sampling frames: HAVO West and HAVO East. HAVO West was divided into two smaller subregions based on elevation: Upper Kahuku (KAHI) and Lower Kahuku (KALO) within the Kahuku section (Figure 4.15-1). The HAVO East location was divided into three sub-regions: MaunaLoa Road (MLR) within the MaunaLoa section, Hilina Pali (HP), and Chain of Craters Road (COC) within the Kīlauea section (Figure 4.15-2). All monitoring sites were along roads or associated buffers. PACN collected additional pilot data from these frames from May through December 2008 and in January 2009.

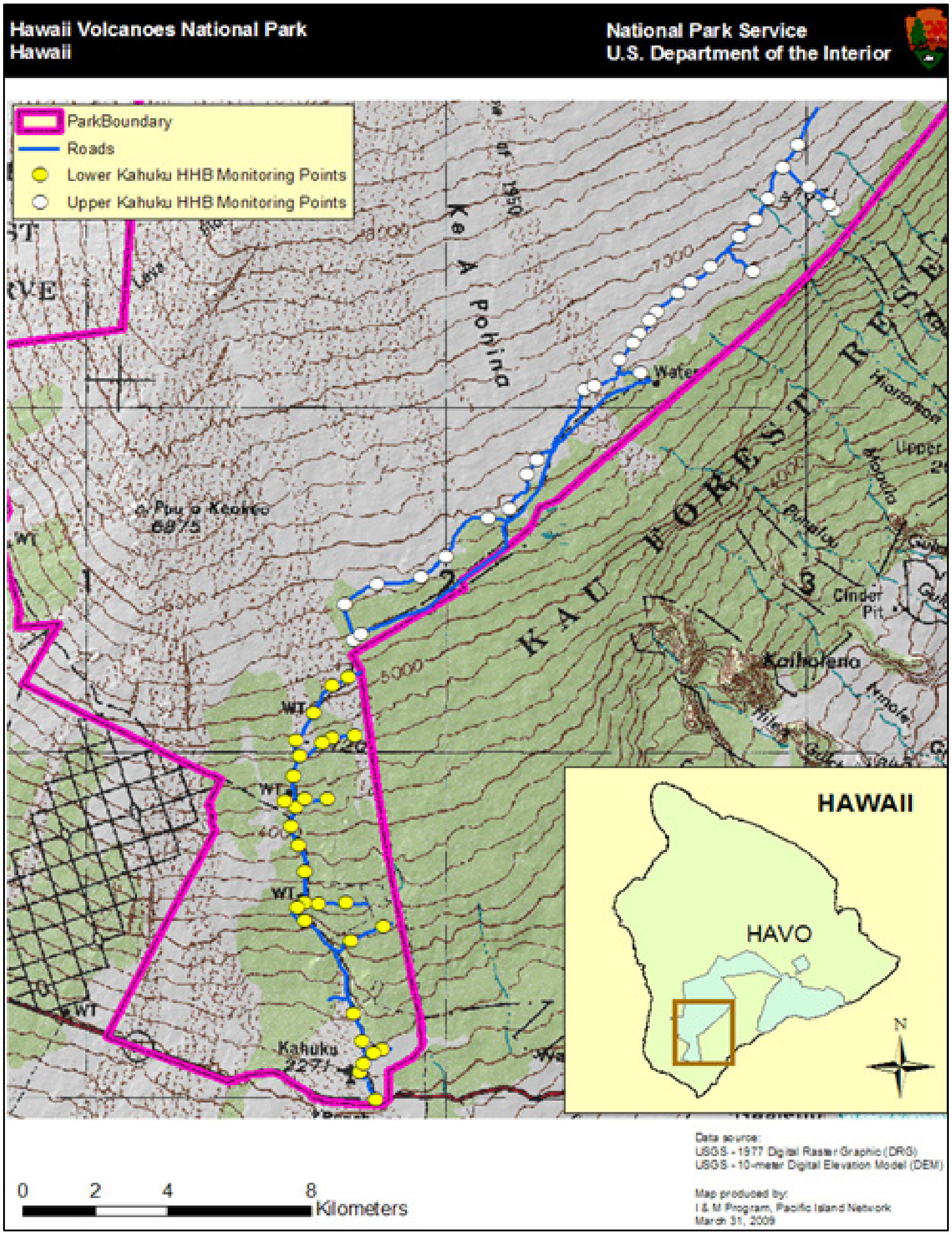

Figure 4.15-1. Long-term monitoring points at HAVO West (Lower and Upper Kahuku) from Fraser and HaySmith (2009).

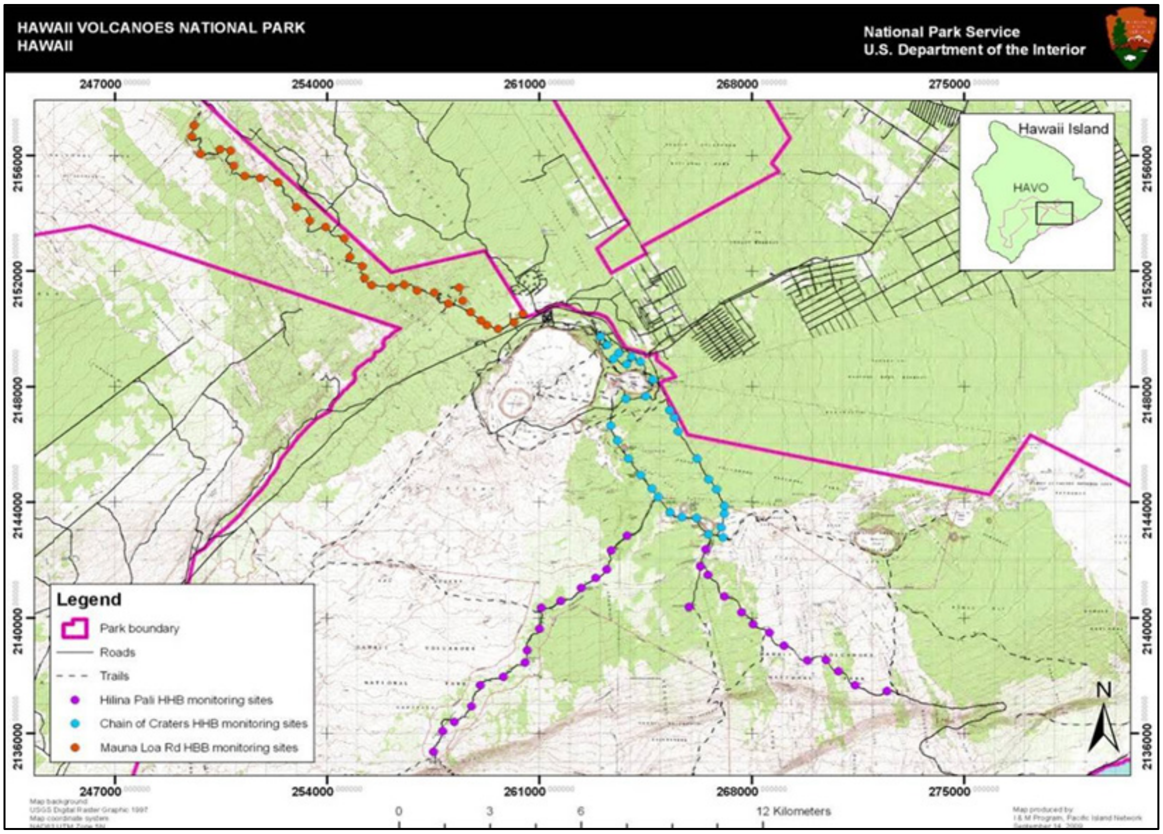

Figure 4.15-2. Long-term monitoring points at HAVO East (MaunaLoa Road [MLR], HilinaPali [HP], and Chain of Craters Road [COC]) from Fraser and HaySmith (2009).

Table 4.15-1 presents the sampling effort from 2007 to 2009. For future long-term monitoring in HAVO, 150 sites covering areas of MaunaLoa Road, HilinaPali Road, Chain of Craters Road, and Kahuku have been identified for continued monitoring. However, Hawaiian hoary bat monitoring has not been conducted at HAVO since January 2009 due to limited resources.

Table 4.15-1. Total bat detector nights in HAVO (2007–2009).

	HAVO East Sub-regions			HAVO West Sub-regions		HAVO Total
Season	**COC**	**HP**	**MLR**	**KA.HI**	**KA.LO**	**Entire Park**
Breeding Season	196	225	295	40	170	196
Non-Breeding Season	119	224	251	91	90	119
Both Seasons (Total)	**315**	**449**	**546**	**131**	**260**	**315**

Current Condition

Presence/Absence of Bats

Data collected from these areas showed that Hawaiian hoary bats were active in all sampled areas within HAVO (Table 4.15-2).

Table 4.15-2. Measured bat activity (pulses per detector night) at HAVO East and HAVO West subregions. Numbers in parentheses indicate the percent of detector locations that recorded activity during the sampling periods. Some seasons had more than one sampling period and a range is reported.

Season	HAVO East Sub-regions			HAVO West Sub-regions		HAVO Total
	COC	**HP**	**MLR**	**KA.HI**	**KA.LO**	**Entire Park**
Breeding Season	0.58 (16%–27%)	0.06 (0–33%)	1.22 (20%–50%)	7.78 (50%)	5.43 (100%)	1.86
Non-Breeding Season	0.18 (6%)	0.00 (0%)	25.42 (40%–53%)	5.75 (46%)	3.13 (80%)	9.30
Both Seasons (Total)	**0.43**	**0.03**	**12.34**	**6.37**	**4.63**	**5.25**

Bat Activity Rates

Of all the subregions sampled, bats were the most consistently active within the two Kahuku subregions in HAVO West (Kahuku section). Bats were detected both during the breeding and non-breeding season and were widespread (i.e., detected in many locations) (Table 4.15-2), particularly within the lower Kahuku subregion. In HAVO East, HilinaPali and Chain of Craters Road within the Kīlauea section had relatively lower activity levels regardless of season. This could be attributed to the open habitat, dominated by barren lava flows with scattered trees. Bat activity appeared to be much higher at MaunaLoa Road (MaunaLoa section) during the non-breeding season than during the breeding season. During the non-breeding season at MaunaLoa Road, bats were detected at nearly half of the detectors deployed, indicating that bats are using a large proportion of the sampled area (Table 4.15-2) during that time.

Threats and Stressors

Management of the Hawaiian hoary bat is currently limited by a lack of information on reproduction, key roosting and foraging areas, food habits, seasonal movements, and reliable population estimates (USFWS 1998). However, one possible threat to the Hawaiian hoary bat is lack of prey availability, which can be affected by the use of pesticides or the introduction of nonnative insects. Other threats could include predation and roost disturbance (USFWS 1998).

Overall Condition

Bats appear to be ubiquitous at HAVO, present year round within the Kahuku section and seasonally present in the Kīlauea and MaunaLoa sections. The overall condition for bats at HAVO is moderate with an unknown trend.

Information Gaps/Level of Confidence
The extent of knowledge for Hawaiian hoary bats is ranked B (status data). Bats are actively using HAVO during the breeding and non-breeding seasons particularly along MaunaLoa Road and within HAVO West. However, given the high variability in acoustic data, confidence in bat activity levels and extent of distribution in the Park is fairly low due to limited sampling. Repeated sampling at the locations identified in Fraser and HaySmith (2009) will increase the confidence in the distribution and extent of Hawaiian hoary bat activity at HAVO. Efforts should be made to have repeated sampling between years to enable year-to-year comparisons. Standardizing the sampling methodology and metrics reported with the larger bat research community in Hawai‘i will also be important to enable valid comparisons between studies. This will enable a greater understanding of the level of bat utilization at different habitats at HAVO and the importance of HAVO to the conservation of the endangered Hawaiian hoary bat.

Subject Matter Experts Consulted

- Frank Bonaccorso, Ph.D. Research Wildlife Biologist, Pacific Island Ecosystems Lead Scientist, USGS.

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4.16. Endangered and Threatened Marine Vertebrates

Background

Three species of federally and state-listed marine vertebrates occur along the coastline within HAVO. The endangered hawksbill turtle (*Eretmochelys imbricata*) nests regularly on the beaches of HAVO (Figure 4.16-1), the threatened green sea turtle or honu (*Chelonia mydas*) has been found basking on the beaches, and the endangered Hawaiian monk seal (*Monachus schauinslandi*) occasionally hauls out along the HAVO coastline.

Hawksbill turtles are found in tropical and circum-tropical waters of the Atlantic, Pacific, and Indian Oceans (Witzell, 1983, Ernst et al. 1994). Current global estimates are between 60,000 and 78,000 nesting adult female hawksbills. While only 100 adult females were tagged on the Island of Hawai‘i between 1991 and 2009, Hawai‘i is the principle nesting ground for hawksbills in the United States, excluding territories (Sietz et al. 2012).

Ninety percent of the documented hawksbill turtle nests occur on Hawai‘i Island’s south coast which includes the beaches of HAVO (Pratt et al. 2011). The nesting season (egg laying to hatchling emergence) in Hawai‘i begins in April and extends to February with a peak egg laying period from late-July to mid-September. Hawksbill turtles exhibit high site fidelity with 87% of individuals documented using only one nesting site in Hawai‘i (Seitz et al. 2012). The same turtles return regularly to HAVO beaches to nest.

Green turtles are found throughout the world, primarily in tropical, and to a lesser extent, subtropical waters. The Hawaiian green turtle is genetically distinct from the other green sea turtle populations in the Pacific, nesting primarily in the French Frigate Shoals of the Northwestern Hawaiian Islands and feeding in the coastal areas of the main Hawaiian Islands. After 30 years of protection, the number of basking turtles and nest abundance has increased in the Central Pacific (USFWS 2007). Green turtles have been documented basking on the beaches of HAVO and are expected to use the coastal waters off HAVO.

The majority of the Hawaiian monk seals reside in the remote Northwestern Hawaiian Islands. The population is declining at a rate of approximately 4% a year (Baker et al. 2011). Out of a total estimated abundance of just 1,161 seals in 2008, over 100 seals are estimated to occupy the main Hawaiian Islands. While the population is declining in the Northwestern Hawaiian Islands, the Main Hawaiian Island population is increasing (Baker et al. 2011). Monk seals are known to occasionally haul out on the beaches of HAVO. The main restoration strategy for the monk seal population in HAVO is to protect it from human disturbance (Pratt et al. 2011).

Figure 4.16-1. Hawksbill turtle (*Eretmochelys imbricata*) nesting at ‘Āpua Point (Photo: NPS 2011).

Measures

- Number of nesting turtles, nests, and average hatch success of hawksbill turtles
- Presence/absence of green sea turtles
- Presence/absence of monk seals

Reference Condition/Value

Historical data on the presence and nesting activity of hawksbill turtles is extremely limited (Seitz et al. 2002). Consequently, no reference conditions exist for the number of nesting turtles and nests. Average hatch success of hawksbill turtles documented around the world is used as a reference condition for the turtles nesting on HAVO beaches. However because only incidental sightings of the green turtle and monk seal are documented at HAVO, no reference condition was developed for these measures.

Existing Data

Data for hawksbill turtles were compiled by Seitz et al. (2012). This report summarizes two decades of monitoring on the south shore of the Island of Hawai‘i.

Presence/absence data for the green turtle and Hawaiian monk seal were obtained from Pratt et al. (2011). Monk seal sightings by the general public are also reported to the Pacific Islands Fisheries Science Center and a summary of monk seal sighting from 2003 to 2012 is presented in Guerin (2013).

Current Condition

Number of Nesting turtles, Nests and Hatch Success of Hawksbill Turtles

Hawksbill turtles nest regularly at two locations in HAVO: ‘Āpua Point, and Halapē. Nesting occurs occasionally at Keauhou and is unconfirmed at Kakiwai, as the site is inaccessible from land, but nesting turtle tracks have been seen at the site from air and sea (Seitz et al. 2012).

Of the three monitored sites, ‘Āpua Point has the highest nesting activity per year while Keauhou has the least (Table 4.16-1). There was no difference in nesting activity detected over the years. Between

1989 and 2009, the mean annual number of female observed to nest was two for ‘Āpua Point and one for Halapē (Table 4.17 and 4.18). Females would come up to re-nest multiple times during the nesting season. Activity could be highly variable with some years having no observed females or nests. Also, females may nest one year, and not return for several years to nest. This remigration interval was typically 3 years but could vary between two and eight years. High variability in nesting behavior among females, and a small population of turtles (e.g.100 females documented islandwide) will likely require many more years of monitoring to obtain sufficient data for trend analysis of nesting activity.

Table 4.16-1. Mean nest hatch success for the Hawksbill turtle at three locations in HAVO.

Location	Size of Beach (m^2)	Years of Data	No. of Nests Documented/Year	Mean Nest Hatch Success
‘Āpua Point	4,300	1988–2009	6.9	70% ± 2% (n = 114)
Keauhou	1,030	1997–2009	0.8	71 ± 9% (n = 9),
Halapē	3,000	1989–2009	2.3	49 ± 4% (n = 46),
Kakiwai	Unknown	Inaccessible	–	no data
Average for Ka‘ū Coast	**–**	**–**	**–**	**72%**
Reference Condition	**–**	**–**	**–**	**70%**

Mean hatch rates for ‘Āpua Point and Keauhou are similar to the reference condition and the Ka‘ū average, while the Halapē hatch rates are lower. Hatch rates at Halapē are thought to be lower because of the shorter incubation time. At Halapē, hatchlings sometimes emerge during hot daylight hours and become dehydrated and desiccated. Park staff are collaborating with the National Oceanic and Atmospheric Administration (NOAA) and the University of Alabama to understand the relationship between temperature, incubation time, and hatch success (Seitz et al. 2012).

Table 4.16-2. Hawksbill activity at ‘Āpua Point, HAVO, 1988-2009.

Year	Observed Nesting Turtles	Observed Turtles	Nests	Mean Nest Hatch Success (%)
1988	0[1]	0[1]	4	ND
1989	0	0	8	97, n=1
1990	0	0	6	ND
1991	2	2	4	50 ± 16, n=4
1992	1	1	6	ND

[1] Nests and/or crawls found, but no turtles were observed.

[2] Adult female hawksbill found dead.

Table 4.16-2 (continued). Hawksbill activity at ʻĀpua Point, HAVO, 1988-2009.

Year	Observed Nesting Turtles	Observed Turtles	Nests	Mean Nest Hatch Success (%)
1993	3	4	13	78 ± 8, n=11
1994	2	2	9	83 ± 6, n=9
1995	2	2	7	78 ± 7, n=6
1996	4	4	21	67 ±7, n=13
1997	2	3	7	70 ± 12, n=7
1998	3	4	7	68 ± 12, n=7
1999	1	3[2]	6	79 ± 10, n=5
2000	0	0	0	NA
2001	1	2	2	30 ± 5, n=2
2002	3	3	9	63 ± 12, n=9
2003	0	0	0	NA
2004	2	4	5	47 ± 14, n=5
2005	4	4	11	73 ± 8, n=11
2006	2	2	5	66 ± 10, n=5
2007	1	2[2]	2	82 ± 10, n=2
2008	1	2	4	74 ± 14, n=3
2009	4	4	15	71 ± 7, n=14
Mean (n=21)	2	2	7	70 ± 2 (n=114)

[1] Nests and/or crawls found, but no turtles were observed.

[2] Adult female hawksbill found dead.

Table 4.16-3. Hawksbill activity at Halapē, HAVO, 1989-2009.

Year	Observed Nesting Turtles	Observed Turtles	Nests	Mean Nest Hatch Success (%)
1989	0	0	1	NA
1990	0	0	0	NA
1991	0	0	0	NA
1992	0	0	0	NA
1993	0	0	0	NA
1994	0	0	0	NA
1995	0*	0	5	37 ± 19, n=4
1996	0	0	0	NA
1997	0*	0	0	NA

* Nests and/or crawls found, but no turtles were observed.

Table 4.16-3 (continued). Hawksbill activity at Halapē, HAVO, 1989-2009.

Year	Observed Nesting Turtles	Observed Turtles	Nests	Mean Nest Hatch Success (%)
1998	0*	0	2	74 ± 24, n=2
1999	0*	0	0	NA
2000	1	1	2	58 ± 1, n=2
2001	0*	0	0	NA
2002	1	1	2	29 ± 11, n=2
2003	1	1	5	36 ± 15, n=5
2004	2	2	7	41 ± 10, n=7
2005	0	1	1	31, n=1
2006	1	1	4	83 ± 1, n=3
2007	2	3	7	52 ± 15, n=7
2008	3	3	9	66 ± 6, n=9
2009	1	2	4	21 ± 7, n=4
Mean (n=21)	1	1	2	49 ± 4 (n=46)

* Nests and/or crawls found, but no turtles were observed.

Nesting sites at HAVO are typically small isolated pockets of sand, with scattered cobblestone and/or coral, found intermittently along rocky cliffs. Immediate and persistent threats include human disturbance from campers, disorientation of turtles by artificial light, predation and invasive plants. Longer term and more stochastic threats range from habitat loss from geologic activity (subsidence, erosion, earthquakes, lava) and inundation events associated with natural disasters and climate change. While threats due to geologic changes and inundation events can be difficult or impossible to address, the more immediate and persistent threats can be prioritized. These are listed in Table 4.16-4.

Table 4.16-4. Threats at nesting Hawksbill turtle beaches, summarized from Seitz et al. (2012).

Location	Size of Suitable Nesting Area* (m^2)	Human Disturbance	Artificial Light	Predation	Alien Plants
ʻĀpua Point	760	low	low	low	high
Keauhou	550	high	high	high	moderate
Halapē	2,300	high	high	high	high
Kakiwai	unknown	none	none	likely low	likely low

*Above the high tide mark.

Presence/Absence of Green Sea Turtles

Green turtles are commonly observed along coastal waters of HAVO; less often they are seen resting and basking at park beaches (Figure 4.16-2). In the 2010 to 2011 nesting season, one green sea turtle attempted to nest at a beach at HAVO (NPS 2011) and is the first documented green turtle nesting attempt on the Island of Hawaiʻi. There is no green turtle population estimate for HAVO (Pratt et al. 2011). No active management of green turtles occurs at HAVO but this species will benefit from the management measures implemented for the hawksbill turtle.

<u>Presence/Absence of Monk Seals</u>
Monk seals have been observed hauled-out along the Park coast at ʻĀpua Point, Kaʻaha, and several beaches near Halapē by Park biologists (Figure 4.16-2). Twenty-one monk seal sightings along the HAVO coastline from 2003 through 2012 were reported by the general public (Guerin 2013). These sightings were localized to the three main coastal campsites of the Park: Ka'aha, Halapē, and Keauhou. Three individual seals, an adult female, a juvenile female, and a subadult male, were identified and account for 12 of the 21 sightings. These three seals represent nearly half of the population on Hawaiʻi Island (Guerin 2013). No monk seal births have been documented in HAVO, but two of 10 documented births on Hawaiʻi Island were at nearby Kamilo Beach (Guerin 2013). Park biologists consider all beaches in HAVO to be potential sites for monk seals to bask, rest, or give birth (Pratt et al. 2011). Numbers of sightings at HAVO are expected to remain low as the monk seal population on the main Hawaiian Islands follows a gradient, with the highest numbers being found in the islands in the northwest and decreasing towards the southeast (NOAA 2007).

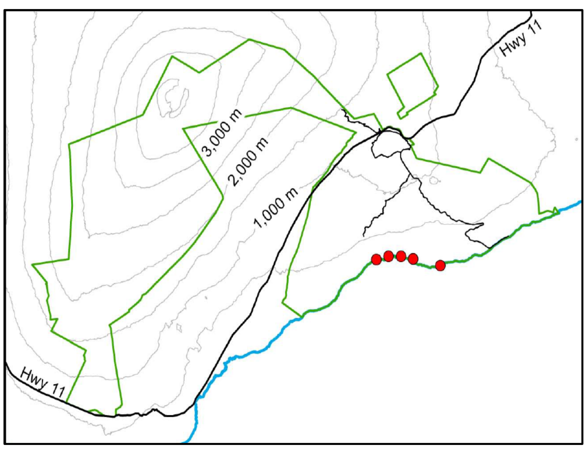

Figure 4.16-2. Monk seal and green turtle haulout/basking locations from Pratt et al (2011).

<u>Threats and Stressors</u>
Human activity in the campgrounds near the nesting sites has the potential for disturbing nesting turtles. Lights (such as from campfires) can disorient nesting females or hatchlings and cause them to become stranded and die. With human activity, the activity levels of introduced predators such as mongooses and rats also tend to be higher, associated with the increase in trash and discarded food. Invasive plants can encroach on the small amount of available nesting habitat and also can entangle nestlings on their way to the ocean. Geologic activity and coastal processes can change the topography and substrate of the nesting site and create significant barriers, such as the replacement of sand with cobblestones and large rocks which trap hatchlings and occasionally strand nesting females

(such as at ‘Āpua Point). Increased sea level rise forecasted by climate change models may further alter or reduce suitable nesting habitat.

Park rangers have moved camp sites and provided information to educate campers to minimize the effects of human disturbance and decrease the amount of artificial lighting. These efforts have benefited monk seals and green turtles. Predator trapping is also conducted at sites with high numbers of predators, and alien plant removal is conducted to prevent encroachment into suitable nesting habitat and reduce the rates of hatchling entanglements (Seitz et al. 2012, NPS 2010, 2011, 2012). For nesting sites where hatchlings become entangled on their way to the ocean (either in vegetation or cobblestones), the nest sites are corralled so that nestlings can be collected and released to the ocean, or corridors for safe passage are created (Seitz et al. 2012).

Overall Condition

The overall condition for this indicator is moderate with possible stable trends. The annual number of nesting females and nests at the Park’s two most active nesting beaches did not change over a twenty year monitoring period. With current management, hawksbill turtle nest hatch success meets the reference condition. However, only presence/absence data are available for green turtles and monk seals along the HAVO coastline.

Information Gaps/Level of Confidence

The level of confidence in the hawksbill turtle nesting data to date is high, with the 20-year data set and yearly monitoring. However, high variability in nesting behavior among females and the small number of observed turtles (e.g.100 females documented islandwide) will likely require many more years of monitoring to obtain sufficient data for reliable trend analysis.

The confidence in the distribution of monk seals and green turtles in HAVO is low. Systematic data collection will increase confidence in the extent of usage of the HAVO coastline by these two species. Additional data are potentially important for the seal due to its highly endangered status, combined with its upward population trend in the MHIs and nearby pupping.

These data can be collected in conjunction with the hawksbill turtle monitoring.

Overall, the extent of knowledge is ranked B (status data), as long-term data are available for hawksbill turtles, but not for monk seals or green turtles.

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4.17. Native Insect and Springtail Communities

Background

The Hawaiian Islands contain large radiations from nearly all major invertebrate groups with over 6,000 native invertebrate species. This profuse speciation has made this Faunaunique, with 98.3% of the species endemic to Hawaiʻi. These species also comprise a large percentage of the world Fauna(*Lispocephala*: over 100 out of 150 species; *Sierola*: 180 out of about 200 species; *Colletidae*: 60 out of about 700 species; *Drosophilidae*: about 600 out of 3,300 species, with many more undescribed). Thus, their conservation is of local and global importance (Magnacca and Foote 2006).

At HAVO, 1,490 invertebrates have been documented, representing approximately 15% of all arthropods documented in the state of Hawaiʻi (Karl Magnacca, Oahu Army Natural Resource Program, pers. comm. ~2013). Native invertebrates in Hawaiʻi are largely restricted to areas of predominantly native vegetation (Magnacca and Foote 2006) and insects comprise 87% of the invertebrate fauna of HAVO. Many native Hawaiian insects are host-specific, and could be in danger of extirpation because many native Hawaiian host plants are rare or endangered (e.g., Mauna Loa silverswords). These native plant-dependent insects (e.g., *Drosophila*, moths, and planthoppers) are in turn hosts of native specialist predators and parasitoids (e.g., *Sierola*), which can follow their host into extinction.

Among the Hawaiʻi National Parks, HALE and HAVO have the greatest diversity of vegetation types and highest proportion of intact native vegetation (Magnacca and Foote 2006).Native insects can be found along the entire elevation range encompassed by HAVO from the coastal strand vegetation to the sparsely vegetated subalpine zone.

The documented assemblage of insects found within the entire Park is first discussed, before focusing on native insect groups of interest. Specific native insect groups discussed in this report include *Drosophila* and Lepidoptera (moths and butterflies), which are dramatic examples of speciation and adaptive radiation; yellow-faced bees (*Hylaeus* spp.) (Figure 4.17-1), an important group of native pollinators; and springtails (*Collembola* spp.), which are non-insect arthropods and part of the soil microarthropod community that plays and important role in soil decomposition (Vtrov 1993) and can serve as good indicators of soil conditions.

In addition, five listed or proposed listed species of terrestrial invertebrates currently occur, have been previously documented, or have the potential to occur at HAVO. Of these, four species are picture-wing *Drosophila* species and each species is discussed individually (Table 4.17-1). The fifth species is the orange-black damselfly (*Megalagrion xanthomelas*) and is discussed in Section 4.19 (Anchialine Pools).

Figure 4.17-1. Endemic yellow-faced bee (*Hylaeus* sp.) found within the Kīlauea section of HAVO (Photo: Karl Magnacca 2000).

Table 4.17-1. Listed invertebrates found within HAVO.

Scientific Name	Common Name	Status
Drosophila heteroneura	Pomace fly, hammerhead picture-wing fly	Endangered
Drosophila mulli	Pomace fly, Mull's picture-wing fly	Threatened
Drosophila digressa	Pomace fly, pāpala picture-wing fly	Endangered
Drosophila ochrobasis	Pomace fly, enigmatic picture-wing fly	Endangered

Measures

- Percent of native insect and springtail species present on Hawaiʻi Island that occur within HAVO
- Percent of native insect and springtail species within HAVO
- Number of native Lepidotera present
- Number of native yellow-faced bees present
- Number and biomass of springtails in ʻŌlaʻa tract
- Number of *Drosophila* species in ʻŌlaʻa tract
- Distribution of proposed and listed native insects and springtails

Reference Condition/Value

The condition of invertebrate communities is often measured by the presence and abundance of native invertebrates and the proportion of native or endemic invertebrates to nonnative invertebrates. Generally, non-disturbed areas with relatively intact native vegetation are expected to harbor a greater abundance and proportion of native invertebrate fauna, though species groups may have specific habitat requirements.

The number of species and percent of native insects and springtails currently documented in HAVO is compared to the total number of native insects and springtails recorded for the Island of Hawaiʻi. The percentage of native insect and springtail species present on the island that are represented in the Park is used to assess the condition of the insect and springtail Faunain the Park. Although no reference condition is defined, since HAVO only covers 10% of Hawaiʻi Island, a high percentage (e.g., more than 50%) would indicate that a significant proportion of the insects and springtail species are represented within HAVO.

Similarly, for the percent of native/endemic insect and springtail species to introduced species within HAVO, no reference condition is set; however, a high percentage of native species would indicate that the insect or springtail assemblages have not become dominated by nonnative species.

The reference condition for the number of native *Drosophila* in the ʻŌlaʻa tract is based on the baseline data collected in 1971 and 1972 and reported by Carson (1986). For the other invertebrate groups (Lepidotera, yellow-faced bees, and springtails), similar historical reference conditions do not exist, and a simple comparison of the number of species present in HAVO is made with the number of native species present on Hawaiʻi Island.

For proposed and listed species, the historic distribution of these species within HAVO is used as the reference condition.

Existing Data

Available data for native terrestrial invertebrates in HAVO are comprised of a species checklist, as well as several studies that focus on specific groups of invertebrates and their threats. The following datasets and reports were used.

- Non-certified invertebrate lists were provided by the I &M staff (NPS, unpublished data). These lists are considered preliminary and have not been reviewed by a subject matter expert. However, these lists are considered adequate to provide a general summary and estimate of the number of terrestrial invertebrate species known to be present in the Park current until 2007. Only species already known to occur in HAVO were considered. Many other species that are probably present, but not yet documented were not included.
- A species checklist for the Island of Hawaiʻi and the state of Hawaii was provided by Dr. Karl Magnacca (unpublished data).
- Giffin and Rowe (2007) surveyed the newly acquired Kahuku section of HAVO for Lepidoptera in 2006. Most work was centered at mid-elevations primarily along the Kaʻū Forest Reserve boundary where moth diversity was expected to be highest.

- Vtorov (1993) sampled microinvertebrates at the various sites in the ʻŌlaʻa tract and measured the effects of pig exclusion on native microinvertebrate diversity and abundance. The dominant group (numbers and biomass) within leaf litter and soil was the springtails.
- Carson (1986) surveyed *Drosophila* species and abundance in the ʻŌlaʻa tract and compared his results to a 1971 and 1972 census.
- Foote and Carson (1995) reported results of a *Drosophila* survey in the ʻŌlaʻa tract in 1992 and 1993 and analyzed trends from data collected in the past three decades.
- Pratt et al. (2011) provide current distribution maps and descriptions of proposed and listed invertebrates within the Park.

<u>Current Condition</u>

Percent of Native Insect and Springtail Species Present on Hawaiʻi Island that Occur within HAVO

More than 50% of all species of springtails and insects found on Hawaiʻi Island are present within HAVO (Figure 4.17-2). Insects that are well represented at HAVO (more than 50% of known species are present in HAVO) include beetles (Order: Coleoptera), true flies (Order: Diptera, especially native *Drosophila*), true bugs (Order: Hemiptera), bees, wasps, ants and sawflies (Order Hymenoptera), and butterflies and moths (Order: Lepidoptera). The 17 native species of springtails in HAVO represent nearly 70% of the native springtails documented on the island. The diversity of native insects and springtails present at HAVO is high, considering that HAVO covers a mere 10% of Hawaiʻi Island.

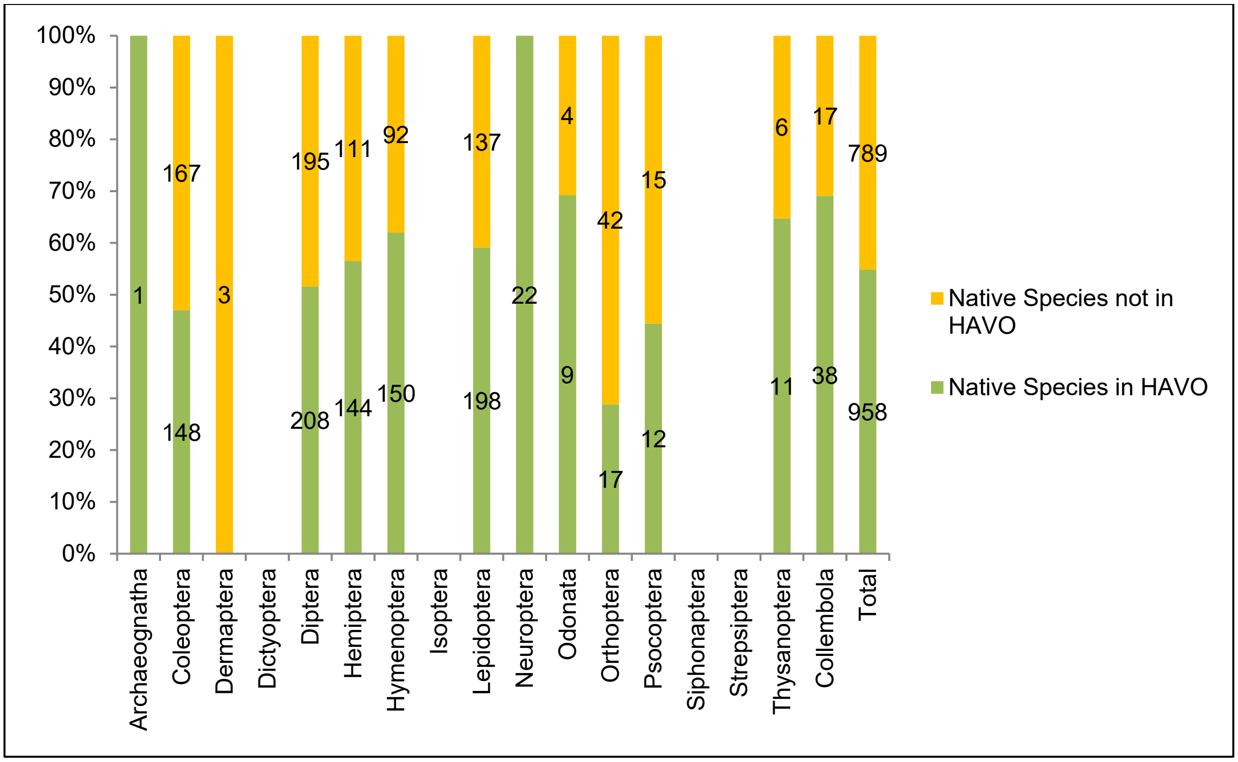

Figure 4.17-2. Percent of native insect and springtail species present on Hawai'i Island that occur within HAVO. Numbers within columns are the number of species (NPS unpublished data).

Percent of Insect and Springtail Species within HAVO that are Native

Insects represent 87% of the documented terrestrial invertebrates in HAVO, with over 1,200 species recorded. Overall, a relatively high percentage, more than 70% of the insects recorded in HAVO, are native species (Figure 4.17-3).

Dominant insect orders include beetles (Order: Coleoptera), true flies (Order: Diptera, especially native *Drosophila*), true bugs (Order: Hemiptera), bees, wasps, ants and sawflies (Order Hymenoptera), and butterflies and moths (Order: Lepidoptera) (Figure 4.17-2). Within HAVO, these dominant orders have between 188 and 291 species each (native and nonnative), with between 65% and 83% of the species considered native. Native springtails (Class Entognatha; Order: Collembola) comprise 45% of the documented springtail species in HAVO.

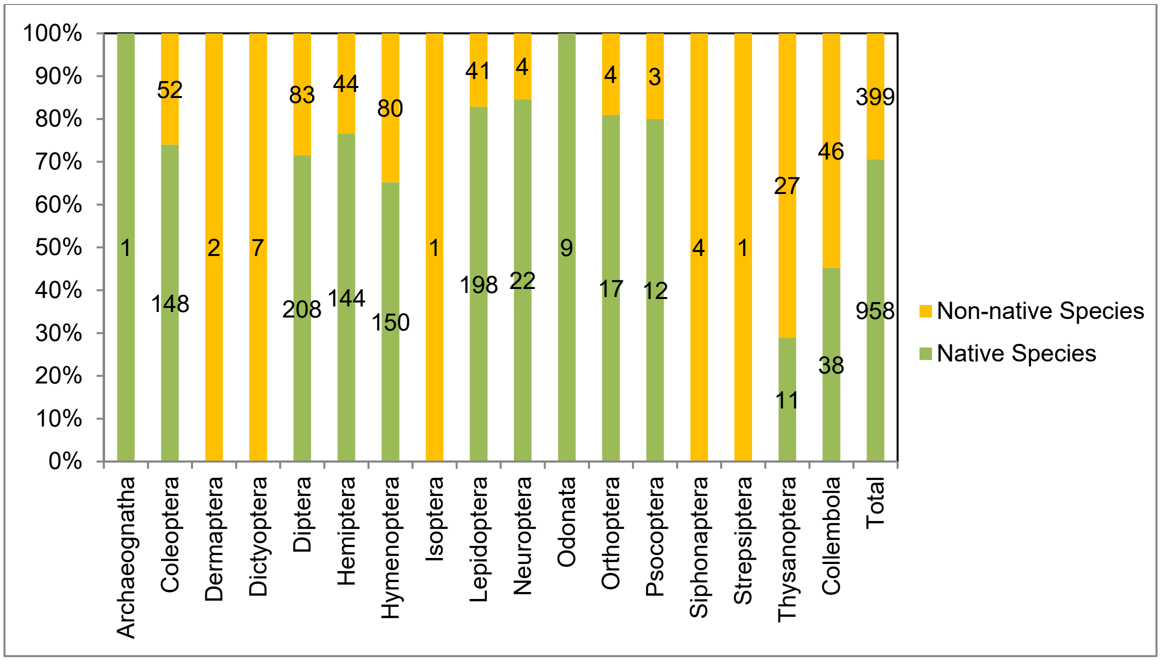

Figure 4.17-3. Percent of insect and springtail species within HAVO that are native. Numbers within columns are the number of species (NPS unpublished data).

Number of Native Lepidoptera Present

Giffin and Rowe (2007) documented 145 species and morpho-species of moths in 18 families at the Kahuku section. Of these, 107 species (73.8 %) were endemic, 33 species (22.8 %) were nonnative, and 5 species (3.4 %) were deliberately introduced as biocontrols. A number of undescribed species were also encountered. Overall, slightly less than one-third of the island-wide total was encountered at Kahuku. Giffin and Rowe (2007) also state that the species diversity at Kahuku is relatively high compared to other montane areas on the Island of Hawai‘i, such as Waiakea Forest Reserve (94 species sampled), despite the fact that many of the collecting sites were situated in highly degraded forest.

The status and abundance of Hawaiian leaf roller moths (Crambidae: *Omiodes* spp.) are of particular concern at HAVO. A substantial decline in Hawaiian leaf roller moths was noted by entomologists as early as 1954 (Giffin and Rowe 2007). Of the 18 species recorded from the Island of Hawai‘i, at least 11 still exist on the island. Seven *Omiodes* species were collected at Kahuku during the survey period (Giffin and Rowe 2007).

Overall, the diversity of moths at Kahuku is high and with restoration and the return of native vegetation, diversity could be expected to increase. Species present in the adjacent Ka‘ū Forest Reserve will likely colonize the Kahuku section as restoration progresses and new species may also be discovered with additional sampling.

Number of Native Yellow-Faced Bees Present

Twenty-nine species of yellow-faced bees have been documented on the Island of Hawai‘i. Eighteen of these species are known to occur at HAVO. All of the yellow-faced bees recorded in HAVO are native and collectively represent 62% of the yellow-faced bees species present on the island. Most of the collections have occurred in the mesic/wet forest and mid-elevation seasonal forest near Kīlauea.

Visitation records (Daly and Magnacca 2003) and identification of pollen loads (unpubl. data) indicate that yellow-faced bees are frequent visitors to many of the native Hawaiian plants such as ʻaʻaliʻi, pūkiawe, and ʻolapa (*Cheirodendron trigynum*) and are important for native plant reproduction and hence ecosystem health (Magnacca 2007). In addition, in areas where rare species are present, several species (e.g., silverswords, ʻōhai) are regularly visited by yellow-faced bees. For many of these plants, yellow-faced bees are almost the only regular floral visitors. Conversely, yellow-faced bees are also dependent on native ecosystems for their continued existence as they visit only a few nonnative plants.

Number and Biomass of Springtails in the ʻŌlaʻa Tract

Eighty-four documented species are present in HAVO. Of these, 45% are native to Hawaiʻi. Springtails have been well studied in the soil and leaf litter of the ʻŌlaʻa tract in HAVO. Vtorov (1993) compared diversity and abundance of microarthropods in areas with pigs with areas that had been pig-free for 2, 4, and 7 years. Seven years after removal of pigs, total density of microarthropods in the forest nearly doubled, and biomass increased 2.5 times. Springtails were the most dominant microarthropods both in numbers (55%) and biomass (45%) in the leaf litter and topsoil for all sites. Endemic springtails are dominant species in sites without pigs and the biomass of endemics increased 12 times from soils recovering from pig damage (Figure 4.17-4).

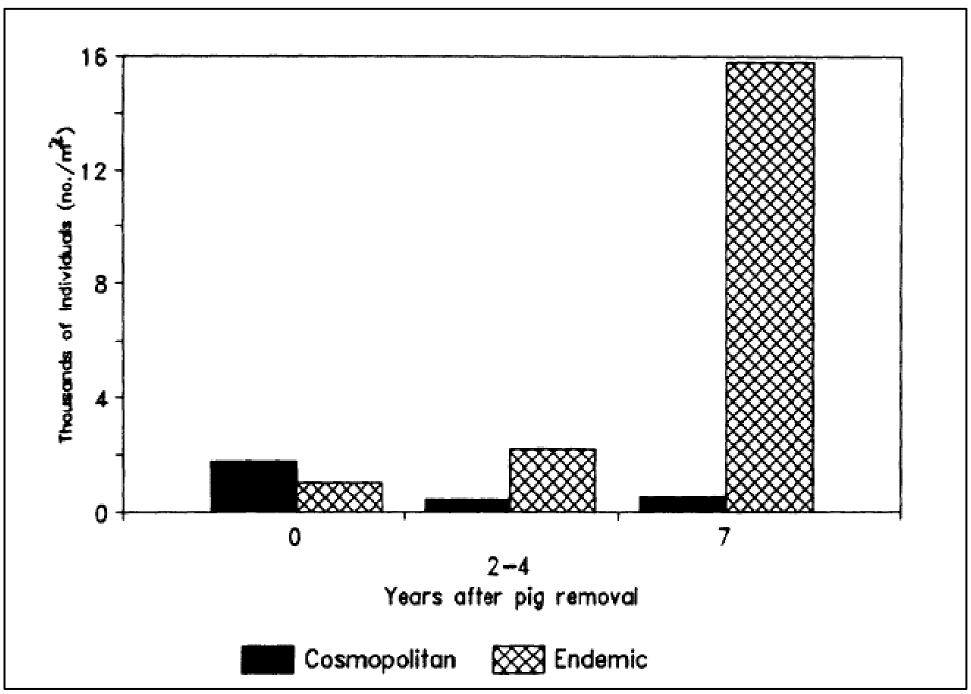

Figure 4.17-4. Changes in cosmopolitan and endemic springtail (Order: Collembola) abundances as soils recover from pig disturbance from Vtorov (1993).

The comparisons by Vtorov (1993) show that feral pigs can significantly decrease the number and biomass of springtails. Numbers and biomass of springtails within the ‘Ōla‘a tract were primarily affected by soil density, which is thought to be the result of trampling by ungulates such as pigs.

Number of Drosophila Species in ‘Ōla‘a Tract

Drosophila have also been monitored at ‘Ōla‘a tract in HAVO for over three decades with surveys done in 1971–1972, 1981–1986, and 1992–1993. Comparing results from 1971–1972 (reference condition) with later surveys, approximately 18% of the species originally documented in ‘Ōla‘a have been lost (four out of 14 species) (Magnacca and Foote 2004). Additionally, abundances of several species have declined between the two surveys. Declines in *Drosophila* abundance and diversity appear to be linked to the loss of host plants. Carson (1986) and Foote and Carson (1995) note the decline of two species of *Drosophila* (*D. murphyi* and *D. setosimentum*) and the disappearance of *D. heteroneura* and *D. silvestris* (Figure 4.17-5).

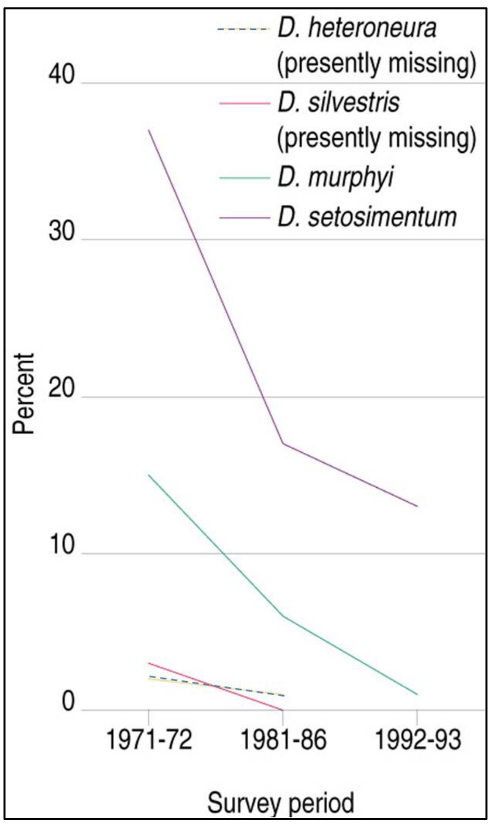

Figure 4.17-5. Decline of ‘ōhā dependent *Drosophila* at ‘Ōla‘a tract based on percent of total observations during the survey period from Foote and Carson (1995).

D. heteroneura and *D. silvestris* breed primarily on Hawaiian lobeliods or ‘ōhā (*Clermontia* spp.) and these plant species are endangered and are declining in numbers or are now rare at HAVO. *D. heteroneura* is listed as endangered and discussed in greater detail below. Conversely, *D. sproati*, a species that appears to breed exclusively in rotting bark of one of the most common trees in this rain forest, olapa (*Cheirodendron trigynum*), is increasing.

Another factor for the decline of *Drosophila* may have been the invasion of ʻŌlaʻa Forest by alien western yellowjackets (*Vespula pennsylvanica*) in the early 1980s. The wasps have become dominant predators of other insects and may have contributed to the decline of picture-wing *Drosophila* by feeding on larvae that are particularly exposed on ʻōhā (Carson 1986, Foote and Carson, unpublished data). Given the existing data, *Drosophila* species dependent on rare plant species are declining.

Distribution of Listed and Proposed Native Insects and Springtails

Four federally and state listed or proposed listed *Drosophila* species are currently known to occur, could occur, or used to occur within HAVO. These are discussed in detail below. The fifth insect species is the orange-black damselfly (*Megalagrion xanthomelas*) and is discussed in Section 4.19 (Anchialine Pools).

The pāpala picture-wing fly is only found on the Island of Hawaiʻi and is dependent on its host plant pāpala (*Charpentiera* spp.). Most of the recent sightings of this fly are from the ʻŌlaʻa section at HAVO; however, numbers are declining and its range within HAVO has likely been reduced (Carson 1986, Pratt et al. 2011) (Figure 4.17-6). Previously, the pāpala picture-wing fly was found within Bird Park and ʻŌlaʻa tract in HAVO. The only other known population is in the Manuka Natural Area Reserve within the Manuka Forest Reserve (USFWS 2013, Pratt et al 2011).

Mull's picture-wing fly has never been recorded within HAVO even though its host plant (loulu, *Pritchardia* spp.) occurs in the ʻŌlaʻa Forest. Most of the observations come from ʻŌlaʻa Forest Reserve, adjacent to the ʻŌlaʻa Tract of HAVO (Perreria and Kaneshiro 1990, Pratt et al. 2011).

There is only one record of the endangered *Drosophila ochrobasis* in HAVO in the nineteenth century in what is now the Kahuku section. Additional populations, however, are known to be present in forest adjacent to the ʻŌlaʻa section. This species has also been recorded on Kohala mountains south to the Kaʻū district and has a disjunct distribution.

The hammerhead picture-wing fly is currently not in HAVO. The only recent sightings of the hammerhead picture-wing fly are from the KonaUnit of Hakalau Forest National Wildlife Refuge (Foote 2000). The species was observed regularly in the 1970s and 1980s in ʻŌlaʻa Forest and around Nāhuku (Thurston Lava Tube) in association with large ʻōhā (Carson 1986), and was also noted as abundant at Kahuku Ranch, now Kahuku Unit of HAVO (Carson et al. 1989, Pratt et al. 2011). The hammerhead picture-wing fly mostly disappeared from the Park when the western yellowjacket wasp first arrived in the late 1970s.

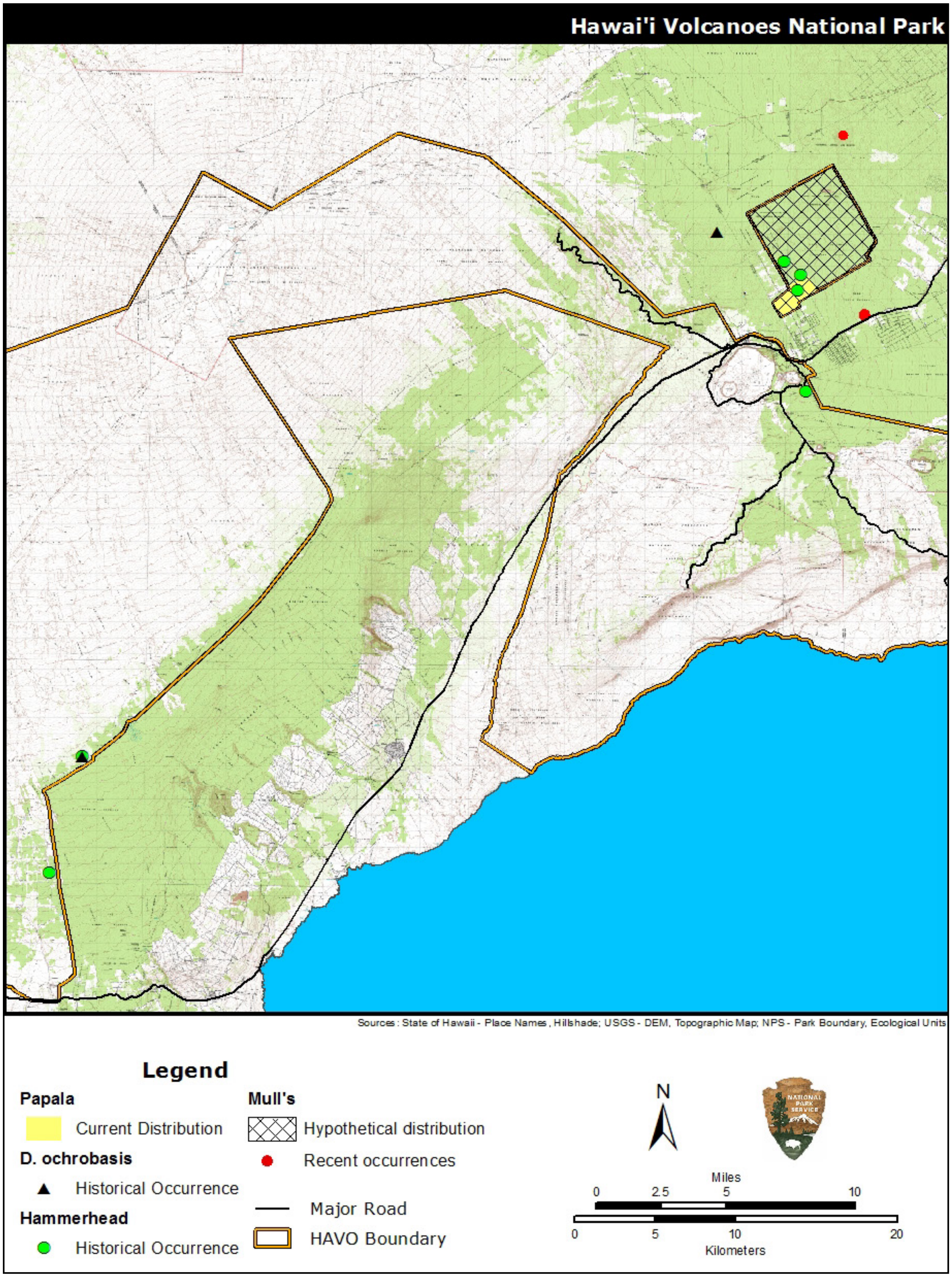

Figure 4.17-6. Current and/or historic distribution of Pāpala picture-wing fly, hammerhead picture-wing fly, Mull's picture-wing fly, and *Drosophila ochrobasis* (Pratt et al. 2011).

Threats and Stressors

Major threats listed for all native terrestrial invertebrates in HAVO include invasive insects, invasive plants, invasive vertebrates, visitor impacts, nearby development, rare plant extinctions, restricted populations, and climate change (Magnacca and Foote 2006).

Native Lepidoptera are vulnerable to disturbances and degradation of native habitat (Giffin and Rowe 2007, Giffin 2007) which occur due to the presence of introduced ungulates or the spread of invasive plants. Many of these insects have narrow host requirements and larvae of some species feed exclusively on the leaves, seeds, pollen, and wood of native plants. Some species may restrict their activities to a single species of host plant and thus are restricted by the distribution of these species (Giffin and Rowe 2007, Giffin 2007).

As mentioned above, the degradation of native habitat results in the loss of native plant species and could negatively affect yellow-faced bees which are dependent on native ecosystems for their continued existence. Yellow-faced bees also face competition from nonnative pollinators such as the honey bee (*Apis mellifera*) (Magnacca 2007). Introduced yellow-jacket wasps are also known to reduce visitation rates of yellow-faced bees to ‘ōhi’a flowers and could affect the persistence of yellow-faced bees in addition to reducing the fruit production of ‘ōhi’a (Hannaet al. 2013). Invasive invertebrates are discussed in more detail in Section 4.6.

Other major impacts to native insects and springtails in HAVO are trampling by ungulates, such as pigs, and predation by western yellowjackets. The wasps may have contributed to the decline of picture-wing *Drosophila* by feeding on larvae that are particularly exposed on ‘ōhā (Carson 1986, Foote and Carson 1995, unpublished data).

Threats to the recovery of the pāpala picture-wing fly include feral pigs and cattle that forage on the host plants of this species. The western yellowjacket wasp preys on picture-wing flies and may limit this fly’s distribution to wetter forests where the wasps are not common (Foote and Carson 1995). The most likely threat to the Mull’s picture-wing fly is loss of the host plant species, the loulu palm, which suffers from extensive seed depredation by pigs and rats in montane wet forests. Threats to the recovery of *Drosophila ochrobasis* include feral pigs and ungulates that attack host plants of this species. The western yellowjacket wasp preys on picture-wing flies and may have contributed to the scarcity of this species (Pratt et al. 2011). Losses of host plants to feral cattle, pigs, and mouflon sheep have probably contributed to the rarity of the species (Foote and Carson 1995).

Overall Condition

Given that many of the listed species are restricted in range or extirpated from the Park, the overall condition of this indicator is ranked “of concern” with declining trend. This ranking is given despite the fact that HAVO is home to a significant portion of the native invertebrate and springtail species present on Hawai‘i Island and that the proportion of nonnative species is relatively low.

Information Gaps/Level of Confidence

Information on the native invertebrates in HAVO is available for certain areas of the Park that are expected to support higher diversity of native species. However, given the large diversity of insects in HAVO, and the large extent of the Park that has yet to be surveyed, repeat surveys in the same area have often been separated by 10-year gaps or more. Thus, only very broad conclusions can be drawn about the condition of the indicator.

Results from studies that have already been conducted also need to be analyzed and reported. Much more scientific work has been done than is currently reported and available for reference.

The "Appendix E: Invertebrate FaunaReport" by Magnacca and Foote (2006) indicated that shorter-term monitoring of springtails from the soil and litter invertebrate community along transects in montane rainforests in HAVO was being conducted. Currently results from such monitoring efforts are unavailable. When these survey results are analyzed, these can be compared to the data from Vtorov (1993) or used as a more recent baseline and contribute to the long-term data set monitoring native springtails, as well as soil health within the Park.

Monitoring of *Drosophila* is currently dormant and should be revived as there are indications that species of *Drosophila* dependent on rare plant species are declining. Monitoring of bees and other pollinators of rare plants, such as MaunaLoa silverswords and ʻōhai, may be called for upon completion of an upcoming research study on rare plant limiting factors.The extent of knowledge is ranked C (limited data), as most data are limited to presence/absence of species.

Subject Matter Experts Consulted

- Karl Magnacca, Biologist, Oahu Army Natural Resource Program

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4.18. Cave and Lava Tube Communities

Background

According to the Federal Cave Resources Protection and Management Act of 1988, as amended 1990, a cave is a "naturally occurring void, cavity, recess, or system of interconnected passages that occurs beneath the earth's surface or within a cliff or ledge large enough to be traversed by people, whether or not the entrance is naturally formed or manmade." Any material or substance occurring naturally in caves (including animals, plants, paleontological deposits, sediments, minerals, speleothems and relief features) are considered cave resources (16 USC §§4301–4310).

Caves can form by a variety of processes including rock dissolution, wave action, rock fracturing, and lava flows (Santucci et al. 2001). Lava tubes are subterranean channels that were created by flowing molten lava. These ecosystems are typically formed in fast moving pahoehoe lava (Howarth 1973). Because pahoehoe lava does not fuse with the existing surface, extensive horizontal spaces and vesicle-like channels develop. When the surface crust of a lava flow cools, the underlying flow is insulated allowing it to travel for many miles while retaining much of its heat energy. As the volcanic eruption ceases, the molten lava drains from the channel leaving an empty passage, or lava tube. Sections of lava tube often collapse creating skylights, sinkholes, cracks, and trenches (Howarth 1983, Kauahikaua et al. 2004, SWCA 2008).

These subsurface environments are important for several reasons. First of all, they contain interesting geological and mineralogical features. Cave minerals are formed by different forces and display a wide array of sizes, morphology, and colors. Caves and lava tubes are also known to attract and trap surface-living animals, resulting in the occurrence and accumulation of paleontological resources that can have both scientific and educational value. The relatively stable cave environment provides natural protection from weathering and erosion, and aids in the long-term preservation of organic material (Santucci et al. 2001, Howarth et al. 2007). In Hawai‘i, well preserved fossil skeletons of endangered and extinct birds have been discovered in lava tubes (James et al. 1987, Olson and James 1991, Ziegler 2002, James and Olson 2003, Howarth and Stone 1998).

Unique flora and Faunacan be present in these environments. Cavernicoles can be classified into three categories: 1) troglobites, which are specialized obligate cave species; 2) troglophyles, which can live in caves or other cave-like (moist cool dark) habitats; and 3) trogloxenes, which can be found in caves, but do not live their entire life in caves (Howarth 1973, 1983). Troglobites are characterized by a number of anatomical and physiological adaptations to cave life including loss of pigment, loss of sclerotization (hardening of exoskeletons), reduction or loss of eyes, elongation of appendages and sensory structures with long hairs, lengthened life span, modified life history patterns, and metabolic adaptations to nutrient-poor conditions. Specialized cave-adapted animals are typically restricted to the deep zone and mesocaverns, which are dark regions that typically have high levels of carbon dioxide (CO_2) and low levels of oxygen (O_2).

Hawaiian caves and lava tubes support a diverse array of rare cave-adapted plants and highly specialized invertebrates due to the moist and stable microclimates and protection from grazing ungulates (USFWS 1997). Over 75 species of troglobites are recognized throughout the Hawaiian Islands. Of these, 44 occur on the Island of Hawaiʻi (Stone and Howarth 2005).

Finally, archaeologists have also found important cultural resources within caves. In Hawaiʻi this includes petroglyphs, cultural artifacts, stone structures, and human remains (Ziegler 2002, Thornberry-Ehrlich 2009).

According to a recent geologic resources inventory of the Park (Thornberry-Ehrlich 2009), about 1,000 cave entrances and nearly 320 km (200 mi) of caves have been surveyed within HAVO. These include lava tubes, crater vent caves, fissure and rift zone caves, pressure ridge caves, tree mold caves, and sea caves (Stone et al. 2005). While some caves are small, others are more extensive with a diversity of passage types. Thurston Lava Tube, Highcastle Lava Tube, ʻĀinahou Cave, and Bird Park (Puaulu) Cave are among the more well-known caves and lava tubes in the Park. As mentioned above, many of HAVO's caves and lava tubes contain important natural resources such as geological formations and features, minerals, paleontological remains, and rare troglobites and their habitats (Stone et al. 2005).

Figure 4.18-1. Researcher in HAVO cave (Photo: NPS, no date).

Measures

- Occurrence of ecological or mineralogic formations/features

- Presence of native cave animals
- Presence of native cave vegetation
- Presence of paleontological resources

Reference Condition/Value

According to NPS' Natural Resource Management Reference Manual #77 (NPS 2004), caves are considered significant if they possess specific features, characteristics, or values within the following resource types: Biota, Cultural, Geologic, Mineralogic, Paleontological, Hydrologic, Recreational, Educational or Scientific. The reference conditions for caves in HAVO are derived from this manual.

The reference condition of geologic or mineralogic formations/features is that these features are fragile, or exhibit interesting formation processes, or that are otherwise useful for study. For cave animals and vegetation, the reference condition is that the cave "provides seasonal or yearlong habitat for organisms or animals, or contains species or subspecies of flora or Faunathat are native to caves, or are sensitive to disturbance, or are found on State or Federal sensitive, threatened, or endangered species lists" (NPS 2004). For paleontological resources, the reference condition is that these resources have the potential to contribute useful educational and scientific information.

Because cava data are considered highly sensitive, and specific cave locations are kept confidential under U.S. cave law, these reference conditions are assessed collectively for the Park, rather than on a site-specific basis.

Existing Data

Surveys of HAVO's caves have occurred since the early 1900s; however, systematic inventories of caves and cave resources only began within the last 35 years (Stone et al. 2005). The results of these surveys often are not published due to the sensitive nature of these ecosystems. Locality, name, and cultural/archaeological/paleontological information are sensitive and often are not provided in reports (including this report).

The following sources were used to assess the cave and lava tube indicator.

- Frank Howarth surveyed various caves within the Park in the early 1970s (Howarth 1972, 1973). Hawaiian cave adapted species were first discovered during these surveys.
- Favre (1993) summarizes the findings of several members of the Speleological Society of Geneva while surveying pit craters and lava tubes in the Park between November and December 1981. Ka'ū Desert Pit Craters and MaunaUlu Crater Cave were mapped during this survey.
- Selected HAVO caves were inventoried by a team of researchers in 1990 through 1993. The results of these surveys were summarized and assessed in findings reports/management plans for eight caves in HAVO (Howarth et al. 1992a, 1992b, Howarth et al. 1994, Pearthree, Stone, and Howarth 1992, Pearthree et al. 1992, 1994, Stone, Howarth, and Pearthree 1992, Stone et al. 1993). These reports also incorporated previous observations by early speleologists such as Wood, Kempe, and Halliday.

- Bunnell (2000) and Camara (2000) briefly discuss the mineral resources of two caves within HAVO.
- In February through June 2005, the Bishop Museum was contracted to re-inventory caves that were originally surveyed in the early 1990s. Additional caves were also surveyed during this inventory, increasing the total to 30 caves in the Park. Inventories provided notes on general cave descriptions, surface and entrance vegetation, species observed in the cave and collected from pitfall bait traps (Bernice P. Bishop Museum, 2005 unpublished data).
- Stone et al. (2005) discuss the various lava caves (i.e., tubes, crater vent caves, fissure and rift zone caves, pressure ridge caves, tree mold caves, and sea caves) and their resources throughout HAVO. This report also provides a history of speleological inventories in the Park.
- Thornberry-Ehrlich (2009) describes prominent and representative geological features in HAVO, including a discussion on the Park's lava tube caves. The results of many earlier surveys (e.g., Wood 1980, Halliday and Fulks 1997a, 1997b, Halliday 2007) are briefly summarized in this report.
- White (2010) sampled secondary minerals from a selection of caves on Hawaiʻi Island and briefly described formations with a single HAVO cave.
- Benitez et al. (2008) and Pratt et al (2011) provide information on rare plants found in caves at HAVO.

<u>Current Condition</u>

Occurrence of Geologic or Mineralogic Formations/Features

Many of the caves surveyed in the Park have unique, interesting, or abundant geological or mineralogical formations and features. For example, Laeʻapuki Cave is reported to contain large and extensive speleothems (White 2010). Several caves have been noted to contain lava stalactites ('lavacicles') and stalagmites, which are types of speleothems that hang from the ceiling or rise from the floor, respectively. These deposits exhibit a range of shapes, sizes, and colors in HAVO's caves including tubular or shark tooth stalactites, red-tinted Pele's Hair encrusting stalactites, moonmilk, soda straws, cave coral, and rare driblet spires that resemble a cockscomb (Howarth et al. 1992a, 1992b, Pearthree et al. 1994, Bunnell 2000, Camara 2000, Bishop Museum 2005 unpublished data). Researchers have noted that some minerals are abundant in HAVO caves.

Another important geological feature described in HAVO's caves is the exposed ash or oxidized soil layer. This indicates erosional lowering of the floor (Pearthree, Stone, and Howarth 1992a). Other geological and mineralogic features noted by researchers in HAVO include pendants, deposit of mirabilite, lava splatters, lava ledges and shelves, lava volcanoes, lava tongues, lavafalls, and flow ripples (Pearthree et al. 1992b, Favre 1993, Stone et al. 1993, Bishop Museum 2005 unpublished data, Stone et al. 2005, Thornberry-Ehrlich 2009).

Some features have been damaged or removed by visitors. In Thurston Lava Tube, which is a popular visitor destination, some features identified in earlier reports have disappeared or conditions have deteriorated, while others have remained unchanged (Bernice P. Bishop Museum 2005 unpublished data). Accidental destruction of formations in other caves has also been described (Stone et al. 2005).

Presence of Native Cave Animals

Roughly 25 endemic obligate cave species have been documented in HAVO's caves (Table 4.18-1). The first Hawaiian cave-adapted species (a blind cixiid or planthopper) was discovered by Frank Howarth in Bird Park Cave in 1971 (Howarth 1972, 1973).

Table 4.18-1. Obligate endemic cave adapted species recorded in HAVO caves. Sources: Howarth et al. 1992a, 1992b, 1994, Pearthree, Stone, and Howarth 1992, Pearthree et al. 1992, 1994, Stone et al. 1992, 1993, Bernice P. Bishop Museum 2005 unpublished data.

Scientific Name	Common Name
Caconemobius fori	Lava flow cricket
Caconemobius sp.	Cricket
Caconemobius sp. *A*	Rock cricket
Caconemobius sp. *B*	Rock cricket
Caconemobius varius	Cave rock cricket
Cavaticovelia	Water treader
Erigone sp.	Sheetweb spider
Erigone stigius	Sheetweb spider
Foveacheles sp.	Rhagidiid mite
Lithobius sp.	Rock centipede
Lycosa howarthi	Small-eyed wolf spider
Meioneta sp.	Sheetweb spider
Nannolene sp.	Native millipede
Neanura hawaiiensis	Springtail
Nesidiolestes sp.	Threadlegged bug
Nesomedon	Small rove beetle
Oliarus polyphemus	Planthopper
Oliarus sp.	Cabe planthopper nymph
Oonops sp.	6-eyed jumping spider
Schrankia sp.	Cave moth
Sinella yosiia	Ppringtail
Thaumatogryllus cavicola	Cave tree cricket
Thaumatogryllus sp.	Tree cricket
Theridion sp.	Cobweb spider
Tyrannochthonius howarthi/Vulcanochthonius	Pseudoscorpion

Following the surveys conducted in 1990 through 1993, Howarth et al. (1994) stated that ʻĀinahou Cave was the "most important biological cave in the state" due to its high biotic diversity. At least 19 endemic obligate cave-adapted species were documented in ʻĀinahou Cave, some of which are only known from this cave (Howarth et al. 1994). Cave moths (*Schrankia* sp.), millipedes (*Nannolene* sp.), and crickets (*Caconemobius* sp.) appear to be among the most widely observed animals in HAVO caves (see Information gaps/Level of confidence section). No federally or state listed cave invertebrates occur on the Island of Hawaiʻi.

While some caves such as ʻĀinahou Cave and Bird Park Cave are rich in endemic cave-adapted species, others have low invertebrate population levels, with only one or a few animals observed per visit. The number of cave species is generally correlated with deep cave conditions (low O_2, high CO_2, high humidity, constant temperature), deep penetrating tree roots, calm air flow, and size of suitable habitat (Howarth 1993, Stone et al. 2005, Stone and Howarth 2005).

Presence of Native Cave Vegetation

Troglobites feed on ʻōhiʻa roots or other plant roots that penetrate the lava tube roof and pass through the open cavity (Howarth 1973, 1983, Howarth et al. 2007). A paucity of roots penetrating into caves limits the food resources available to cave animals. In the recent surveys by the Bishop Museum, some caves were reported to have a "rich root room" (Bernice P. Bishop Museum 2005 unpublished data).

Cave entrances and lava tube skylights provide habitat for common and rare Hawaiian plants. The endangered Island Peruvian spleenwort (*Asplenium peruvianum* var. *insulare*) has been recorded in the MaunaLoa strip and subalpine environments in Kahuku in deep, dark recesses of lava tubes and on walls and ceilings within the lighted zone (Benitez et al. 2008, Pratt et al. 2011). A variety of more common native plants have been documented in cave entrances in HAVO (Howarth et al. 1992a). These environments provide protection from grazing ungulates.

Presence of Paleontological Resources

Fossil plant remains have been documented in several caves and lava tubes in HAVO. Some caves contain prime examples of fossilized plants in wall cinders (Howarth et al. 1994). In addition, bird and bat bones of unknown taxa have also been observed (Pearthree et al. 1992, Howarth et al. 1994). During the surveys by the Bishop Museum, several caves were noted to contain potential bird bone sites (Bernice P. Bishop Museum 2005 unpublished data), suggesting that further investigation is needed. However, many of the caves in HAVO are too young to contain significant paleontological resources (Howarth et al. 1994).

<u>Threats and Stressors</u>

Troglobites are highly vulnerable to surface activities due to their absolute dependence on energy and nutrient input from the surface, such as plant roots and detritus and organisms that enter caves (Howarth 1973, 1983, Howarth et al. 2007). Obligate cave species also have narrow and specific ecological requirements (Howarth and Stone 1990) and do not acclimate well to rapid changes in their physical, biological, or chemical environment (Barr 1968, Culver 1982).

Cave resources can be drastically altered by physical and biological changes or disturbance over the surface. Toxins, herbicides, or pollutants on the surface can affect the subterranean ecosystem (Howarth and Stone 1998, Howarth et al. 2007). Loss of surface vegetation (especially ‘ōhi‘a) can be devastating to cave animals that are totally dependent on the roots penetrating the subsurface. The input of excess soil and debris restrict water and nutrients from reaching deeper voids by blocking interstices or openings. At HAVO, ungulate grazing and fires can result in the removal of plants whose roots are important sources of nutrition. Nonnative animals, including spiders, centipedes, scorpions, and rats, can consume or compete with native invertebrates. New lava flows can destroy existing caves and their resources (Stone et al. 2005).

Finally, these fragile habitats are also threatened by human intrusion, trampling, and vandalism that could cause breaches in the lava tube ceiling, floor, and walls, as well as change the cave microclimate. Researchers or visitors at HAVO have the potential to intentionally or unintentionally damage cave resources. Humans can also create pathways for nonnative species (Howarth and Stone 1998, Stone et al. 2005, Stone and Howarth 2005).

Overall Condition

Collectively, the caves and lava tubes in the Park meet or exceed all of the reference conditions or values. Interesting and fragile geological or mineralogic formations/features have been documented. Paleontological resources in some caves and tubes are useful for scientists and educators. Furthermore, specialized cavernicoles have been found in numerous caves and lava tubes and these ecosystems provide important habitat for a listed endangered fern, as well as other native plants.

Information Gaps/Level of Confidence

Overall, the available data for this indicator are considered limited. Various reports (Stone et al. 2005, Burrell and Blakemore 2008, Thornberry-Ehrlich 2009) mention that intermittent cave and lava tube surveys have been conducted in the Park in recent years. Stone et al. (2005) also indicate that a cave database containing inventory information and condition assessments for all caves is being developed. However, information from many cave surveys is unpublished or not assembled possibly due to the sensitive nature of the ecosystems and lack of Park resources. As a result, this assessment was limited to reports provided by Park staff or available to the public. More recent reports are primarily notes from field surveys (i.e., raw data); many of the animals recorded in these surveys were not identified even to genus or only common names were provided. It would be worthwhile to compile unpublished data for all caves in HAVO to be able to provide a more detailed assessment.

Stone et al. (2005) state that the National Speleological Society previously conducted a survey in the Kahuku Unit; however, this information was not available for this report. It has been noted that numerous unsurveyed lava tubes are present in Kahuku (Benitez et al. 2008). Surveys and reporting for this area are warranted.

Available information suggests that many of the biological inventories are restricted to a single visit. Many cave species are cryptic and require intensive searching, thus, the potential to come across new species and distributions is likely. However, the ability to conduct thorough cave surveys is limited by the hazardous and difficult nature of such surveys; caves and lava tubes are unstable and dynamic geology, as well as the possibility of researchers unintentionally damaging resources.

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4.19. Anchialine Pools

Background

Anchialine pools are unique coastal water bodies that have no surface connection to the sea, but display both tidal fluctuations and salinity ranges that indicate subsurface connections to the groundwater table and the ocean (Holthuis 1973). According to Polhemus et al. (1992), the surface level of these euhaline to mixohaline lentic waters is an "inland extension of marine water table, with mixohaline water resulting from diluting of intruding ocean water with seawater-percolating groundwater." Anchialine pools are generally found on geologically young and porous substrate such as lava flows within the coastal tropics and subtropics (Chai et al. 1989). The water may be visible in fissures, caverns in lava tubes, or in rock basins (Tango et al. 2012).

Anchialine pools can harbor a distinctive assemblage of native species including bacterial mats, algae, emergent aquatic plants, mollusks, and crustaceans (Maciolek and Brock 1974, Maciolek 1983). In undisturbed conditions, these pools are considered to be windows into a far more extensive subterranean brackish water ecosystem. The Faunaof anchialine habitats usually consists of marine invertebrates that have invaded through subterranean interstices (Polhemus et al. 1992).

Within the United States, natural anchialine habitats are only found in the Hawaiian Islands. Most of these pools occur on Hawai'i Island, with an estimated 600 pools. More than half of the pools on Hawai'i Island occur along the western coast from Kawaihae to Kailua-Kona. Fewer anchialine pools occur in low-lying areas on Maui (~50 pools), O'ahu (~3 pools), and Moloka'i (only 1 pool) (Stone 1989, Brock and Kam 1997).

Several rare species are found in Hawaiian anchialine pool systems including one proposed endangered anchialine pool shrimp (*Vetericaris chaceorum*, no common name) and three shrimp species that are listed as candidate species by the USFWS (scavenging anchialine pool shrimp [*Metabetaeus lohena*]; *Palaemonella burnsi*, no common name; and *Procaris hawaiana*; no common name). Rare damselflies, such as the candidate orange-black damselfly (*Megalagrion xanthomelas*), also inhabit anchialine pools.

Roughly 20 anchialine pools have been described along HAVO's coast (Chai et al. 1989). The Park displays a range of pool types, from excavated or otherwise modified well sites to deep fissure-pools in pāhoehoe lava flows. Pools at HAVO support populations of the rare scavenging anchialine pool shrimp, as well as a diverse assemblage of cyanobacterial crusts, algal mats, molluscs, other crustaceans, fishes, and a subterranean eel. Some of the Park's pools are densely vegetated along the margins and provide foraging and roosting habitat for shorebirds and other wildlife (Pratt et al. 2011, David Foote, Wildlife Biologist, PIERC-USGS, pers. comm. 2014).

Figure 4.19-1. Anchialine pool in HAVO (Photo: Kelly Kozar 2009).

Anchialine pools are highly threatened throughout the state of Hawaiʻi (Stone 1989, Mitchell et al. 2005, USGS 2005). Prior to European contact, early Hawaiians modified the pools to function as baths, fishponds, or water sources. It is estimated that roughly 90% have been destroyed or degraded due to human activities, especially coastal resort development. Remaining pools are threatened by impending future development, invasive species, and groundwater withdrawal for human use. Introduced fish are considered to be the greatest threat to anchialine shrimps (USFWS 2012) and native fish also consume native pool species (Robert Kinzie, Ecologist, SWCA, pers. comm. 2014). Anchialine pools are also subject to senescence as leaf litter accumulates in the water over years, reducing pool size and eventually converting them into a marsh (Brock and Kam 1997).

Measures

- Abundance and surface area of pools
- Native species richness
- Abundance of native species
- Number of listed species/SOC
- Presence of invasive pool Fauna
- Presence of pool vegetation
- Water quality

Reference Condition/Value

An historical reference condition for pool abundance and surface area in HAVO does not exist. The earliest survey of anchialine pools in HAVO was conducted in 1988 (Chai et al. 1989), when human-related activities, such as habitat modification and introduction of nonnative species, had already impacted Park resources. In addition, more recent pool surveys have used different pool naming systems and survey methods, making direct comparisons to the Chai et al. (1989) survey challenging. For these reasons, reference conditions for anchialine are based on general information known about anchialine pools throughout Hawaiʻi Island. When it is not possible to identify a reference condition, general comparisons are made between HAVO's pools and other anchialine pools on Hawaiʻi Island. In some cases, data from Chai et al. (1989) and more recent surveys are considered collectively for comparison purposes.

For the pool abundance and surface area measure, the reference condition is based on surveys conducted by Maciolek and Brock in the 1970s on the west coast of Hawaiʻi Island. This survey found that 40% of the anchialine pools had surface areas less than 10 m^2 (108 ft^2), half had surface areas between 10 and 100 m^2 (1,076 ft^2), and 10% were greater than 100 m^2 in surface area. Brock and Kam (1997) categorize these pool sizes as small, intermediate, and large, respectively. These size categories are compared to surface areas recorded at HAVO.

The reference condition for native species richness is that HAVO's pools contain the usual suite of anchialine pool shrimp expected to occur on Hawaiʻi Island. Ten native shrimp are known to occur in Hawaiʻi Island anchialine pools; however, some of these species are not common. Characteristic anchialine pool shrimp species include scavenging anchialine pool shrimp, ʻōpae ʻula (*Halocaridina rubra*), ʻōpae ʻoehaʻa (*Macrobrachium grandimanus*), and ʻōpae huna (*Palaemon debilis*) (Brock and Kam 1997). This reference condition is restricted to shrimp species due to the lack of survey data for the other groups.

The reference condition for number of listed species and SOC is that all four proposed endangered or candidate shrimp and the candidate damselfly are present within the Park. The reference condition for invasive pool Faunais the complete absence of these species. Nonnative fish adversely impact key anchialine species through competition and predation (Brock and Kam 1997).

<u>Existing Data</u>

The following literature and datasets were referenced and assessed to evaluate this indicator.

Chai et al. (1989) were the first to conduct a detailed survey of the physical and biological resources associated with HAVO's pools. These surveys were conducted in May and July 1988. This survey and report focused heavily on pool crustaceans. Comparisons are provided between HAVO and other Hawaiian anchialine pools.

As part of the anchialine pool invertebrate inventory conducted by D. Foote in 2003 and 2004, all anchialine pool complexes (defined as pools that show surface connection during high tide) in HAVO were resurveyed (Foote et al. in prep.). However, data collected during this survey have not been compiled and summarized and were not available for this report.

NPS's I&M Program collected pilot data at HAVO's anchialine pools between 2008 and 2010 to assist with finalizing the anchialine pool monitoring protocol (Kelly Kozar, NPS, pers. comm.). This information is available in the I&M Anchialine Pool Monitoring access database (NPS 2011) which stores all data related to anchialine pool monitoring in the PACN. The database includes information on plant cover, substrate, pool surface area and depth, and the results of trapping and biological sampling.

Pratt et al. (2011) provide distribution maps of rare anchialine species at HAVO and briefly summarize known information about HAVO's anchialine pools.

Current Condition

Abundance and Surface Area of Pools

During surveys in 1988, Chai et al. (1989) identified 19 pools at seven complexes within the Park boundaries (Table 4.19-1). Three of these pools were not extensively surveyed due to a lack of surface water. The total surface area reported of all pools during this survey was 526 m^2 (5,662 ft^2). The smallest pool was 0.3 m^2 (3 ft^2) and the largest was 130 m^2 (1,400 ft^2). The survey found that 50% of the pools surveyed were small, 44% were intermediate in size, and 6% (one pool) were large. Comparing these pools to other pool systems on Maui and Hawai‘i, Chai et al. (1989) concluded that the total surface area of HAVO's anchialine pools was lo. Pool depths ranged from 0.1 m (0.3 ft) to 15.0 m (49 ft) (Chai et al. 1989).

Table 4.19-1. Anchialine pools and complexes identified by Chai et al. (1989).

Complex Name	Pool Name	Distance from Shore (m)	Surface Area (m^2)	Depth (m)
East Keauhou	Pool A	40	10 - small	0.25
	Pool B	40	15 - intermediate	0.2
	Pool C	40	60 - intermediate	0.2
	Pool D	40	10 - small	0.45
Halapē	Pool A	70–80	60 - intermediate	2.5
	Pool B	25	12 - small	3.0
	Pool C	20	90 - intermediate	3.0
	Pool D	<20	5 - small	1.0
Halapē, Boulder Bay	–	20	130 - large	0.7
Ka‘aha Crack	–	100	45 - intermediate	>3.0
Kalu‘e Crack	–	35	18 - intermediate	0.8-15
Waha‘ula Cave	Pool A	700	36 - intermediate	2.7
	Pool B	700	8 - small	2.7
	Pool C	700	4.5 - small	2.7
West ‘Āpua	Pool A	20	5 - small	0.4
	Pool B	20	0.3 - small	0.1

The I&M database identifies 17 anchialine pools in the Park within three main complexes: ‘Āpua, Kapapala, and Keauhou. The majority of the pools occur in the Kapapala complex (Table 4.19-2). The total surface area of the pools identified in the I&M database is 366 m^2 (3,940 ft^2), with a range between 0.3 m^2 (3 ft^2) and 78 m^2 (840 ft^2). Roughly 41% are considered small, 59% are intermediate in size, and no large pools were recorded. Depths were reported between 0.05 m (0.2 ft) and 3.20 m (10 ft) (NPS 2011).

Table 4.19-2. Anchialine pools and complexes identified by I&M Anchialine Pool Monitoring access database. (-) = no depth provided (NPS 2011).

Complex Name	Pool Name	Average Surface Area (m^2)	Average Depth (m^2)
Āpua	‘Āpua_001	23.6 - Intermediate	–
	‘Āpua_002	19.6 - Intermediate	–
	‘Āpua_003	5.5 - Small	0.70
Kapapala	Kapapa_001	59.6 - Intermediate	2.90
	Kapapa_002B	10.9 - Intermediate	1.80
	Kapapa_003	4.8 - Small	0.60
	Kapapa_004	11.0 - Intermediate	2.30
	Kapapa_005	43.8 - Intermediate	2.00
	Kapapa_006	77.8 - Intermediate	3.10
	Kapapa_007a	6.3 - Small	–
	Kapapa_007b	7.8 - Small	–
	Kapapa_007c	7.8 - Small	–
	Kapapa_007d	7.8 - Small	0.60
Keauhou	Keauho_001	0.3 - Small	0.30
	Keauho_002	21.9 - Intermediate	0.05
	Keauho_003	11.8 - Intermediate	0.05
	Keauho_005	45.2 - Intermediate	0.20

As mentioned above, it is not possible to cross-reference exact anchialine pool sites between the Chai et al. (1989) and I&M surveys due to the lack of geo-coding in early surveys, as well as sampling differences (David Foote, Wildlife Biologist, PIERC-USGS, pers. comm.). Surface area also often fluctuates with the tides. Therefore, trends in the number and surface area of anchialine pools in HAVO cannot be assessed; however, it is known that at least one pool complex (Waha‘ula Cave) recorded in the 1988 survey is no longer present because it was covered by lava. Differences in total surface area can be partially attributed to loss of some pools due to lava flows and timing of surveys. The Halapē/Kapapala area appears to consistently have the highest number of anchialine pools in HAVO. Compared to the pools surveyed by Maciolek and Brock (1974), HAVO appears to support a relatively low number of large pools.

Native Species Richness

Twelve native species were identified in the pools by Chai et al. (1989). This includes six fish, five crustaceans, and one mollusc (Table 4.19-3). The mollusc pipiwai (*Theodoxus cariosus*) and the shrimp ‘ōpae huna were the most frequently recorded species, reported from nearly 43% of the surveyed pools.

Table 4.19-3. Native and nonnative pool species observed at HAVO and percentage of pools recorded.

Species class	Species Name	Common Name	% of Pools in HAVO*		
			Status	Chai et al.	I&M
Crustaceans	*Halocaridnarubra*	‘Opae ‘ula	Endemic	35.7	52.9
	Macrobrachium grandimanus	‘Opae ‘oeha‘a, ‘ōpae Kāla‘ole	Indigenous	28.6	11.8
	Macrobrachium lar	Tahitian prawn	Nonnative	28.6	23.5
	Metabetaeus lohena	Scavenging anchialine pool shrimp	Endemic	21.4	47.1
	Metapograpsus thukuhar	‘Alamihi	Indigenous	28.6	11.8
	Palaemon debilis	‘Opae huna	Indigenous	42.9	47.1
Molluscs	*Theodoxus cariosus*	Pipiwai	Endemic	42.9	0.0
Fish	*Abudefduf sordidus*	Blackspot sergeant, kūpīpī	Indigenous	7.1	5.9
	Acanthurus triostegus	Manini	Native	14.3	0.0
	Awaous stamineus	‘O‘opu nākea	Endemic	0.0	5.9
	Bathygobius fuscus	Brown goby	Indigenous	14.3	0.0
	Carangoides sp.*	Papio	Indigenous	7.1	0.0
	Eleotris sandwicensis	‘O‘opu akupa	Endemic	7.1	0.0
	Kuhlia sandvicensis	Aholehole	Indigenous	21.4	5.9
	Mugil cephalus	Striped mullet	Indigenous	0.0	5.9
	Unknown goby	–	?	–	–
	Unknown fish	–	?	–	–
Insects	*Anax junius*	Common green darner	Indigenous	0.0	5.9
	Pantala flavescens	Wandering glider	Indigenous	0.0	11.8

* Based on biological surveys, not trap surveys.

The I&M program recorded 11 pool species including two insects and two fish not previously recorded by Chai et al. (1989). ‘Ōpae ‘ula were found in over half of the pools during the biological surveys (Table 4.19-3). This species has been noted as a keystone herbivorous species in Hawaiian anchialine systems (Brock and Kam 1997). During biological surveys, the majority of the species observed were native (Table 4.19-4). All of the anchialine pools species (not including marine species) recorded by Chai et al. (1989) were re-sighted during the I&M surveys (NPS 2011).

Native species richness at HAVO is similar to that reported at other anchialine pools (Brock and Kam 1997, Tango et al. 2012). All four of the characteristic native shrimp known in anchialine pools have been recorded at HAVO. Only one native mollusc was observed at HAVO. In other parks, up to five native mollusks were seen (Tango et al. 2012). Chai et al. (1989) concluded that HAVO had a low diversity of representative anchialine species compared to Konapools primarily because of the lower salinity in HAVO’s pools.

Table 4.19-4. Number of biological pool surveys conducted and percentage of native species observed (NPS 2011).

Native Species	Number of Surveys and Year(s) Conducted*	Total # of Aquatic Species Observed	Percentage Native
‘Āpua_001	0	N/A	N/A
‘Āpua_002	4 (2009)	3	100
‘Āpua_003	2 (2008)	2	100
Kapapa_001	10 (2008, 2009)	4	75
Kapapa_002B	18 (2008, 2009)	3	100
Kapapa_003	20 (2008–2010)	7	100
Kapapa_004	24 (2008, 2009)	6	100
Kapapa_005	3 (2008)	3	100
Kapapa_006	9 (2008, 2009)	2	100
Kapapa_007a	0	N/A	N/A
Kapapa_007b	2 (2008)	2	100
Kapapa_007c	2 (2008)	2	50
Kapapa_007d	1 (2008)	1	0
Keauho_001	2 (2008)	2	50
Keauho_002	1 (2008)	1	100
Keauho_003	0	N/A	N/A
Keauho_005	2 (2008)	1	100

* Based on biological surveys, not trap surveys.

According to researchers at USGS, recent surveys in HAVO’s pools have documented a high diversity of pool insect Fauna (David Foote, Wildlife Biologist, PIERC-USGS, pers. comm). Data from these surveys were not available.

Abundance of Native Species

Because anchialine pool species inhabit interstitial spaces, surveys often document species presence and absence rather than abundance estimates (USFWS 2012). Chai et al. (1989) reported that the pools in HAVO had a low abundance of rare and common native species compared to other pools within the state; however, quantitative values were not provided.

Abundance values were not collected during the I&M biological surveys; however, information is provided on the number of each species caught in traps deployed at six Kapapala pools. In total, 2,647 individuals were caught in 452 traps (NPS 2011). The number of each species caught is provided in Table 4.19-5.

Table 4.19-5. Number of species caught in traps within Kapapala pools during trapping by the I&M program (NPS 2011).

Species Class	Species Name	Common Name	Status	# of Individuals in Traps
Crustaceans	*Halocaridinarubra*	ʻōpae ʻula	Endemic	1,861
	Macrobrachium grandimanus	ʻōpae ʻoehaʻa, ʻōpae kālaʻole	Indigenous	483
	Macrobrachium lar	Tahitian prawn	Nonnative	68
	Metabetaeus lohena	scavenging anchialine pool shrimp	Endemic	161
	Metapograpsus thukuhar	ʻalamihi	Indigenous	5
	Palaemon debilis	ʻōpae huna	Indigenous	69
Fish	*Eleotris sandwicensis*	ʻoʻopu akupa	Endemic	1

Number of Listed species/SOC

Two candidate arthropods have been reported at HAVO's pools: scavenging anchialine pool shrimp and the orange-black damselfly. The three other listed or candidate shrimp (*Vetericaris chaceorum*, *Palaemonella burnsi*, and *Procaris hawaiana*) have not been recorded at HAVO, although they occur in other pools on Hawaiʻi Island.

The native scavenging anchialine pool shrimp was recorded in three of the pools surveyed by Chai et al. (1989) and eight of the pools surveyed by the I&M program (NPS 2011). According to the USFWS, this species occurs in only 26 pools across Maui, Hawaiʻi, and Oʻahu (USFWS 2012).

The distribution of the orange-black damselfly in the Park is limited. It was previously observed at Wahaʻula, which was covered by a lava flow. More recently, it was observed at Halapē within the Park. The orange-black damselfly is more abundant outside of the Park in the adjacent Kaʻū District (Pratt et al. 2011).

Presence of Invasive Pool Fauna

It is notable that nonnative fish have not been recorded at the pools in HAVO given that predation by introduced nonnative fish is considered to be the greatest threat to anchialine shrimps (USFWS 2012). Furthermore, the likelihood of fish being introduced to the pools is unlikely due to their remote location. The Tahitian prawn (*Macrobrachium lar*) is the only invasive species recorded within HAVO pools (Table 4.19-3 and 4.19-5). This species may compete with some native animals for food. It was reported to occur at high densities in some pools, such as Halapē (Chai et al. 1989).

Table 4.19-6. Plant species and cover values recorded at the anchialine pools surveyed by the I&M Program (NPS 2011).

Species Name	Status	# of Pools Present	Range of % Cover Values where Present		
			Emergent	Canopy	Peripheral
Cocos nucifera	nonnative	2	1	5-10	0
Fern	unknown	1	0	0	20
Fimbristylis dichotoma	indigenous	4	20–40	0	10–70
Grass	unknown	4	0	0	20–50
Ipomoea sp.	unknown	1	0	0	1
Morinda citrifolia	nonnative	1	0	0	15
Pluchea carolinensis	nonnative	8	0	1–70	15–60
Sesuvium portulacastrum	indigenous	1	0	0	20
Thespesia populnea	indigenous	2	70	80–95	10–80

Presence of Pool Vegetation

The amount and type of pool vegetation can play an important role in the condition of anchialine pools by contributing leaf litter or providing important habitat for rare insects (Tango et al. 2012). Chai et al. (1989) identified 37 emergent and adjacent plant species during his survey in 1988.

Three native and three nonnative plant species were identified at HAVO's pools by the I&M program, as shown in Table 4.19-6 (NPS 2011). Sourbush (*Pluchea carolinensis*) was the most common species recorded; this nonnative species can contribute large amounts of leaf litter if dense stands form. The native milo tree (*Thespesia populnea*), although only present at two pools, had a high percentage of cover in all vegetation layers. The native sedge *Fimbristylis dichotoma* dominated the peripheral and emergent vegetation in some pools (NPS 2011). Characteristic native pool vegetation not found at HAVO includes ʻōhelo kai (*Lycium sandwichense*) and kaluhā (*Bolboschoenus maritimus*).

Water Quality

Water quality parameters can influence the type and distribution of pool organisms. Chai et al. (1989) reported that HAVO had a high water quality compared to other pool systems on Hawaiʻi and Maui, although the criteria for this ranking is not stated. Temperatures at HAVO reported by Chai et al. (1989) ranged from 25.5°C to 29.3°C. Salinity ranges were reported between 0.8 and 17.3 ppt, with a mean of 7.6 ppt (Figure 4.19-2). Anchialine habitats have salinities typically ranging from 2 to 32 ppt (Maciolek 1983). Chai et al. (1989) noted that the salinity levels at HAVO are low compared to those on the Konacoast potentially due to higher rainfall in the Park. More recent water quality measurements have not been collected at HAVO's pools.

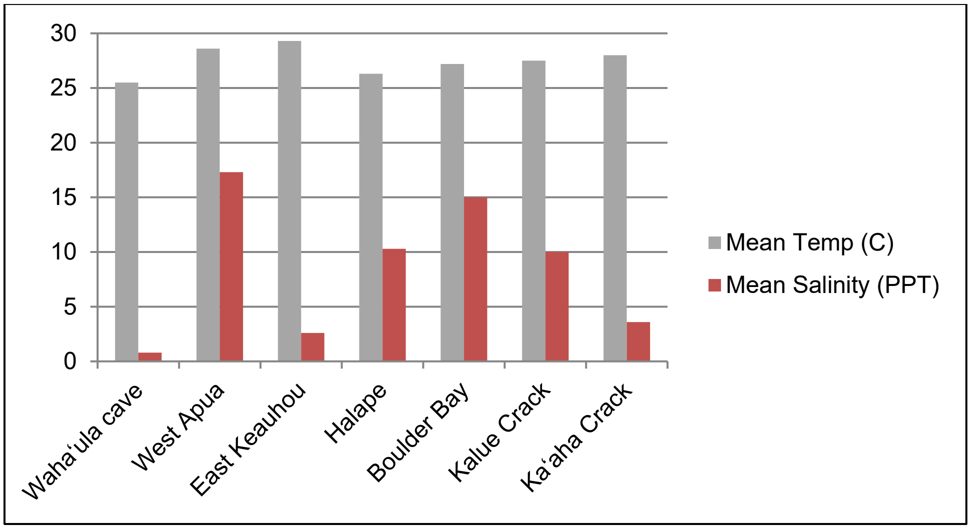

Figure 4.19-2. Mean temperature and salinity values at HAVO's pool complexes surveyed by Chai et al. (1989).

<u>Threats and Stressors</u>

A primary threat to anchialine pools is the presence of invasive species. Introduced Tahitian prawns and fishes, such as guppies (e.g., *Poecilia reticulata* and *Gambusia affinis*) and tilapia *(Oreochromis* and *Tilapia* spp.), compete with or prey on native fauna. This can result in shifts in community composition, which in turn may alter processing and recycling of nutrients (Capps et al. 2009). It is unlikely, but not impossible, that nonnative fish will be introduced to HAVO pools due to their remote location and the Park's protected status (Pratt et al. 2011). Other invasive species, such as nonnative ants and spiders, also consume adult native damselflies that utilize pool vegetation (Pratt et al. 2011).

Dense plant growth can accelerate the sedimentation process by dropping litter into pools. Invasive plants, notably sourbush, can increase the natural rate of anchialine pool senescence (Chai et al. 1989). Accumulation of sediments can also prevent biota from accessing interstitial groundwater zones (Tango et al. 2012).

Historically, anchialine pools have functioned as bathing areas, fishponds, or sources of water. Today, use of pools for these activities continues to threaten their condition. Trash and litter dumping by visitors and the use of soaps while bathing in pools may impact the condition of anchialine pools at HAVO.

Simply due to their proximity to active volcanoes, the persistence of anchialine pools at HAVO may be impacted by lava flows. Pool complexes are known to have been covered by lava in recent times. Climate change may also modify the pools due to alterations in water depths and salinity (Tango et al. 2012).

Overall Condition
All four of the characteristic anchialine pool shrimp species and two candidate species known from Hawai‘i Island occur in the Park’s pools. Furthermore, nonnative fish, which are considered a significant threat to these systems, have not been recorded at the pools. On the other hand, the nonnative Tahitian prawn has been documented and HAVO supports fewer large pools compared to other areas on the island. Thus, the current condition does not meet all or most of the reference conditions, placing it in the Moderate condition category, within no trend.

Information Gaps/Level of Confidence
Overall, the extent of the knowledge base for this indicator is classified as “B.” Quantitative data exist for the majority of the measures. It is not possible to determine trends.

Several groups of pool organisms have not been surveyed or the information is not available. The earliest surveys of HAVO’s pools focused on crustaceans and pool macrofauna, while aquatic insects and other biota were not surveyed. Surveys conducted by the I&M program and Dr. Foote in 2003 and 2004 surveyed a broader range of groups; however, this information was either not available or was not summarized and analyzed (which is out of the scope of this report). Availability of this information would be helpful to determine the condition of other pool species. Little information is provided on algae and cyanobacteria in the pools, although these are often prominent features of anchialine pool systems (Tango et al. 2012) and likely ecologically important. Plankton surveys also have not been conducted in the pools at HAVO.

No quantitative or qualitative data are available on the amount of trash dumped or other human impacts; thus, lack of evidence of human impacts cannot be used as a reference condition at this time. Nutrient levels in anchialine ponds are indicative of land use practices, on-site activities, and biological process and data can provide a warning if these systems are altered (NPS 2003, DeVerse and DiDonato 2006). Baseline water quality measurements (temperature, pH, salinity, dissolved oxygen, total dissolved solids, conductivity, TP, TN, chlorophyll *a*, and turbidity) have not been conducted in recent years. This would be helpful to potentially show evidence of anthropogenic impacts. Information on human impacts, nutrient levels, and water quality could be used to assess pool condition in the future.

Finally, estimates of the stage of senescence of each pool would help to determine conditions within the Park. In addition to pool depth, this could include quantifying the amount of leaf litter, encroaching vegetation, sediments, and algal mats.

Subject Matter Experts Consulted

- Foote, David. Wildlife Biologist, PIERC-USGS.

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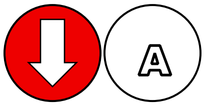
4.20. Fire Regime



Background

The reconstruction of historical and pre-settlement fire regimes for the archipelago is difficult because the native ecosystems have undergone extensive transformations and pre-settlement fire regime research is sparse. Continuous tree growth patterns and other factors preclude the use of dendrochronology and fire scar analysis so most evidence of fire occurrence has been derived from coarser estimates based on charcoal deposits in bogs (Smith and Tunison 1992; Tunison et al. 2001, Abrahamson 2013, Ainsworth and Kauffman 2009). Prior to human habitation, fires were likely to have been very infrequent with volcanism as the primary ignition source and, much less commonly, lighting. While natural fire regimes in Hawai'i are difficult to reconstruct, they are, for most areas "best characterized as fire-independent" (Smith and Tunison, 1992 in Cuddihy and Stone, 1990). Evidence from burn layers in soil strata, paleoecological evidence, and observations by early European explorers suggest that early Polynesians used fire in the coastal lowlands to clear areas for agriculture and to stimulate growth of thatching material (Tunison et al. 2001, NPS 2009).

Despite our limited understanding of Hawai‘i's past fire regime, all evidence shows a dramatic change in the last century. Fire frequency has increased almost five-fold across the state between1904 to 1939 and 1940 to1976 (Cuddihy and Stone, 1990 in Abrahamson). Between 1920 to 1970 and 1970 to 1995, there has been a three-fold increase in frequency and a 60-fold increase in fire size recorded at HAVO (Abrahamson 2013). Increased human ignitions, destruction of forest and the spread of nonnative fire-adapted grasses have all contributed to this increased fire frequency (Abrahamson 2013).

Studies have shown that some Hawaiian plants possess fire-tolerant traits that allow persistence after fire or that respond positively to fire (Hodgkinson and Oxley 1990; D'Antonio et al. 2000, Tunison et al. 2001, Abrahamson 2013). It is unknown whether these species traits are adaptations in response to fire in their early evolutionary history prior to establishment in Hawai‘i, or as a response to other disturbances common to Hawai‘i's natural disturbance regime, such as lava flows or hurricanes (Ainsworth and Kauffman 2009). Despite their ability to tolerate fire, most native species do not require fire to survive and reproduce. Most native species have been found to decrease in abundance post fire, usually due to competition by fire-adapted, nonnative plant species (e.g. grasses) (Cuddihy and Stone 1990).

The widespread establishment of non-native, fire-adapted grasses in Hawai‘i's low and mid-elevations has created a destructive grass/fire cycle that has altered the fire regime in the Hawaiian Islands, contributing to larger, more intense wildfires. Nonnative grasses have invaded previously forested areas creating continuous fuelbeds of fine fuels. These species are prone to fires due to their high standing biomass and high ratio of dead-to-live biomass. Following fires, the nonnative grasses recover more rapidly than native species and grow with increased vigor. As a result, burned areas are converted to grasslands with higher fuel loads of fire-prone grasses, further facilitating the spread of fire (D'Antonio and Vitousek 1992, LaRosa et al. 2008).

Large, intense wildfire can cause habitat destruction and loss of species. In addition, these events can have more profound and subtle ecosystem impacts. They can alter nutrient cycling and availability, trophic dynamics, vegetation structure, species regeneration, and disturbance regimes. For example, fire readily volatilizes nitrogen and may exacerbate nitrogen limitation, an important resource for plant growth (D'Antonio and Mack 2006).

In HAVO's seasonally dry submontane and dry lowland environments Fire plays a major role where it has been highly destructive to native ecosystems. Many areas that were previously native woodlands have been converted to nonnative grasslands as a result of fire (Ainsworth and Kauffman 2009). Fire has impacted mesic and wet lowland forest in the vicinity of frequent volcanic activity on Kīlauea's east rift (Figure 4.20-1). In these areas, the coincidence of lava ignitions, fine fuels (uluhe and nonnative swordfern) and prolonged dry periods has produced favorable conditions for wildfires (NPS 2009; Figure 4.20-1).

Figure 4.20-1. Lava-ignited fire in HAVO (Photo: NPS 2009).

The potential for fire varies greatly across HAVO due to differences in substrate and vegetation type. Vegetation response to fire has been found to vary across an elevational gradient within the park (D'Antonio et al. 2000). Fire impacts have been most severe in the seasonal submontane zone where few native species are able to persist and recolonize after wildfire but nonnative fire-adapted grasses rapidly re-establish (D'Antonio et al. 2000, Tunison et al. 1994, Hughes et al. 1991). In contrast, the response of native species is more variable in the coastal lowlands, with some species such as pili grass (*Heteropogon contortus*) doing well following fire, while other species, such as ʻākia (*Wikstroemia sandwicensis*), have poor survival following wildfire. These varied responses may be attributed to climatic differences, or be an artifact of pre-settlement burning practices that may have shaped the coastal lowland communities in favor of more fire-tolerant species.

Drought conditions can occur in any season on the island and large fires have occurred during HAVO's fire history in every month; thus, there appears to be no seasonality in HAVO's fire regime (NPS 2009). Park staff conduct vigorous fire prevention within the Park. For example, the MaunaLoa Strip Road closes to visitors in times of very high and extreme fire danger. At the same time, managers have used prescribed/experimental fires (i.e., intentionally ignited fire) to evaluate the response of native and nonnative plants and ecological processes to fire, and identify conditions under which fire may benefit pili grasslands (NPS 2009).

Measures

- Number of wildfires per year
- Area burned by wildfire per year
- Causes of wildfire
- Persistence of native plants post-fire

Reference Condition/Value

The fire regime under which native species evolved before human settlement was one of infrequent fires about which the exact details are unknown. Given the current understanding of fire impacts on native plant communities, the reference conditions for number of wildfires, area burned, and causes are no wildfires (Table 4.20-1). Prescribe/experimental burns implemented to study fire effects are not included in this analysis.

Table 4.20-1. Fire history, potential, and reference conditions for the various ecological units in HAVO (NPS 2005).

Ecological Unit	Fire History	Fire Potential	Reference Condition
Alpine and Aeolian	No documented fires	Very low	No wildfires
Subalpine	No documented fires in MaunaLoa; Kahuku unknown	Very low	No wildfires
Montane Seasonal	Fires in MaunaLoa and Kahuku	Intermediate	No wildfires
Wet/Mesic Forest	Fires occurred within the East Rift	Low*	No wildfires
Mid-elevation Seasonal	Most fires within HAVO	High	No wildfires
Coastal Lowland	Rare prior to early 1970s, but increased	High	No wildfires
Coastal Habitat	Upper fringe of the strand	Low	No wildfires

* Particularly in areas with high frequency of rainfall.

For native plant post-fire recovery, the reference condition is that native plants are able to recover after fire, and nonnatives are controlled to allow native regeneration and colonization over time.

Existing Data

Numerous fire-related research studies have been conducted in HAVO (not including Kahuku), particularly in the seasonally dry woodlands. The following datasets or documents were used to assess the condition of fire in the Park.

- Tunison et al. (2001) provide information on fire frequency and size between 1924 and 1995, noting trends in these measures. The information is based on detailed fire records dating back to 1924.
- Ainsworth and Kauffman (2009) quantify survival and mortality rates of native woody plant species following wildfires in HAVO between 2002 and 2003.
- Tunison et al. (1994, 1995, and (2009) quantify survival and mortality rates of native woody plant species and cover abundance of native and nonnative plants following wildfires in HAVO between 1972 and 1992.
- HAVO's Fire Management Plan (NPS 2009) provides specific details for the fire program throughout the Park and discusses fire history and potential within the various zones of the Park.
- The primary data source used to assess the fire regime in HAVO is the HAVO Fire Atlas, a database which contains information on all fires that have burned within the Park from 1922 to 2011 (NPS 2012). The GPS files associated with the Fire Atlas contain the following data: fire name, date, cause, and estimated fire size. For fires that did not report an acreage (roughly 50 fires), fire size was calculated by projecting these area data files in GIS. The data included fires that park staff responded to that were located nearby but outside the park. Prescribed fires and controlled burns were not included in the analysis. Data were analyzed in multiple ways to examine trends over time and amount ecological units. No data is available on fires for Kahuku before 2003.

Current Condition

Number of Wildfires Per Year

Between 1922 and 2011, 227 wildfires were reported in HAVO (excluding Kahuku before 2003) (NPS 2012). The number of fires increased significantly after the 1970s (Figure 4.20-3). Tunison et al. (2001) reported that fire frequency increased by about three times between 1924- 1963 (35 fires, or 0.9 fires per year) and 1964- 1995 (97 fires, or slightly more than 3 fires per year). A higher frequency of fires has continued into the twenty-first century. Between 1996 and 2011 there was an average of 3.8 fires per year (NPS 2012).

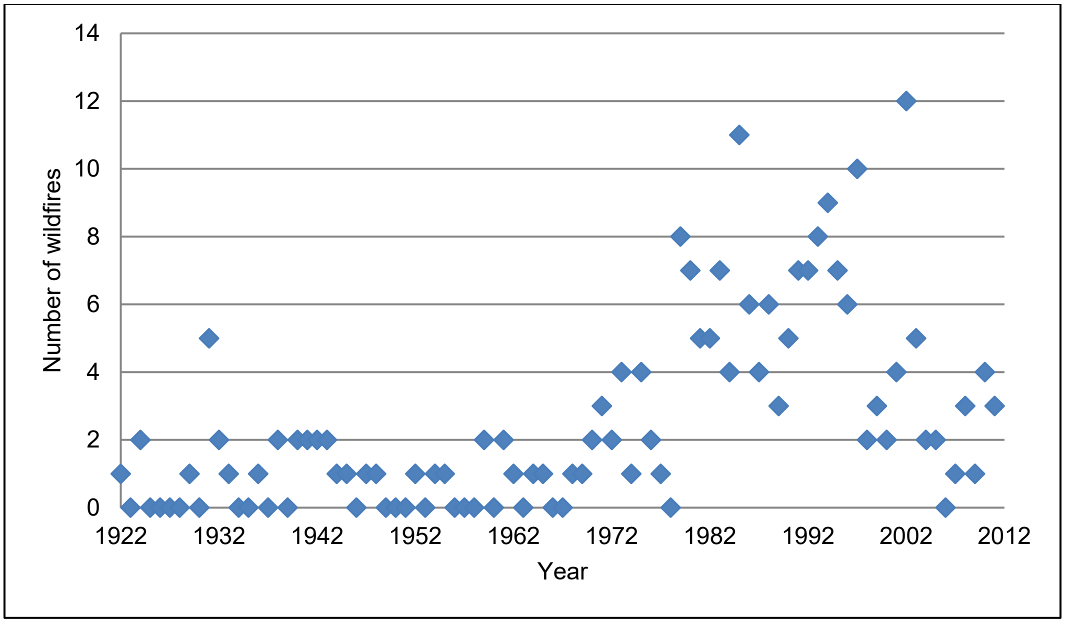


Figure 4.20-2. Number of wildfires per year reported at HAVO, 1922 through 2011. Note: Kahuku not included (NPS unpublished data).

Area Burned Per Year

Altogether, wildfires at HAVO have burned over 20,228 ha (49,963 ac) within the Park (Figure 4.20-4). Many of the largest fires have occurred in the montane seasonal and mid-elevation seasonal ecological units (seasonally dry mid elevation and dry lowland elevation FMUs), with additional large fires occurring in the wet/mesic forest located along the active volcano flows on the east rift of Kīlauea. Nearly two-thirds of the burnable area (e.g. exclude sparsely vegetated Ka‘ū desert) of the mid-elevation seasonal unit burned in the last 40 years (NPS 2009). These include several areas that have reburned. No acres have burned in wet forest of ‘Ōla‘a, in the subalpine or alpine units, and only one large fire occurred in the montane seasonal unit. No data on wildfire in Kahuku is available prior to 2003, and only one small wildfire has occurred (<1-ha or 2.5 ac) in the mid-elevation seasonal unit of Kahuku since the Park acquired the area.

The reported fire size between 1922 and 2011 has ranged from about 10 m^2 (107 ft^2) to over 4,429 ha (10,944 ac). Figure 4.20-4 shows the total hectares burned per year from 1922 to 2011. The number of hectares burned per year has increased dramatically since about 1970 compared to fire data first recorded in the 1920s. Tunison et al. (2001) reported that average fire size increased by roughly 60- between 1924 and 1995. Prior to the 1960s, the largest recorded fire was 81 ha (200 ac). Since 1970, there have been over two dozen fires larger than 100 ha (247 ac).

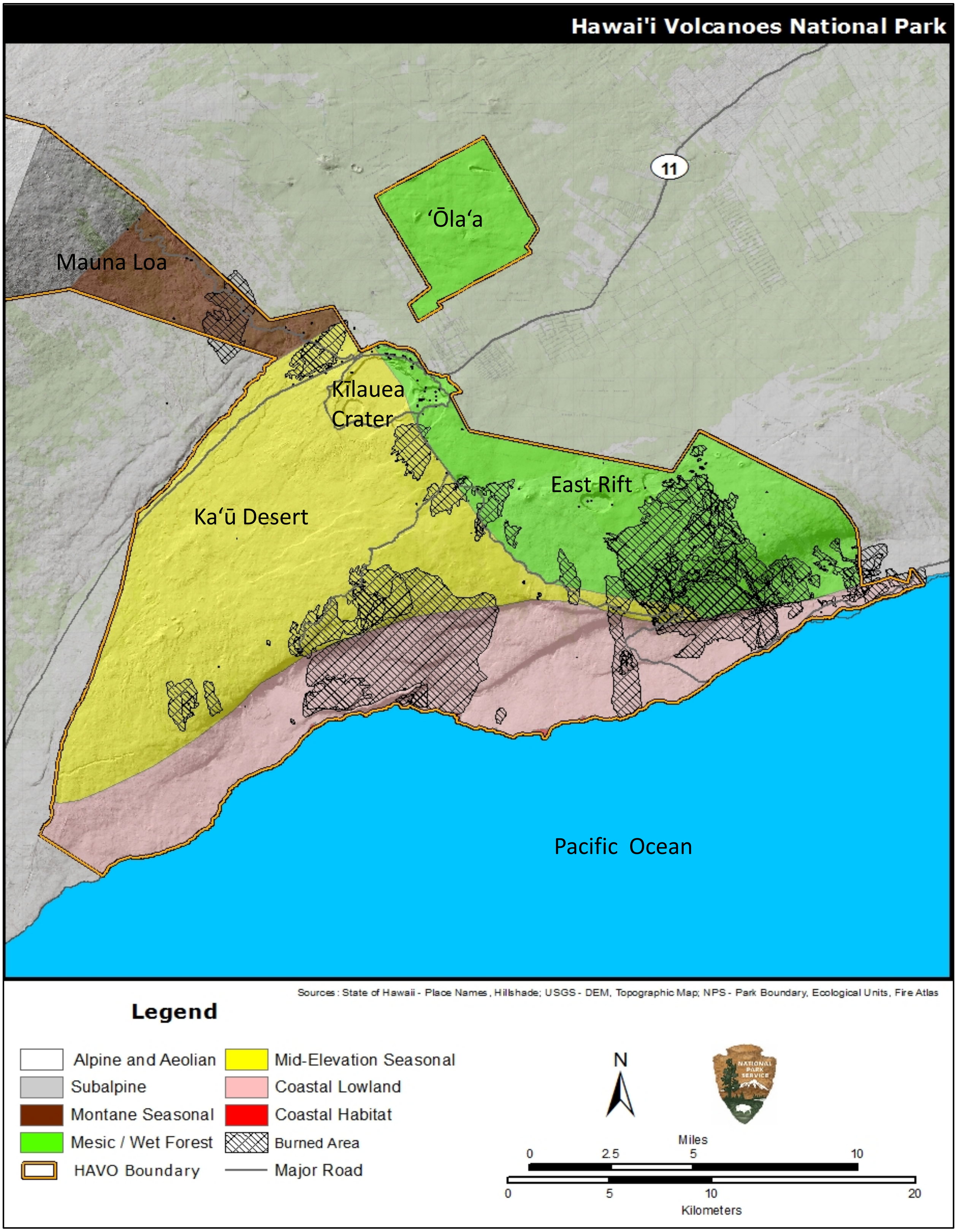


Figure 4.20-3. Burned areas within the ecological units in HAVO, 1922 through 2011 (NPS unpublished data).

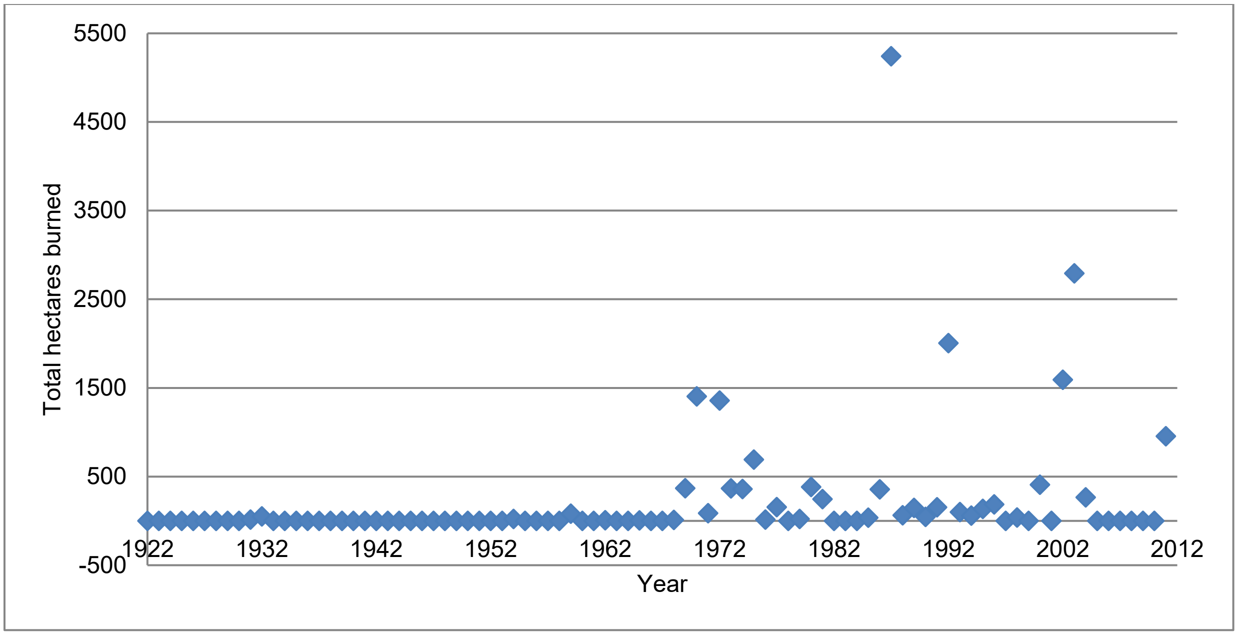


Figure 4.20-4. Number of hectares burned at HAVO per year, 1922 through 2011 (NPS unpublished data).

Fires that burned over 1,000 ha (2,471 ac) are shown in Table 4.20-2. These fires primarily occurred within the Kīlauea section. Several fires burned across multiple units; Naulu burned across mesic, seasonal mid elevation and coastal lowland units and Napau burned across coastal lowland, seasonal mid elevation and mesic units.

Table 4.20-2. Wildfires within HAVO that burned over 1,000 ha from NPS (2012).

Fire Name	Cause	Year	Total Burned Area (ha)
Naulu	Lava	1972	1,353
Kupukupu	Lava	2002	1,363
Napau	Human	1992	1,618
Luhi	Lava	2003	1,897
Uila	Lightning	1987	4,429

Cause of Fires

Approximately 70% of the wildfires in HAVO were reported to be started by humans, (Figure 4.20-5). Between 1922 to 1961 and 1972 to 1991, the number of human-caused fires occurring in a ten-year period have more than doubled. Since fire prevention measures began in the late 1980s, human-caused fires have declined at HAVO (Tunison et al. 2001). Lava-ignited fires and lighting fires comprise 30% of all fires. Lava-ignited fires have increased since the 1960's due to increased volcanic activity generating numerous lava flows inside the park. These fires have burned the most area of any other fire type, followed by human and lighting generated fires, which are approximately the same magnitude of area burned (Table 4.20-3).

Table 4.20-3. Number of wildfires reported and hectares burned by ignition source, 1922 through 2011 (NPS unpublished data).

Cause	Number of Fires	Total Hectares Burned
Human	159	5,152.53
Lava	57	10,229.45
Lightning	9	4,847.20
Unknown*	2	0.04
Total	**227**	**20,228.22**

* Not clear if heat or lava cause the fire.

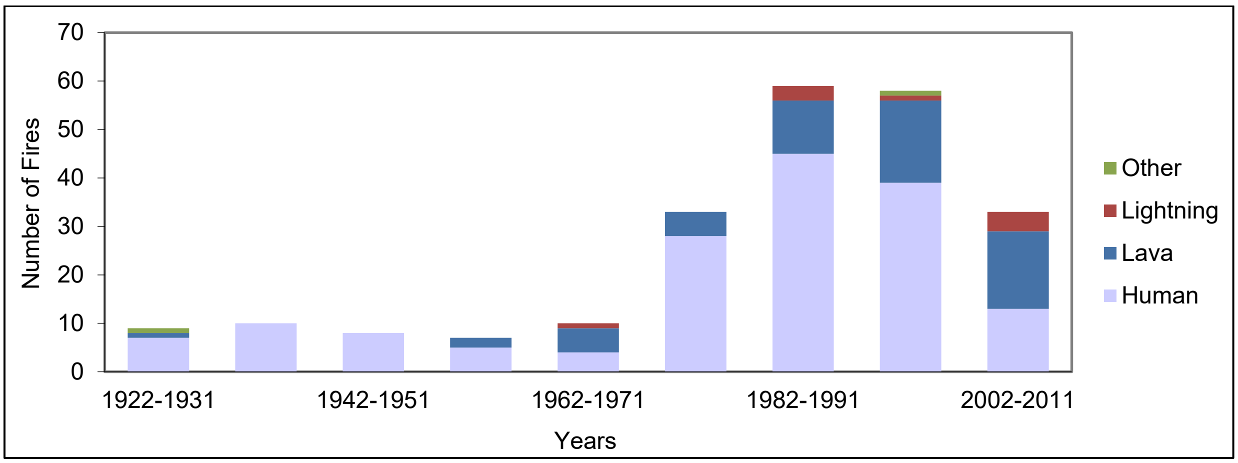


Figure 4.20-5. Number of wildfires in HAVO by cause, 1922 through 2011 (NPS unpublished data).

<u>Persistence of Native Plants Post-fire</u>

Some Hawaiian plants present at HAVO appear to have the capacity to persist following wildfire including koa and ‘a‘ali‘i (Hodgkinson and Oxley 1990, D’Antonio et al. 2000, Tunison et al. 2001). Unpublished studies at HAVO have found that fire can enhance the spread of native pili grass (NPS 2009). Ainsworth and Kauffman (2009) found that 19 native tree, shrub, and tree fern species demonstrated some capacity for post-fire persistence following wildfires at HAVO between 2002 and 2003. More than half the ‘ōhi‘a trees sampled survived fire. Basal sprouting was a primary method of survival. Native species survival differed significantly among diameter classes, with smaller diameter trees re-sprouting more often than larger diameter trees (Ainsworth and Kauffman 2009). However, survival of ‘ōhi‘a is highly variable across burns and is somewhat dependent on moisture; the persistence of ‘ōhi‘a, by seedling recruitment or resprout, was poor to non-existent following several wildfires in the mid-elevation seasonal dry ‘ōhi‘a woodlands(Tunison et al. 1995). Also, severity of burn was also a factor on tree survival, with hotter burns showing poorer tree survival.

However, nonnative species have been shown to limit native species recovery. The proliferation of mat-formatting grasses creates an environment unfavorable for native species regeneration, such as low light levels that inhibit germination or seedling establishment (Hughes and Vitousek 1998, NPS 2009, D'Antonio et al. 2011). This is particularly true for ʻōhiʻa and pūkiawe in dry environments where they have very poor survivorship and recruitment from seedlings is very low.

Threats and Stressors

The fire regime at HAVO has been greatly altered by invasion of nonnative species, particularly grasses. The primary fire promoting grasses at HAVO are broomsedge, bush beard grass, thatching grass, and molasses grass. Nonnative swordfern also promotes fire in the mesic environment. Further expansion of these invasive species could extend the area vulnerable to damaging wildfire in HAVO.

Climate change also has the potential to further negatively affect the fire regime at HAVO. Changes in temperature, precipitation, and frequency and severity of El Nino events can create conditions for increased ignitions and larger fires. Increased drought in particular can alter fuel characteristics and fire behavior.

Fire potential may increase in some portions of Kahuku (particularly the pasture areas) once ungulates are removed (NPS 2013). The recently acquired Kahuku section is adjacent to Hawaiian Ocean View Estates, so this addition creates a new Wildland Urban Interface (WUI) issue for the Park (NPS 2009).

Finally, the frequency of human- and lava-ignited fires may increase if volcanic activity and Park visitation rates rise (Tunison et al. 2001).

Overall Condition

Fires have occurred across most of the ecological units with the exception of the subalpine and alpine and aeolian units. Many of the fires that have occurred at HAVO were started by humans and lava. Human-caused fires increased beginning in the 1970's, then decreased by the early 1990's following the implementation of prevention measures by park fires staff. Since the 1960's, the number of lava-ignited fires have increased. During this same period, invasion by nonnative grasses and swordfern facilitated firespread and resulted in larger fires. Although some native plant species appear to be capable of persisting after fire, the spread of nonnative species often limits native species recovery. Thus, the condition HAVO's fire regime is classified as "Of concern."

HAVO's fire regime has shifted dramatically since fire data were first recorded in the 1920s. The invasion of nonnative fire-promoting grasses, and conversion of forests/woodlands to lower diversity grasslands, has resulted in more frequent and larger fires, particularly in the seasonally dry woodlands. This shift has occurred despite active fire suppression by NPS. Thus, the trend for this indictor is degrading.

Information Gaps/Level of Confidence

Overall, the data for this indicator are ranked high due to the availability of quantitative fire history data over the past century and the well documented ecological impacts of fire on native ecosystems. There are some inconsistencies in the HAVO Fire Atlas (NPS 2012) compared to the data reported by Tunison et al. (2001) and Ainsworth and Kauffman (2009), particularly with regard to fire size. Data may not be consistent over time due to differences in data collection. No data on wildfire in Kahuku is available prior to 2003. However this data gap does not alter our basic conclusions with respect to potential threats and management options.

The HAVO Fire Atlas lacks information on fire behavior variables including duration, rate of spread and intensity of each fire. Fire intensity in particular would be valuable in assessing potential ecological impacts of fire.

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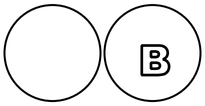
4.21. Soundscape



Background

A soundscape is related to the acoustical environment, which is defined as the total combination of all physical sound sources in an area (NPS 2012). This includes noise from anthropogenic sources as well as the sounds of the natural ambient environment. Noise is defined here as any unwanted, intrusive, or disruptive sound. Existing ambient refers to the acoustic state that includes sounds from both natural and anthropogenic sources, and natural ambient refers to the acoustic state that exists in the absence of sounds from all anthropogenic sources. Various characteristics of noise can affect how it impacts the acoustic environment including rate of occurrence, duration, loudness, pitch, and whether the sound occurs consistently or sporadically (Danielle Foster, Environmental Protection Specialist, NPS HAVO, pers. comm. 2014).

Common natural ambient sounds at HAVO are associated with the wind, rain, ocean surf, rustling vegetation, birds, and new lava flows. Anthropogenic sources include cars, buses, aircraft, cellular telephones, loud talking, and weed-whackers (Lawson et al. 2007). The acoustical environment also consists of sound sources beyond the human range of hearing such as echolocation pulses of the Hawaiian hoary bat.

The sources of sound in a given environment are indicative of the types of events that take place there. These can range from animals using sound to detect prey, avoid predators, define territories, and attract mates to physical processes such as wind, water, and extreme weather events (NPS 2006). Changes in a soundscape can indicate a cause for concern, whether it be a variation in the relative intensities of sound sources, the presence of new sources, or the absence of old sources. For many species, sound plays a critical role in communication, reproduction, and survival. Changes in sound or the presence of noise can adversely impact behavior for some species (Barber et al. 2010), which suggests that soundscape monitoring and analysis can be a valuable tool for conservation and rehabilitation.

In addition, the type and level of sound influences Park visitors' experience. The National Parks Air Tour Management Act of 2000 was passed to preserve natural sounds and quietness. The sound from aircraft can be perceived negatively by visitors and interfere with enjoyment of the Park (NPS 2013). Examples of other potentially disruptive sounds at HAVO may include traffic from Highway 11 and tourist vehicles. An Air Tour Management Plan (ATMP) is in the process of being developed for HAVO to "mitigate or prevent significant adverse impacts, if any, of commercial air tour operations" (Lee et al. 2006).

Given the importance of the soundscape to wildlife and visitor experience, there has been a concerted effort to institute NPS policies that "will require, to the fullest extent practicable, the protection, maintenance, or restoration of the natural soundscape resource" (NPS 2000).

Measures

- Levels of ambient sound
- Relative amount of natural sounds and noise

<u>Reference Condition/Value</u>

An ideal soundscape for most natural areas would be one where the intensity of noise is low relative to the intensity of natural sounds, and the amount of noise is also low. Metrics that can be used to assess these conditions are sound levels and the relative abundance of noise and natural sounds.

The importance of soundscape management has only gained attention in recent years; thus, there is currently a lack of acoustic surveys and standardization of metrics that quantify the state of a soundscape (McCusker and Cahill 2009). As a result, acoustic surveys conducted at national parks each collected different types of data (Bennetts et al. 2012, Kilkus et al. 2011, Lee et al. 2006). By extension, there is a lack of agreement among published NRCAs with soundscape indicators about what measures and associated reference conditions should be used (Bennetts et al. 2012, Bernatz et al. 2010, Kilkus et al. 2011, Lee et al. 2006, Lookingbill et al. 2012).

Despite the lack of standardization with regard to acoustic surveys, a common method has been to segregate parks into acoustic zones based on expected and/or acceptable noise level and noise type (Bennetts et al. 2012, Bernatz et al. 2010, Kilkus et al. 2011, Lee et al. 2006, Lookingbill et al. 2012). While this is a practical way to efficiently collect soundscape metric data, it introduces an intrinsic need to define separate reference conditions for each zone. As each national park is unique, agreement on appropriate reference conditions must be reached through consultation with specialists as well as park representatives.

For HAVO, reference conditions related to soundscape metrics have not yet been decided upon. Reference conditions are expected to be set in the HAVO General Management Plan, which is currently being developed, following further analysis of additional acoustic data (Danielle Foster, Environmental Protection Specialist, NPS HAVO, pers. comm. 2014). In addition, a framework for assessing noise generated by air tours in wilderness is in development (Judy Rocchio, Physical Scientist, NPS Pacific West Region, pers.comm. 2014), and may contribute towards the development of reference conditions.

<u>Existing Data</u>

To date, two acoustic surveys have been conducted in HAVO. The first was performed by the Federal Aviation Administration (FAA), in cooperation with NPS and assistance from the U.S. Department of Transportation John A. Volpe National Transportation Systems Center (Volpe), to determine the baseline acoustic state in various Park zones for the purpose of modeling and evaluating aircraft noise within the Park (Lee et al. 2006). These baseline readings were intended for use in developing an ATMP.

Using sound level meters, over 900 days of acoustic and meteorological data were autonomously sampled between 22 sites throughout HAVO between October 23, 2002, and June 1, 2003 (Figure 4.21-1).

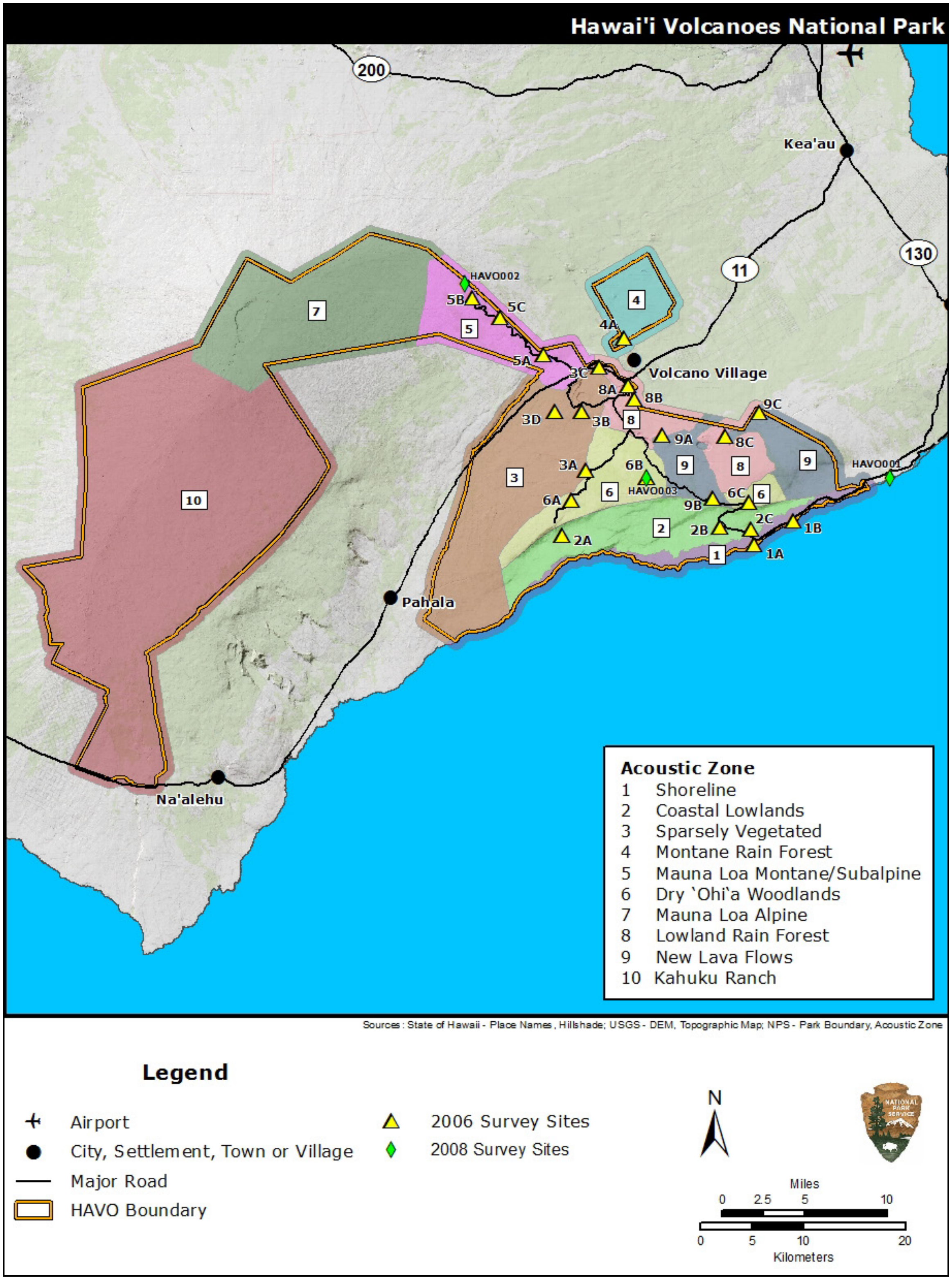


Figure 4.21-1. Acoustic sample sites and zones within HAVO at time of surveys (adapted from Lee et al. 2006, NPS 2008, and NPS 2013).

In addition to the autonomous surveys, staffed acoustic surveys were performed to differentiate between natural and anthropogenic sound sources. The measurement sites were located within 8 of the park's 10 "acoustic zones," or regions considered acoustically representative of the Park. The MaunaLoa Alpine and Kahuku Ranch zones were not surveyed. Weather and accessibility prevented the deployment of a measurement site in MaunaLoa Alpine, and the date of the acquisition of the Kahuku Pastures area did not allow for any data collection in that area (Lee et al. 2006). Figure 4.21-1 illustrates previous zone classifications, and Figure 4.21-2 shows updated zone classifications.

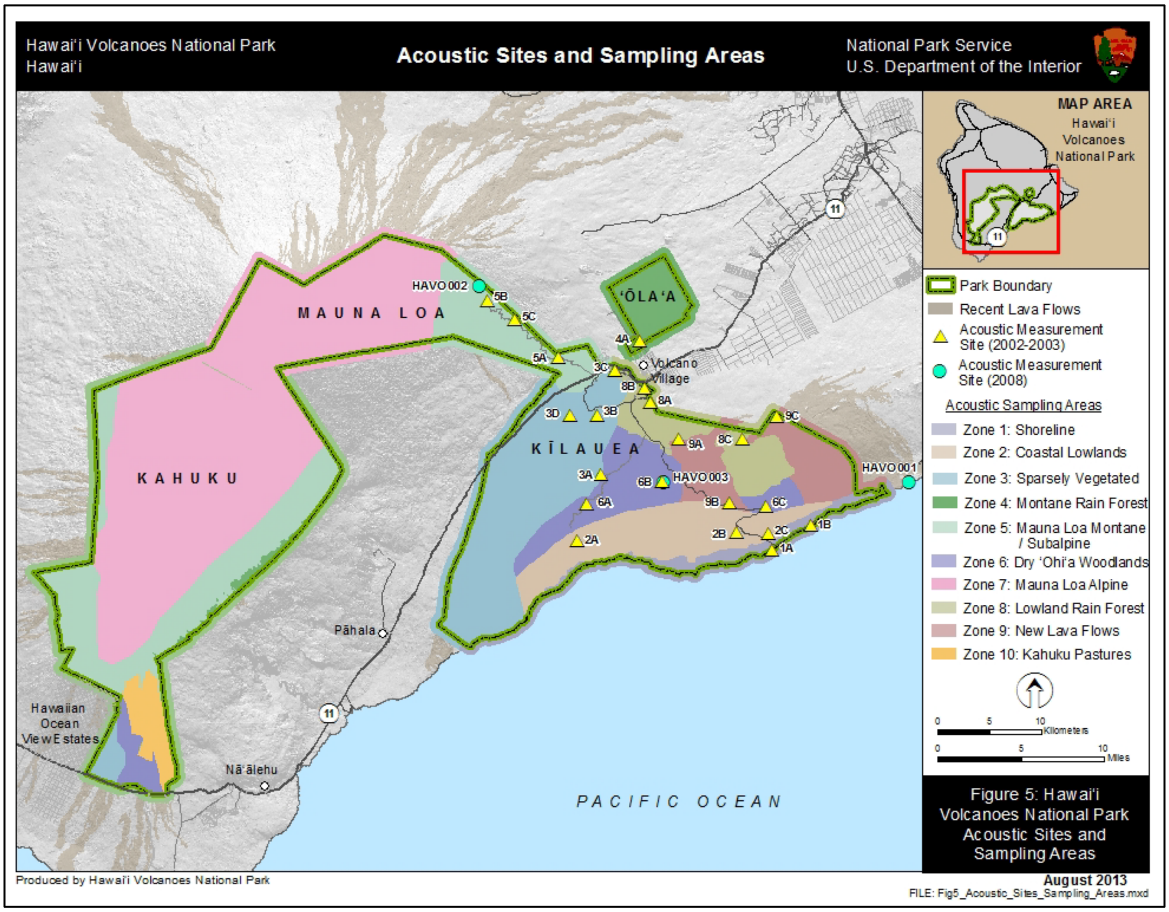


Figure 4.21-2. Current acoustic zone classifications (adapted from Lee et al. 2006, NPS 2008, and NPS 2013).

The second survey was performed by technicians from the NPS Natural Sounds Program. One site (HAVO002) was autonomously surveyed using a sound level meter for 41 days while two others (HAVO001 and HAVO003) were surveyed using MP3 recorders for 3 and 9 days, respectively. While sites HAVO001 and HAVO003 do not have sound level data, staffed acoustic surveys were performed at all three sites (NPS 2008).

Current Condition

Levels of Ambient Sound

Sound level is measured in decibels (dB) and A-weighting (which results in dBA) is a common method of processing sound level data to assess noise exposure and its effect on human hearing (Occupational Safety and Health Administration [OSHA] n.d.). A reference for various A-weighted sound levels is shown in Figure 4.21-3.

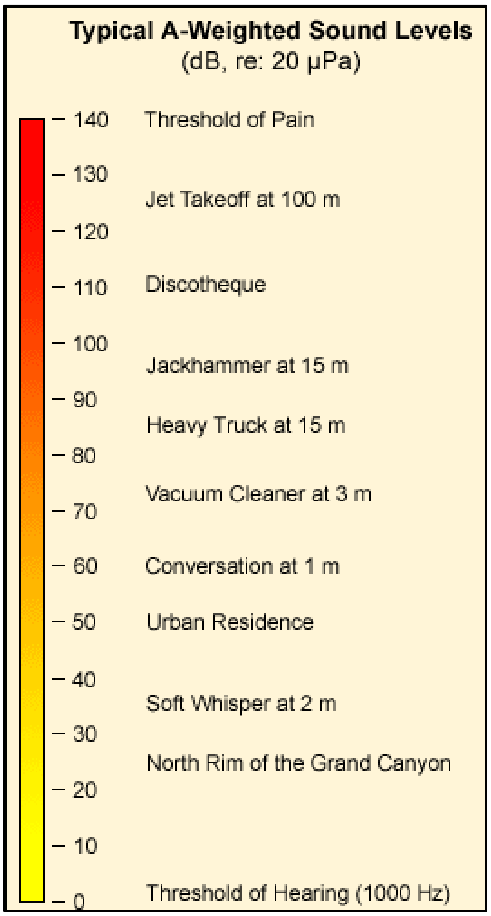


Figure 4.21-3. Reference for various A-weighted sound levels (OSHA n.d.).

In support of a future Air Tour Management Plan for Hawai'i Volcanoes National Park, the NPS (2008) used L50, the A-weighted sound level that is exceeded 50% of the time, to quantify the sound level of an area. This generally can be regarded as the quietest an area will be on average. Both Lee et al. (2006) and NPS (2008) differentiated between sound levels during the day and at night, and observed that the impact of anthropogenic noise is significantly higher during daytime hours (Lee et al. [2006] used 6 am–6 pm, while NPS [2008] used 7 am–7 pm). Thus, the daytime L50 sound levels are used as the representative sound levels.

The sound level meters used in the surveys recorded A-weighted sound levels of the existing ambient environment. To estimate the sound levels of the natural ambient environment, subsets of data were analyzed and filtered of any anthropogenic sound sources. The resultant datasets were then processed to determine the long-term natural ambient L50 sound levels.

The difference in sound level between the existing and natural ambient acoustic states illustrates the effect of anthropogenic noise in the Park, as shown in Table 4.21-1 and Figure 4.21-4. Table 4.21-1 also identifies the expected visitor use for each site based on definitions given by Lee et al. (2006).

Table 4.21-1. L_{50} sound levels under existing and natural ambient conditions from Lee et al. (2006) and NPS (2008).

Acoustic Zone	Site ID	Expected Visitor Use	Survey Duration (days)	L_{50} (dBA)	
				Existing Ambient	Natural Ambient
Zone 1: Shoreline*	1A	Med	14	54.0	54.2
	1B	High	14	46.8	46.6
Zone 2: Coastal Lowlands	2A	Low	85	28.3	28.3
	2B	Med	17	32.4	32.7
	2C	Med	13	33.0	29.1
Zone 3: Sparsely Vegetated	3A	Med	118	28.2	31.4
	3B	High	18	29.6	29.1
	3C	High	14	37.2	32.7
	3D	Med	15	20.2	20.4
Zone 4: Montane Rain Forest	4A	Low	114	33.1	33.5
Zone 5: MaunaLoa Montane/Subalpine	5A	High	56	34.9	35.0
	5B	Med	15	23.4	22.1
	5C	Med	17	27.6	27.5
	HAVO002	N/A	41	19.1	18.1
Zone 6: Dry ‘Ōhi’a Woodlands	6A	Med	108	28.9	28.0
	6B	Low	27	30.8	28.0
	6C	Med	25	33.1	32.7
Zone 7: Mauna Loa Alpine	No Data	–	–	–	–
Zone 8: Lowland Rain Forest	8A	Med	113	43.0	42.6
	8B	Med	15	38.3	38.2
	8C	Low	15	31.4	29.7
Zone 9: New Lava Flows	9A	Low	73	29.5	28.6
	9B	High	17	33.0	28.6
	9C	Low	13	29.2	25.4
Zone 10: Kahuku Pastures	No Data	–	–	–	–

* Sound level data from this zone should be used with caution because of noise contamination of data due to strong trade winds during the surveys (Danielle Foster, Environmental Protection Specialist, NPS HAVO, pers. comm. 2014).

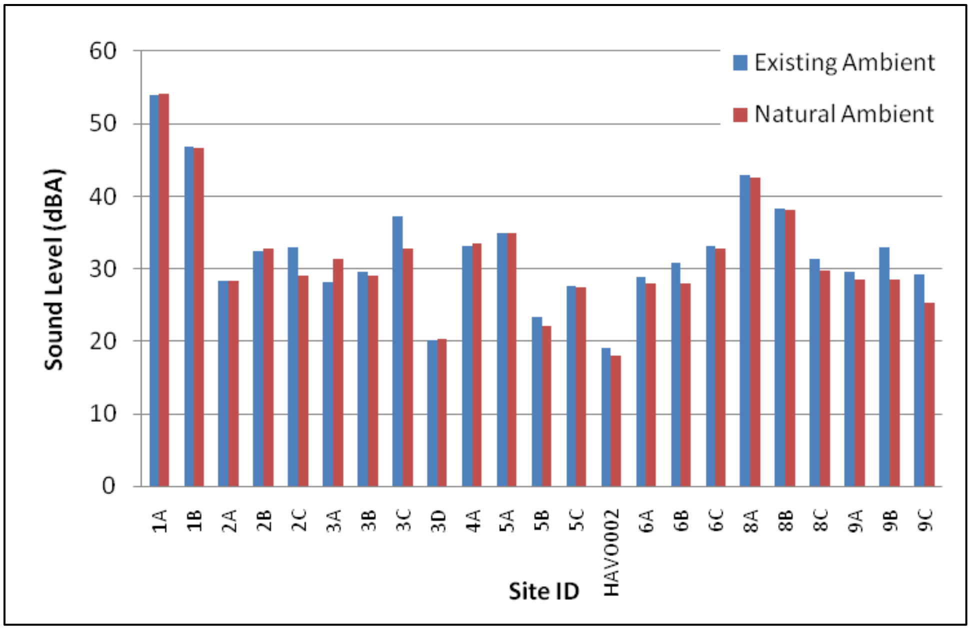


Figure 4.21-4. Comparison of daytime L50 sound levels for existing and natural ambient (Lee et al. 2006, NPS 2008).

High use areas were denoted by having less than 30 minutes walking proximity to locations accessible by automobile or bus; medium use areas would be reachable by 1 hour of hiking; and low use areas were designated wilderness areas, areas with restricted access, or required greater than 1 hour of hiking.

In general, the existing ambient sound levels exceeded those of the natural ambient by <2 dBA, with notable exceptions at sites 2C, 3C, 6B, 9B, and 9C. Although the expected visitor use is medium at 2C and high at 3C and 9B, visitor use is expected to be low at 6B and 9C. Site 9C is within an area that experiences heavy air tour overflight traffic due to the proximity to Puʻu ʻŌʻō.

<u>Relative Amounts of Natural Sounds and Noise</u>
A summary of the staffed acoustic surveys is shown in Table 4.21-2 and Figure 4.21-5. Table 4.21-2 and Figure 4.21-5 suggest that spatially, the distribution of anthropogenic noise is generally focused around a few sites at HAVO. Most sites experience <25% anthropogenic noise, but of the sites that experience >25% anthropogenic noise, sites 6B, 8C, and 9C are expected to have low visitor usage.

Table 4.21-2. Relative amount of natural and human-made sounds at individual sites during staffed acoustic surveys (adapted from Lee et al. 2006 and NPS 2013).

Acoustic Zone	Site ID	Expected Visitor Use	Total Survey Duration (s)	Time Audible (sec)		Time Audible (%)	
				Anthropogenic Sound Sources	Natural Sound Sources	Anthropogenic Sound Sources	Natural Sound Sources
Zone 1: Shoreline	1A	Med	3380	110	3270	3.30	96.70
	1B	High	3171	998	2173	31.50	68.50
Zone 2: Coastal Lowlands	2A	Low	346	0	346	0.00	100.00
	2B	Med	651	0	651	0.00	100.00
	2C	Med	(No observer logging was performed at this site)	–	–	–	–
Zone 3: Sparsely Vegetated	3A	Med	1412	151	1261	10.70	89.30
	3B	High	1011	0	1011	0.00	100.00
	3C	High	(No observer logging was performed at this site)	–	–	–	–
	3D	Med	295	137	158	46.40	53.60
Zone 4: Montane Rain Forest	4A	Low	4901	898	4003	18.30	81.70
Zone 5: MaunaLoa Montane/Subalpine	5A	High	7633	573	7060	7.50	92.50
	5B	Med	3637	810	2827	22.30	77.70
	5C	Med	1059	30	1029	2.80	97.20
	HAVO002*	N/A	N/A	N/A	N/A	18.90	81.10
Zone 6: Dry ‘Ōhi’a Woodlands	6A	Med	3733	140	3593	3.80	96.20
	6B	Low	1073	531	542	49.50	50.50

*Surveys at these sites did not observe non-aircraft anthropogenic sound sources.

Table 4.21-2 (continued). Relative amount of natural and human-made sounds at individual sites during staffed acoustic surveys (adapted from Lee et al. 2006 and NPS 2013).

Acoustic Zone	Site ID	Expected Visitor Use	Total Survey Duration (s)	Time Audible (sec)		Time Audible (%)	
				Anthropogenic Sound Sources	Natural Sound Sources	Anthropogenic Sound Sources	Natural Sound Sources
Zone 6: Dry ʻŌhiʻa Woodlands (continued)	6C	Med	(No observer logging was performed at this site)	–	–	–	–
	HAVO003*	N/A	N/A	N/A	N/A	1.30	98.70
Zone 7: Mauna Loa Alpine	No Data	–	–	–	–	–	–
Zone 8: Lowland Rain Forest	8A	Med	7193	2642	4551	36.70	63.30
	8B	Med	3322	581	2741	17.50	82.50
	8C	Low	3528	2175	1353	61.60	38.40
Zone 9: New Lava Flows	9A	Low	14964	823	14141	5.50	94.50
	9B	High	(No observer logging was performed at this site)	–	–	–	–
	9C	Low	4347	2272	1951	52.30	44.90
Zone 10: Kahuku Ranch	No Data	–	–	–	–	–	–
Outside Park:	HAVO001*	N/A	N/A	N/A	N/A	28.40	71.60

*Surveys at these sites did not observe non-aircraft anthropogenic sound sources.

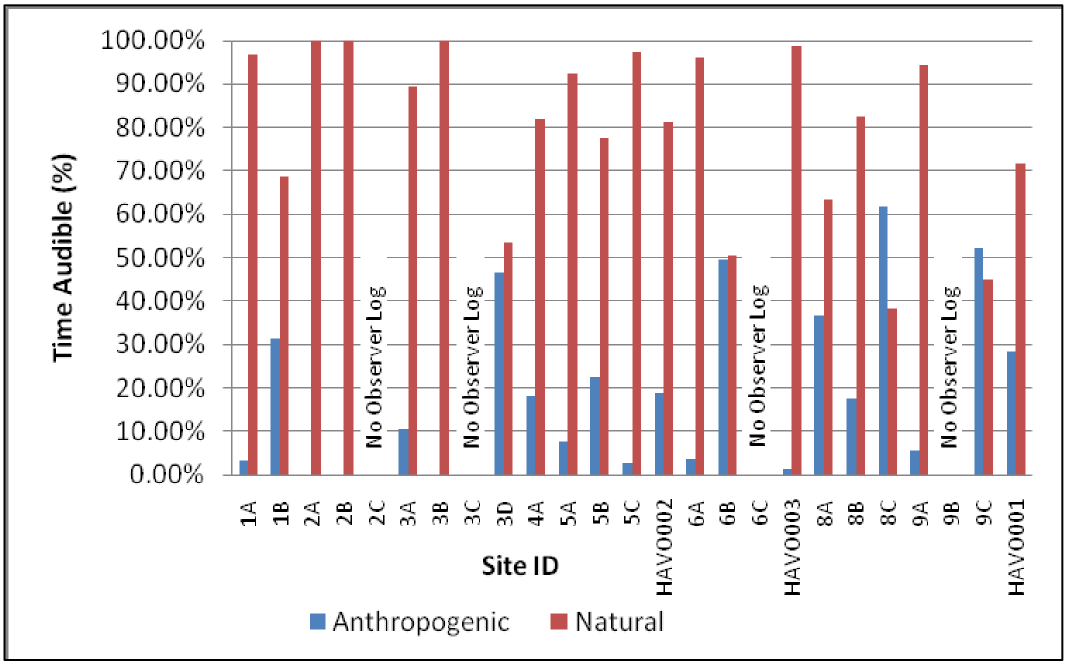


Figure 4.21-5. Relative amounts of natural and anthropogenic sounds at surveyed sites.Sites 8C and 9C are in areas that experience heavy air tour overflight traffic due to the proximity to Pu‘u ‘Ō‘ō and air tour routes (adapted from Lee et al. 2006, and NPS 2013).

Although site HAVO001 experiences >25% anthropogenic noise, it is located outside of the Park and NPS (2008) notes that it is expected to receive a large amount of foot traffic and aircraft exposure.

Threats and Stressors

The coqui frog is an invasive species in Hawai‘i, and poses a direct threat to the existing soundscape at HAVO. Coqui frogs create particularly loud noises at night, reaching 85 to 90 dB at 0.5 m distance (Beard et al. 2009). There is an active effort to remove and control coqui populations and prevent further spread, but there is possibility for growth and expansion of this species within the Park. Thus, the potential impact to the soundscape is not known at this time.

Park operations, research activities (including USGS monitoring of the volcano) and visitor activities all impact the soundscape. These include the use of vehicles, human voices, helicopters and motorized equipment, and other equipment used in the day to day administration of the Park, maintenance of frontcountry landscapes, search and rescue and law enforcement activities, volcanic research and resource protection. Also visitor impacts caused by buses, vehicles, tour helicopters, and day use and overnight camping also impact soundscape. The Final Plan / Environmental Impact Statement for Protecting and Restoring Native Ecosystems by Managing Non-native Ungulates (NPS 2013) described in more detail how administrative activities contribute to impacts on the sound environment. It identifies alternative D as the preferred alternative for ungulate management, which is expected to have “short-term moderate adverse impacts to soundscapes, but ultimately result in “long-term beneficial impacts” (NPS 2013). FAA, NPS, and Volpe are currently working on developing an ATMP for HAVO. Depending on the outcome of this process, commercial air tour operations may change within the Park, and therefore have the potential to impact the existing soundscape.

<u>Overall Condition</u>

As reference conditions for the measures have not been set, the condition of the soundscape at HAVO is unknown at this time and a trend cannot be determined.

<u>Information Gaps/Level of Confidence</u>

While two acoustic surveys have been conducted at HAVO, the sampled areas were different, meaning that trends cannot be assessed at this time. As such, the extent of the knowledge base for the soundscape is given a rank of B.

The data processing method used in Lee et al. (2006) allowed for the possibility of calculating natural ambient sound levels to have greater values than those of the existing ambient, while the data processing method used in NPS (2008) was designed to guarantee that the natural ambient sound level be less than that of the existing ambient. All future data will be analyzed using the methods used in the 2008 NPS report (Danielle Foster, Environmental Protection Specialist, NPS HAVO, pers. comm.).

The total survey durations for both autonomous and staffed surveys varied across all of the sites (Table 4.21-2). Having survey durations of a minimum predetermined length at every site would improve consistency and confidence. Additionally, surveys have not yet been conducted in the Kahuku or the alpine zones.

The possible growth of coqui frog populations introduces a need in future surveys to distinguish between desired natural sounds and disruptive noise that comes from natural, but nonnative sources. An extension of this would be the ability to note changes in the soundscape after restoration and management activities. For example, the approved *Final Plan / Environmental Impact Statement for Protecting and Restoring Native Ecosystems by Managing Non-native Ungulates* (NPS 2013) states that reducing ungulates has the potential to enhance native bird populations, thereby changing the soundscape.

In general, the soundscape data for HAVO, as well as other national parks, focus on the human perception of noise. Data regarding the impact of various sound levels on native Hawaiian wildlife are not available.

Subject Matter Experts Consulted

- Cynthia Lee, Engineer, U.S. Department of Transportation.
- Danielle Foster, Environmental Protection Specialist, NPS

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Chapter 5. Discussion

The purpose of this chapter is to provide a holistic summary of condition findings by areas and topics of interest based on information discussed in Chapter 4. It also summarizes recommendations to address additional information needs. A more complete assessment of each individual indicator, including the amount and quality of the data used to determine conditions, is available in Chapter 4.

5.1. Park-Wide Condition

Due to the large size of HAVO, its diverse ecological units and habitats, large rainfall and elevational gradients and dynamic volcanic landscape, assessing the condition of HAVO on a park-wide scale is challenging. Resource studies have typically focused on areas of the Park where particular resources are most likely to occur or to be most impacted by threats or stressors. Park-wide summaries are further complicated because resources could be improving in condition in some sections of the Park, while declining or have an unknown status in other regions of the Park. For example, relatively few inventories and long-term monitoring has occurred in the newly acquired Kahuku section compared to older sections of HAVO (MaunaLoa, Kīlauea, and ‘Ōla‘a). It is difficult to determine the condition of many indicators in Kahuku due to the lack of historic or current data for this section of the Park.

The condition rankings, trends and extent of knowledge for all 21 indicators are summed in Table 5.1-1. The most common condition of the indicators chosen for HAVO is “Moderate” (9 indicators total) where the current conditions do not meet all or most of the reference conditions or values; however, the differences are not excessive (see Figure 3.2-1 for definitions). Eight of the indicators are “Of Concern” where the current conditions do not meet all or most of the reference conditions or values and the differences are excessive. One indicator (Cave and Lava Tube Communities) is considered in “Good” condition because currently all or most of the reference conditions/values are met or exceeded. For the remaining three indicators (Air Quality, Volcanic Features and Processes, and Soundscape) the condition is unknown because there was not enough evidence to determine condition during the preparation of this report.

Table 5.1-1. Number of HAVO indicators by condition ranking, trend, and extent of knowledge base. A=data with trends; B=status data; C=limited data; D=raw data; E=no available data.

Measure	Rating	Number of Indicators
Condition	Good	1
	Moderate	9
	Of Concern	8
	Unknown	3
	Total	**21**
Trend	Improving	1
	Stable	3
	Degrading	3
	Unknown	14
	Total	**21**

Table 5.1-1 (continued). Number of HAVO indicators by condition ranking, trend, and extent of knowledge base. A=data with trends; B=status data; C=limited data; D=raw data; E=no available data.

Measure	Rating	Number of Indicators
Extend of Knowledge Base	A	5
	B	13
	C	2
	D	0
	E	1
	Total	**21**

Most conditions have unknown trends, which is a reflection of the fact that for most of the indicators, currently only status data (ranked "B") are available. For some indicators, although trend data may be available for a single species or measure, it is not enough to determine a trend for the entire indicator (e.g., Invasive Terrestrial Plants, Focal Native Plant Taxa). Long-term monitoring is currently being planned for several indicators, and it is expected that as monitoring programs develop, trend analysis will be possible for a larger suite of indicators.

Table 5.1-2 summarizes the condition rankings, trends and extent of knowledge for all 21 indicators at HAVO within the NRCA framework. It is important to note that conditions and trends are based on the measures and reference conditions/values developed for each indicator. Establishing reference conditions or values was challenging for many indicators. While there is value in providing useful comparisons in order to place condition assessments within a larger context, it is difficult to quantify reference conditions in the Hawaiian Islands because historic data is often limited, few undisturbed sites remain, and high habitat diversity on a small spatial scale results in a wide range of acceptable resource conditions.

Table 5.1-2. Summary of conditions for HAVO indicators within the NRCA framework.

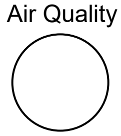
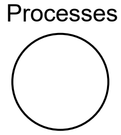
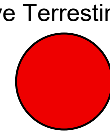
Level 1	Level 2	Indicator Condition	Indicator Ranking
Air & Climate	Air Quality	Air Quality 	Air Quality B
Geology & Soils	Subsurface Geologic Processes	Volcanic Features & Processes 	Volcanic Features & Processes B
Biological Integrity	Invasive Species	Invasive Terrestiral Plants 	Invasive Terrestiral Plants A

Table 5.1-2 (continued). Summary of conditions for HAVO indicators within the NRCA framework.

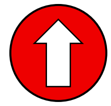
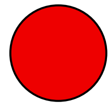
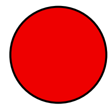
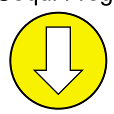
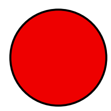
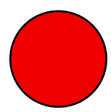
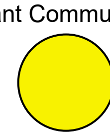
Level 1	Level 2	Indicator Condition	Indicator Ranking
Biological Integrity (cont'd)	Invasive Species (cont'd)	Invasive Ungulates 	Invasive Ungulates B
		Invasive Small Mammals 	Invasive Small Mammals B
		Invasive Terrestrial Insets 	Invasive Terrestrial Insets A
	Focal Species or Communities	Coqui Frogs 	Coqui Frogs A
		Focal Native Plant Taxa 	Focal Native Plant Taxa B
		Wet Forest Plant Communities 	Wet Forest Plant Communities A
		Subalpine Plant Communities 	Subalpine Plant Communities B
		Mānele/ Koa/ ʻŌhiʻa Montane Mesic Forest Plant Communities 	Mānele/ Koa/ ʻŌhiʻa Montane Mesic Forest Plant Communities B
		Coastal Strand Communities 	Coastal Strand Communities B

Table 5.1-2 (continued). Summary of conditions for HAVO indicators within the NRCA framework.

Level 1	Level 2	Indicator Condition	Indicator Ranking
Biological Integrity (cont'd)	Focal Species or Communities (cont'd)	Landbirds	Landbirds B
		Seabirds	Seabirds B
		Hawaiian Hoary Bats	Hawaiian Hoary Bats B
		Endangered & Threatened Marine Vertebrates	Endangered & Threatened Marine Vertebrates B
		Native Insect & Springtail Communities	Native Insect & Springtail Communities C
		Cave & Lava Tube Communities	Cave & Lava Tube Communities C
		Anchialine Pools	Anchialine Pools B
Landscapes	Fire & Fuel Dynamics	Fire Regime	Fire Regime A
	Soundscape	Soundscape	Soundscape B

The only **Air and Climate** indicator at HAVO (Air Quality) is unknown; two of the values required to assign an overall air quality condition (ozone and wet deposition) did not meet criteria for assigning condition values. Visibility is considered of moderate concern with a degrading trend. An overall trend cannot be determined, in part, because air quality is primarily affected by emissions from Kīlauea and MaunaLoa Volcano, which vary from year to year.

The condition of the only **Geology and Soils** indictor (Volcanic Features and Processes) is unknown at this time. Defining reference conditions for this indicator is not appropriate given the unique and dynamic nature of these naturally occurring features and events. Currently, there is no quantitative data on how human activities impact volcanic features and process at HAVO.

For invasive species within the **Biological Integrity** category, the condition is mostly determined as "Of Concern" (Invasive Plants, Ungulates, Small Mammals and Insects). Only the Coqui Frogs indicator is in "Moderate" condition. Despite the success of various programs to contain, reduce, or eradicate invasive species in portions of HAVO, many invasive species are widely distributed across the Park and are known to adversely impact a variety of native species and ecosystems. Trends are only available for ungulates and coqui frogs. While the number of coqui frogs reported in HAVO has generally increased since the initial sightings in 2001, ungulate populations are declining compared to historical levels due to on-going management.

The majority of the focal species/communities within the **Biological Integrity** category are in "Moderate" condition. In all four plant communities assessed in this report, invasive target plant species that can outcompete native species occur extensively, portions of the focal communities are unprotected from ungulates, and listed plant species/SOC are declining. At the same time, the Wet Forest Plant Communities, Subalpine Plant Communities, and Mānele/ Koa/ ʻŌhiʻa Montane Mesic Forest Plant Communities contain a high diversity of native species or rare imperiled plant communities. Stable trends are reported for Seabirds, Landbirds, and Endangered and Threatened Marine Vertebrates. Focal species or communities ranked "Of Concern" include Focal Native Plant Taxa and Native Insect and Springtail Communities where declines or extirpations of listed species or SOC previously reported within HAVO have been documented. The Caves and Lava Tube Communities in HAVO meet or exceed all reference conditions due to the high value of the geological/ mineralogical formations and features, paleontological resources, and specialized cavernicoles and flora.

Of the **Landscape** indicators at HAVO, the Fire Regime is "Of Concern" with a declining condition due to the reported increase in fire size and frequency. A current condition for Soundscape could not be determined because reference conditions for soundscape measures have not been developed for HAVO.

5.2. Information Gaps and Recommendations

The unique biological and physical processes occurring at HAVO have attracted countless researchers to the Park since its establishment. Compared to other Parks in the PACN, HAVO has a long history of repeated data collection (HaySmith et al. 2005). Despite these efforts, additional data would be useful to determine resource conditions.

Information gaps for the various indicators and recommendations for further studies identified in Chapter 4 are summarized in Table 5.2-1. For most indicators, standardization of survey methods and search areas and more regular monitoring will allow for better trend analysis as longer-term data becomes available. Sporadic surveys with large time gaps often have different survey methodologies making comparisons difficult. Detailed monitoring protocols have been developed by the PACN I&M for selected indicators and will be implemented in the near future (Ainsworth et al. 2011, 2012).

Table 5.2-1. Information gaps and recommendations for HAVO indicators.

Indicator	Data Gaps/Recommendations
Air Quality	• Additional monitoring for ozone and wet deposition of nitrogen and sulfur compounds through NADP/NTN. • Determine a 5-year visibility average for the Park according to NPS guidelines.
Volcanic Features and Processes	• Determine whether a study is necessary to evaluate human related impacts (e.g., human-accelerated erosion) to volcanic features. • Data exists for some measures through other agencies, but is not readily available for analysis.
Invasive Terrestrial Plants	• Standardize monitoring locations and methodologies. • Develop appropriate invasive plant management strategies for Kahuku. • Regular monitoring for incipient invasive plants could reduce the severity of future invasions.
Invasive Ungulates	• Estimates of pig densities in managed and unmanaged units are sporadic and methods are likely not consistent between surveys. • Describe sample periods, sample sizes, and survey methods that were used to determine ungulate abundance/density estimates (excluding mouflon in Kahuku).
Invasive Small Mammals	• More focused studies of impact of rodents to listed plant species and SOC.
Invasive Terrestrial Insects	• Areas requiring yellow jacket wasp control should be identified and an annual monitoring and control protocol developed and implemented.
Coqui Frogs	• Consider expanding monitoring beyond roadsides.
Focal Native Plant Taxa	• Similar monitoring studies on other focal plants in HAVO to help determine the condition and best management strategies for these other species. • A consistent monitoring scheme for focal plants would be beneficial to identify overall trends in the Park. • More surveys should be done within the Kahuku section as it may contain more focal species than seen in the recent survey.
Wet Forest Plant Communities	• Implement long-term, systematic approach to monitoring wet forest with standardized locations and methodologies.
Subalpine Plant Communities	• Complete more up-to-date, systematic monitoring in the subalpine zone, with standardized locations and methodologies.
Mānele/ Koa/ ʻŌhiʻa Montane Mesic Forest Plant Communities	• Limited data is available for communities in other areas of the Park besides Kīpuka Puaulu and Kīpuka Kī. • Recommend separating mesic communities from wet communities during inventorying, monitoring, and data analysis.

Table 5.2-1 (continued). Information gaps and recommendations for HAVO indicators.

Indicator	Data Gaps/Recommendations
Coastal Strand Communities	• There is a general lack of quantitative information (i.e., cover, density, frequency) within this specific plant community. • Recommend separating coastal strand from coastal lowland during inventorying, monitoring, and data analysis.
Landbirds	• Lowland birds should be monitored at intervals to check for persistence of native species, as well as to detect additional alien invasions that may pose a threat to persisting native bird populations. • ʻElepaio densities in HAVO warrant further monitoring in order to detect a potential population decline and identify and manage threats.
Seabirds	• Surveys for Newell's shearwaters and band-rumped storm petrels should continue in areas where breeding is suspected to occur. Routine monitoring at intervals for Hawaii petrels using protocols developed by the NPS Inventory and Monitoring program should be implemented to determine the status and trend of populations in the park.
Hawaiian Hoary Bats	• Repeated sampling at the locations identified in Fraser and HaySmith (2009) will increase the confidence in the distribution and extent of Hawaiian hoary bat activity at HAVO.
Endangered and Threatened Marine Vertebrates	• Continued long term monitoring is needed to determine status and trend of hawksbill turtles in park. Systematic data collection will increase confidence in the extent of usage of the HAVO coastline by monk seals and green sea turtles.
Native Insect and Springtail Communities	• Results from studies that have already been conducted also need to be analyzed and reported. • Monitoring of *Drosophila* is currently dormant and should be revived as there are indications that species of *Drosophila* dependent on rare plant species are declining.
Cave and Lava Tube Communities	• Unpublished data for all caves in HAVO should be compiled and analyzed to enable a more detailed assessment. • Numerous lava tubes are present in Kahuku are not yet surveyed.
Anchialine Pools	• Recent data collected on pool insect Faunaand other biota should be summarized and analyzed. • Little information is provided on algae and cyanobacteria in the pools, although these are often prominent features of anchialine pool systems and likely ecologically important. • Plankton surveys have also not been conducted in the pools at HAVO. • No quantitative or qualitative data are available on the amount of trash dumped or other human impacts.
Fire Regime	• Information lacking in the HAVO Fire Atlas includes the duration of each fire and fire intensity.

Table 5.2-1 (continued). Information gaps and recommendations for HAVO indicators.

Indicator	Data Gaps/Recommendations
Soundscape	• Further development and standardization of the methodology used to determine natural ambient sound levels is required. • Agreement must also be reached on what sound sources will be used and excluded in analysis. • Surveys have not yet been conducted in the Kahuku zone. • Reference conditions should be developed.

Of all the indicators, the following have been identified as having a paucity of publically available data: Volcanic Features and Processes, Native Insects and Springtail Communities, Anchialine Pools and Cave and Lava Tube Communities. NPS's understandable concern for the security of lava tubes and caves at HAVO, which may have important cultural value, has in part contributed to the information gaps for these systems. Analysis of unpublished data will contribute further to interpreting the condition of these indicators.

5.3. Conclusion

Similar to other natural areas throughout the Hawaiian Islands, the physical environment and ecological communities at HAVO have been adversely impacted and risk further degradation by a myriad of threats and stressors. As a result of these perturbations, many of the indicators at HAVO do not meet the established reference conditions and values. Despite these findings, intact examples of native Hawaiian ecosystems, unique native species, and high biodiversity remain in many areas at HAVO.

HAVO protects and restores unique and diverse ecosystems and rare endemic species that are the result of over 30 million years of evolution on an active volcanic landscape (NPS 2013). The Park provides critically important habitat to native bird populations (Judge et al. 2011); pit craters and other areas protected from feral ungulates support rare plants or plant communities (Benitez et al. 2008, Pratt et al. 2011); and vast networks of underground lava tubes or caves contain a diverse array of endemic cave-adapted invertebrates (Stone et al. 2005). HAVO also protects and interprets the largest and most continuously active shield volcanoes in the United States, and provides the best physical evidence of island building processes that continue to form the Hawaiian Archipelago. The Park is significant on a national level by serving as a living laboratory for scientific investigations (NPS 2013).

Managing such a large, unique and ecologically diverse Park is a daunting task. Mitigating physical threats ranging from volcanism and fires is often difficult or impossible. Invasive species are the biggest threat to the biological integrity of HAVO. Invasive plants and animals are present both within and outside the Park and have the potential to impact nearly all ecosystems and native organisms within HAVO. HAVO requires constant and active management to prevent degradation of habitat and enable the persistence of many native species. Active management also allows for restoration, possible range expansion of native and listed species, and even the return of species extirpated from the Park. Regular monitoring of indicators is essential to preserving natural resources. Standardization of monitoring methods and regular monitoring of indicators should allow for trend analysis in the coming years. Furthermore, future studies in the newly acquired Kahuku Section will provide better information on the condition of the various indicators within HAVO.

5.4. Literature Cited

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Appendix A. Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Table A-1. Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Amphibian	Bufonidae	*Bufo marinus*	Cane toad, giant toad	Present in Park	Rare	Vagrant	Nonnative
Amphibian	Eleuthero-dactylidae	*Eleutherodactylus coqui*	Common coqui	Present in Park	Rare	Vagrant	Nonnative
Amphibian	Ranidae	*Ranacatesbeiana*	Bullfrog	Present in Park	Rare	Vagrant	Nonnative
Amphibian	Ranidae	*Ranarugosa*	Wrinkled frog	Present in Park	Rare	Vagrant	Nonnative
Bird	Anatidae	*Branta sandvicensis*	Nēnē , Hawaiian goose	Present in Park	Uncommon	Breeder	Native
Bird	Accipitridae	*Buteo solitarius*	‘Io, Hawaiian hawk	Present in Park	Common	Breeder	Native
Bird	Ardeidae	*Bubulcus ibis*	Cattle egret	Present in Park	Occasional	Vagrant	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Bird	Ardeidae	*Nycticorax nycticorax*	Aukuʻu, black-crowned night-heron	Present in Park	Occasional	Vagrant	Native
Bird	Charadriidae	*Pluvialis fulva*	Kōlea, lesser golden plover, Pacific golden plover	Present in Park	Common	Migratory	Native
Bird	Falconidae	*Falco peregrinus*	Peregrine falcon	Probably Present	N/A	N/A	Nonnative
Bird	Fregatidae	*Fregata minor palmerstoni*	ʻIwa, great frigatebird, iwa	Present in Park	Uncommon	Vagrant	Native
Bird	Hydrobatidae	*Oceanodroma castro*	ʻAkēʻakē, band-rumped storm-petrel	Present in Park	Rare	Breeder	Native
Bird	Laridae	*Anous minutus melanogenys*	Noio, black noddy, Hawaiian noddy,	Present in Park	Common	Resident	Native
Bird	Laridae	*Gygis alba rothschildi*	Manu-o-kū, white tern	Present in Park	Rare	Migratory	Nonnative
Bird	Laridae	*Larus philadelphia*	Bonaparte's gull	Present in Park	Unknown	Vagrant	Nonnative
Bird	Laridae	*Sternafuscata*	Wooty tern	Present in Park	Rare	Migratory	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Bird	Phaethontidae	*Phaethon lepturus dorotheae*	Koa`e kea, white-tailed tropicbird	Present in Park	Common	Breeder	Native
Bird	Phaethontidae	*Phaethon rubricauda*	Koa`e `ula, red-tailed tropicbird	Present in Park	Rare	Migratory	Nonnative
Bird	Procellariidae	*Pterodroma sandwichensis*	`Ua`u, Hawaiian petrel, dark-rumped Hawaiian petrel	Present in Park	Uncommon	Breeder	Native
Bird	Procellariidae	*Puffinus auricularis*	`A`o, Newell's shearwater	Present in Park	Unknown	Unknown	Native
Bird	Procellariidae	*Puffinus pacificus*	`Ua`u kani, wedge-tailed shearwater	Present in Park	Occasional	Vagrant	Nonnative
Bird	Scolopacidae	*Arenaria interpres*	‘Akekeke, ruddy turnstone	Present in Park	Uncommon	Migratory	Native
Bird	Scolopacidae	*Calidris alba*	Hunakai, sanderling	Present in Park	Uncommon	Migratory	Native
Bird	Scolopacidae	*Heteroscelus incanus*	‘Ulili, wandering tattler	Present in Park	Uncommon	Migratory	Native
Bird	Scolopacidae	*Numenius tahitiensis*	Kioea, bristle-thighed curlew	Present in Park	Occasional	Migratory	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Bird	Scolopacidae	*Phalaropus fulicaria*	Red phalarope	Present in Park	Occasional	Migratory	Native
Bird	Columbidae	*Columba livia*	Rock dove	Probably Present	N/A	N/A	Nonnative
Bird	Columbidae	*Geopelia striata*	Barred dove, zebra dove	Present in Park	Uncommon	Breeder	Nonnative
Bird	Columbidae	*Streptopelia chinensis*	Spotted dove	Present in Park	Uncommon	Breeder	Nonnative
Bird	Numididae	*Numida meleagris*	Helmeted guineafowl	Present in Park	Unknown	Unknown	Nonnative
Bird	Odontophoridae	*Callipepla californica*	California quail	Present in Park	Rare	Breeder	Nonnative
Bird	Phasianidae	*Alectoris chukar*	Chukar	Present in Park	Uncommon	Breeder	Nonnative
Bird	Phasianidae	*Coturnix japonica*	Japanese quail	Present in Park	Occasional	Vagrant	Nonnative
Bird	Phasianidae	*Francolinus erckelii*	Erckel's francolin	Present in Park	Common	Breeder	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Bird	Phasianidae	*Lophura leucomelanos*	Kalij pheasant	Present in Park	Common	Breeder	Nonnative
Bird	Phasianidae	*Meleagris gallopavo*	Wild turkey	Present in Park	Rare	Breeder	Nonnative
Bird	Phasianidae	*Pavo cristatus*	Common peafowl	Present in Park	Unknown	Unknown	Nonnative
Bird	Phasianidae	*Phasianus colchicus*	Common pheasant, ring-necked pheasant	Present in Park	Rare	Breeder	Nonnative
Bird	Phasianidae	*Phasianus versicolor*	Green pheasant	Present in Park	Rare	Breeder	Nonnative
Bird	Alaudidae	*Alauda arvensis arvensis*	European skylark, skylark	Present in Park	Uncommon	Breeder	Nonnative
Bird	Cardinalidae	*Cardinalis cardinalis*	Red cardinal	Present in Park	Common	Breeder	Nonnative
Bird	Corvidae	*Chasiempis sandwichensis sandwichensis*	‘Elepaio, elepaio	Present in Park	Common	Breeder	Native
Bird	Emberizidae	*Paroaria capitata*	Yellow-billed cardinal	Probably Present	N/A	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Bird	Emberizidae	*Sicalis flaveola*	Saffron finch	Present in Park	Uncommon	Breeder	Nonnative
Bird	Estrildidae	*Lonchura cantans*	African silverbill	Probably Present	N/A	N/A	Nonnative
Bird	Estrildidae	*Lonchura punctulata*	Nutmeg mannikin, ricebird, spotted munia	Present in Park	Common	Breeder	Nonnative
Bird	Fringillidae	*Carpodacus mexicanus*	House finch, linnet, papayabird	Present in Park	Common	Breeder	Nonnative
Bird	Fringillidae	*Hemignathus munroi*	ʻAkiapōlāʻau	Present in Park	Rare	Breeder	Native
Bird	Fringillidae	*Hemignathus virens virens*	Hawaiʻi ʻamakihi	Present in Park	Abundant	Breeder	Native
Bird	Fringillidae	*Himatione sanguinea sanguinea*	ʻApapane	Present in Park	Abundant	Breeder	Native
Bird	Fringillidae	*Loxops coccineus coccineus*	ʻAkepeuʻie, ʻAkepa, Hawaiʻi ʻākepa	Present in Park	Common	Breeder	Native
Bird	Fringillidae	*Oreomystis mana*	Hawaiʻi creeper	Present in Park	Uncommon	Breeder	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Bird	Fringillidae	*Serinus mozambicus*	Yellow fronted canary	Present in Park	Rare	Breeder	Nonnative
Bird	Fringillidae	*Vestiaria coccinea*	‘I‘iwi, iiwi	Present in Park	Common	Breeder	Native
Bird	Mimidae	*Mimus polyglottos*	Northern mockingbird	Probably Present	N/A	N/A	Nonnative
Bird	Passeridae	*Passer domesticus*	House sparrow	Present in Park	Uncommon	Breeder	Nonnative
Bird	Sturnidae	*Acridotheres tristis*	Common myna	Present in Park	Common	Breeder	Nonnative
Bird	Sylviidae	*Cettia diphone*	Japanese bush-warbler	Present in Park	Rare	Unknown	Nonnative
Bird	Sylviidae	*Garrulax canorus*	Chinese thrush, hwamei, melodious laughing thrush	Present in Park	Common	Breeder	Nonnative
Bird	Sylviidae	*Leiothrix lutea*	Japanese hill robin, Pekin nightingale, red-billed leiothrix	Present in Park	Abundant	Breeder	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Bird	Turdidae	*Myadestes obscurus*	'Oma'o, Hawaii thrush	Present in Park	Abundant	Breeder	Native
Bird	Zosteropidae	*Zosterops japonicus*	Japanese white eye	Present in Park	Abundant	Breeder	Nonnative
Bird	Strigidae	*Asio flammeus sandwichensis*	Pueo, Hawaiian owl, short-eared owl	Present in Park	Rare	Breeder	Native
Bird	Tytonidae	*Tyto alba*	Common barn owl	Present in Park	Uncommon	Breeder	Nonnative
Fish	Acanthuridae	*Acanthurus sandvicensis*	Convict tang	Present in Park	Unknown	Breeder	Native
Fish	Gobiidae	*Bathygobius fuscus*	\`O\`opu \`ohune	Present in Park	Unknown	Breeder	Native
Fish	Kuhliidae	*Kuhlia sandvicensis*	\`Aholehole	Present in Park	Common	Breeder	Native
Mammal	Bovidae	*Bos taurus*	Domestic cattle (feral)	Present in Park	Occasional	Unknown	Nonnative
Mammal	Bovidae	*Capra hircus*	Goat (feral)	Present in Park	Occasional	Unknown	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Mammal	Bovidae	*Ovis aries*	Feral sheep	Present in Park	Abundant	Unknown	Nonnative
Mammal	Bovidae	*Ovis musimon*	Mouflon sheep	Present in Park	Abundant	Breeder	Nonnative
Mammal	Suidae	*Sus scrofa*	Feral pig, pua'a	Present in Park	Common	Breeder	Nonnative
Mammal	Canidae	*Canis familiaris*	Domestic dog	Present in Park	Rare	Resident	Nonnative
Mammal	Felidae	*Felis silvestris*	Feral cat	Present in Park	Common	Breeder	Nonnative
Mammal	Herpestidae	*Herpestes auropunctatus*	Indian mongoose	Present in Park	Abundant	Breeder	Nonnative
Mammal	Phocidae	*Monachus schauinslandi*	‘Ilio holo-i-ka-uaua, Hawaiian monk seal	Probably Present	N/A	N/A	Native
Mammal	Vespertilionidae	*Lasiurus cinereus semotus*	‘Ope‘ape‘a, Hawaiian hoary bat	Present in Park	Unknown	Breeder	Native
Mammal	Muridae	*Mus musculus*	House mouse	Present in Park	Abundant	Breeder	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Mammal	Muridae	*Rattus exulans*	Polynesian rat	Present in Park	Abundant	Breeder	Nonnative
Mammal	Muridae	*Rattus norvegicus*	Norway rat	Present in Park	Common	Breeder	Nonnative
Mammal	Muridae	*Rattus rattus*	Black rat, 'iole, roof rat	Present in Park	Abundant	Breeder	Nonnative
Reptile	Gekkonidae	*Gehyra mutilata*	Stump-toed gecko	Present in Park	Uncommon	Breeder	Nonnative
Reptile	Gekkonidae	*Hemidactylus frenatus*	Common house gecko	Present in Park	Abundant	Breeder	Nonnative
Reptile	Gekkonidae	*Hemidactylus garnotii*	Indo-Pacific gecko	Present in Park	Uncommon	Breeder	Nonnative
Reptile	Gekkonidae	*Hemiphyllodactylus typus*	Indo-Pacific tree gecko, small tree gecko	Present in Park	Uncommon	Breeder	Nonnative
Reptile	Gekkonidae	*Lepidodactylus lugubris*	Mourning gecko	Present in Park	Abundant	Breeder	Nonnative
Reptile	Scincidae	*Cryptoblepharus poecilopleurus*	Oceanic snake-eyed skink	Present in Park	Uncommon	Breeder	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Reptile	Scincidae	*Lampropholis delicata*	Metallic skink	Present in Park	Abundant	Breeder	Nonnative
Reptile	Cheloniidae	*Chelonia mydas*	Green sea turtle, honu	Present in Park	Rare	Resident	Native
Reptile	Cheloniidae	*Eretmochelys imbricata*	Hawksbill sea turtle	Present in Park	Uncommon	Breeder	Native
Vascular Plant	Apiaceae	*Centella asiatica*	Asiatic pennywort, pohe kula	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Apiaceae	*Daucus pusillus*	American wild carrot	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Apiaceae	*Foeniculum vulgare*	Fennel	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Apiaceae	*Hydrocotyle bowlesioides*	Largeleaf marshpennywort	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Apiaceae	*Hydrocotyle verticillata*	Pohe	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Apiaceae	*Sanicula sandwicensis*	Snakeroot	Present in Park	Rare	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Araliaceae	*Cheirodendron trigynum* ssp. *trigynum*	‘Olapa, lapalapa, olapa	Present in Park	Abundant	N/A	Native
Vascular Plant	Araliaceae	*Hedera helix*	Ivy	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Araliaceae	*Reynoldsia sandwicensis*	\`Ohe, \`ohe\`ohe, \`oheokai	Present in Park	Uncommon	N/A	Native
Vascular Plant	Araliaceae	*Schefflera actinophylla*	Octopus tree	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Araliaceae	*Schefflera arboricola*	Dwarf umbrella tree	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Araliaceae	*Tetraplasandra hawaiensis*	\`Ohe, ohe	Present in Park	Rare	N/A	Native
Vascular Plant	Araliaceae	*Tetraplasandra kavaiensis*	\`Ohe\`ohe	Probably Present	NA	N/A	Native
Vascular Plant	Araliaceae	*Tetraplasandra oahuensis*	\`Ohe, ohe, ohe mauka	Present in Park	Rare	N/A	Native
Vascular Plant	Araceae	*Anthurium* sp. [1]	Anthurium	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Araceae	*Colocasia esculenta*	Kalo, taro	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Araceae	*Monstera deliciosa*	Monstera	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Araceae	*Philodendron* sp. [1]	Philodendron	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Arecaceae	*Cocos nucifera*	Coconut palm, niu	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Arecaceae	*Dypsis lutescens*	Areca palm, golden-fruited palm	Probably Present	NA	N/A	Nonnative
Vascular Plant	Arecaceae	*Phoenix dactylifera*	Date palm	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Arecaceae	*Phoenix roebelenii*	Pygmy date palm	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Arecaceae	*Pritchardia affinis*	Loʻulu	Present in Park	Rare	N/A	Native
Vascular Plant	Arecaceae	*Pritchardia beccariana*	Loʻulu	Present in Park	Uncommon	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Asteraceae	*Acanthospermum australe*	‘Ihi kukae hipa, kukaehipa, pipili	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Achillea millefolium*	Common yarrow	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Ageratinariparia*	Hamakua pamakani, spreading mist flower	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Ageratum conyzoides*	Maile hohono, maile honohono, maile kula	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Ageratum houstonianum*	Maile hohono	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Argyranthemum frutescens*	Marguerite	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Asteraceae	*Argyroxiphium kauense*	‘Ahinahina, ahinahina, MaunaLoa silversword	Present in Park	Rare	N/A	Native
Vascular Plant	Asteraceae	*Argyroxiphium sandwicense ssp. macrocephalum*	‘Ahinahina, Haleakala silversword	Present in Park	Rare	N/A	Native
Vascular Plant	Asteraceae	*Artemisia vulgaris*	Mugwort	Present in Park	Rare	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Asteraceae	*Bidens alba* var. *radiata*	Bidens, romerillo	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Asteraceae	*Bidens cynapiifolia*	West Indian beggarticks	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Bidens hawaiensis*	Ko`oko`lau, ko`oko`olau	Present in Park	Rare	N/A	Native
Vascular Plant	Asteraceae	*Bidens pilosa*	Ki, ki nehe, ki pipili	Present in Park	Common	N/A	Nonnative
Vascular Plant	Asteraceae	*Centaurea melitensis*	Napa thistle, yellow star thistle	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Cirsium vulgare*	Bull thistle	Present in Park	Common	N/A	Nonnative
Vascular Plant	Asteraceae	*Conyza bonariensis*	Hairy horseweed, lani wela	Present in Park	Common	N/A	Nonnative
Vascular Plant	Asteraceae	*Conyza canadensis* var. *canadensis*	Horseweed	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Asteraceae	*Conyza canadensis* var. *pusilla*	Horseweed	Present in Park	Common	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Asteraceae	*Coreopsis lanceolata*	Koʻokoʻolau haole	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Crassocephalum crepidioides*	Redflower ragleaf	Present in Park	Common	N/A	Nonnative
Vascular Plant	Asteraceae	*Cyanthillium cinereum* var. *parviflora*	Little ironweed	Present in Park	Common	N/A	Nonnative
Vascular Plant	Asteraceae	*Dahlia pinnata*	Dahlia	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Delairea odorata*	Cape ivy, German ivy	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Asteraceae	*Dubautia ciliolata* ssp. *ciliolata*	Kupaoa, na`ena`e	Present in Park	Common	N/A	Native
Vascular Plant	Asteraceae	*Dubautia ciliolata X scabra*	–	Present in Park	Rare	N/A	Native
Vascular Plant	Asteraceae	*Dubautia linearis* ssp. *hillebrandii*	Kupaoa, na`ena`e	Present in Park	Rare	N/A	Native
Vascular Plant	Asteraceae	*Dubautia scabra* ssp. *leiophylla*	Na`ena`e, kupaoa	Present in Park	Uncommon	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Asteraceae	*Dubautia scabra* ssp. *scabra*	Kupaoa, na`ena`e	Present in Park	Abundant	N/A	Native
Vascular Plant	Asteraceae	*Elephantopus mollis*	Elephant`s foot	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Emilia fosbergii*	Pua lele	Present in Park	Common	N/A	Nonnative
Vascular Plant	Asteraceae	*Erechtites valerianifolia*	Fireweed	Present in Park	Common	N/A	Nonnative
Vascular Plant	Asteraceae	*Erigeron karvinskianus*	Faisy fleabane	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Euchiton sphaericus*	Cudweed	Present in Park	Common	N/A	Nonnative
Vascular Plant	Asteraceae	*Farfugium japonicum*	Farfugium	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Asteraceae	*Galinsoga parviflora*	Galinsoga	Present in Park	Common	N/A	Nonnative
Vascular Plant	Asteraceae	*Galinsoga quadriradiata*	Peruvian daisy	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Asteraceae	*Gamochaeta purpurea*	Purple cudweed	Present in Park	Common	N/A	Nonnative
Vascular Plant	Asteraceae	*Gazania rigens*	Pied gazania	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Asteraceae	*Helichrysum foetidum*	Stinking everlasting	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Heterotheca grandiflora*	Telegraph weed	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Asteraceae	*Hypochaeris glabra*	Smooth catsear	Present in Park	Unknown	N/A	Nonnative
Vascular Plant	Asteraceae	*Hypochaeris radicata*	Gosmore, hairy cat's ear	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Asteraceae	*Lapsana communis*	Nipplewort	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Asteraceae	*Leucanthemum vulgare*	Ox-eye daisy	Probably Present	N/A	N/A	Nonnative
Vascular Plant	Asteraceae	*Leucanthemum X superbum*	Shasta daisy	Present in Park	Uncommon	N/A	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Asteraceae	*Logfia gallica*	Narrowleaf cottonrose	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Melanthera subcordata*	Nehe	Probably Present	N/A	N/A	Native
Vascular Plant	Asteraceae	*Picris hieracioides*	Hawkweed	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Asteraceae	*Pluchea carolinensis*	Sourbush	Present in Park	Common	N/A	Nonnative
Vascular Plant	Asteraceae	*Pseudognaphalium sandwicensium*	‘Ena‘ena	Present in Park	Common	N/A	Native
Vascular Plant	Asteraceae	*Pseudognaphalium sandwicensium* var. *hawaiiense*	‘Ena‘ena	Present in Park	Rare	N/A	Native
Vascular Plant	Asteraceae	*Pseudognaphalium sandwicensium* var. *kilaueanum*	‘Ena‘ena	Present in Park	Common	N/A	Native
Vascular Plant	Asteraceae	*Senecio madagascariensis*	Madagascar Fireweed	Present in Park	Rare	N/A	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Asteraceae	*Senecio sylvaticus*	Wood groundsel	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Siegesbeckia orientalis*	Small yellow crown beard	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Soliva sessilis*	Field burrweed, field soliva	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Asteraceae	*Sonchus asper*	Prickly sowthistle	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Sonchus oleraceus*	Pualele	Present in Park	Common	N/A	Nonnative
Vascular Plant	Asteraceae	*Sphagneticola trilobata*	Wedelia	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Asteraceae	*Synedrella nodiflora*	Nodeweed	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Taraxacum officinale*	Common dandelion	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Tetramolopium humile* ssp. *humile*	Alpine tetramolopium	Present in Park	Uncommon	N/A	Native

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Asteraceae	*Tridax procumbens*	Coat buttons	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Xanthium strumarium* var. *canadense*	Cocklebur	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Asteraceae	*Youngia japonica*	Oriental hawksbeard	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Athyriaceae	*Deparia petersenii*	–	Present in Park	Common	N/A	Nonnative
Vascular Plant	Campanulaceae	*Clermontia clermontioides* ssp. *clermontioides*	‘Ohā	Present in Park	Uncommon	N/A	Native
Vascular Plant	Campanulaceae	*Clermontia hawaiiensis*	‘Ohā kepau, ‘oha wai nui, `ohaha wai nui	Present in Park	Rare	N/A	Native
Vascular Plant	Campanulaceae	*Clermontia lindseyana*	‘Ohā, ‘oha wai, haha, Lindsey’s ‘ōhā	Present in Park	Rare	N/A	Native
Vascular Plant	Campanulaceae	*Clermontia montisloa*	‘Ohā wai, ‘ōhā wai	Present in Park	Uncommon	N/A	Native
Vascular Plant	Campanulaceae	*Clermontia parviflora*	‘Ohā wai	Present in Park	Common	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Campanulaceae	*Clermontia peleana* ssp. *peleana*	ʻOhā, ʻōhā wai, Pele's ʻōhā	Present in Park	Rare	N/A	Native
Vascular Plant	Campanulaceae	*Cyanea floribunda*	–	Present in Park	Uncommon	N/A	Native
Vascular Plant	Campanulaceae	*Cyanea pilosa* ssp. *longipedunculata*	Hairy cyanea	Present in Park	Uncommon	N/A	Native
Vascular Plant	Campanulaceae	*Cyanea pilosa* ssp. *pilosa*	Hairy cyanea	Present in Park	Rare	N/A	Native
Vascular Plant	Campanulaceae	*Cyanea stictophylla*	Hāhā, kaiholena cyanea, haʻiwale, kanawao keʻokeʻo	Present in Park	Rare	N/A	Native
Vascular Plant	Campanulaceae	*Cyanea tritomantha*	ʻAkū	Present in Park	Rare	N/A	Native
Vascular Plant	Campanulaceae	*Hippobroma longiflora*	Pua hoku, Star-of-Bethlehem	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Campanulaceae	*Trematolobelia grandifolia*	Largeflower false lobelia	Present in Park	Rare	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Campanulaceae	*Wahlenbergia gracilis*	–	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Goodeniaceae	*Scaevola aemula*	–	Probably Present	N/A	N/A	Nonnative
Vascular Plant	Goodeniaceae	*Scaevola chamissoniana*	Naupaka, naupaka kuahiwi	Present in Park	Uncommon	N/A	Native
Vascular Plant	Goodeniaceae	*Scaevola kilaueae*	Naupaka, naupaka kuahiwi, papa`ahekili	Present in Park	Uncommon	N/A	Native
Vascular Plant	Goodeniaceae	*Scaevola taccada*	Naupaka, huahekili, naupaka kahakai	Present in Park	Common	N/A	Native
Vascular Plant	Brassicaceae	*Capsella bursapastoris*	Shepherd's purse	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Brassicaceae	*Cardamine flexuosa*	Bittercress	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Brassicaceae	*Cardamine hirsuta*	Hairy bittercress	Present in Park	Unknown	N/A	Nonnative
Vascular Plant	Brassicaceae	*Coronopus didymus*	Lesser swinecress	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Brassicaceae	*Lepidium hyssopifolium*	Pepperwort	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Brassicaceae	*Lepidium virginicum*	Pepperweed	Present in Park	Common	N/A	Nonnative
Vascular Plant	Brassicaceae	*Lobularia maritima*	Sweet alyssum	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Brassicaceae	*Raphanus raphanistrum*	Wild radish	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Brassicaceae	*Raphanus sativus*	Radish, daikon	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Brassicaceae	*Raphanus sativus* var. *longipinnatus*	–	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Brassicaceae	*Rorippa sarmentosa*	‘Ihi ku kepau, pa`ihi, pa`ihi`ihi	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Aizoaceae	*Lampranthus spectabilis* ssp. *spectabilis*	Ice plant	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Aizoaceae	*Sesuvium portulacastrum*	Akulikuli	Present in Park	Common	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Amaranthaceae	*Amaranthus spinosus*	Pakai kuku	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Amaranthaceae	*Amaranthus viridis*	`Aheahea, aheahea, pakai	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Amaranthaceae	*Charpentiera obovata*	Papala	Present in Park	Rare	N/A	Native
Vascular Plant	Amaranthaceae	*Charpentiera obovata X ovata*	Papala	Present in Park	Rare	N/A	Native
Vascular Plant	Amaranthaceae	*Nototrichium sandwicense*	Kulu`i, kului	Present in Park	Rare	N/A	Native
Vascular Plant	Cactaceae	*Opuntia ficus-indica*	Indian fig, Indian-fig, tuna cactus	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Caryophyllaceae	*Cerastium fontanum* ssp. *triviale*	Common mouse-ear chickweed	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Caryophyllaceae	*Drymaria cordata* var. *pacifica*	Pilipili	Present in Park	Common	N/A	Nonnative
Vascular Plant	Caryophyllaceae	*Polycarpon tetraphyllum*	Fourleaf manyseed	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Caryophyllaceae	*Schiedea diffusa* var. *macraei*	–	Present in Park	Rare	N/A	Native
Vascular Plant	Caryophyllaceae	*Silene gallica*	Common catchfly, Windmill catchfly	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Caryophyllaceae	*Silene hawaiiensis*	Hawai'i catchfly	Present in Park	Rare	N/A	Native
Vascular Plant	Caryophyllaceae	*Stellaria media*	Chickweed, Common chickweed, Nodding chickweed	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Chenopodiaceae	*Chenopodium ambrosioides*	Mexican tea, Wormseed	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Chenopodiaceae	*Chenopodium carinatum*	Tasmanian goosefoot	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Chenopodiaceae	*Chenopodium murale*	`Aheahea, aheahea	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Chenopodiaceae	*Chenopodium oahuense*	Alaweo	Present in Park	Rare	N/A	Native
Vascular Plant	Nyctaginaceae	*Boerhavia acutifolia*	Alena	Present in Park	Rare	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Nyctaginaceae	*Boerhavia herbstii*	Alena	Probably Present	N/A	N/A	Native
Vascular Plant	Nyctaginaceae	*Boerhavia repens*	Alena, nena	Present in Park	Uncommon	N/A	Native
Vascular Plant	Nyctaginaceae	*Bougainvillea glabra*	Paperflower	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Nyctaginaceae	*Mirabilis jalapa*	common four o'clock, Common four-o'clock, Marvel of Peru	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Nyctaginaceae	*Pisonia brunoniana*	Papala, Papala kepau	Present in Park	Uncommon	N/A	Native
Vascular Plant	Nyctaginaceae	*Pisonia umbellifera*	Papala, Papala kepau	Present in Park	Rare	N/A	Native
Vascular Plant	Phytolaccaceae	*Phytolacca sandwicensis*	Hawai'i pokeweed	Present in Park	Uncommon	N/A	Native
Vascular Plant	Portulacaceae	*Portulaca oleracea*	\`Akulikuli, \`ihi, akulikuli	Present in Park	Common	N/A	Nonnative
Vascular Plant	Portulacaceae	*Portulaca pilosa*	\`Akulikuli, akulikuli	Present in Park	Common	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Portulacaceae	*Portulaca sclerocarpa*	Poʻe, ʻihi mākole, ʻihi	Present in Park	Rare	N/A	Native
Vascular Plant	Portulacaceae	*Portulaca villosa*	ʻIhi, ihi	Present in Park	Rare	N/A	Native
Vascular Plant	Aquifoliaceae	*Ilex anomala*	Aiea, kawaʻu, kawau	Present in Park	Abundant	N/A	Native
Vascular Plant	Aquifoliaceae	*Ilex aquifolium*	European holly	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Aquifoliaceae	*Ilex cassine*	Dahoon	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Aquifoliaceae	*Ilex cornuta*	Chinese holly	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Celastraceae	*Perrottetia sandwicensis*	Piaʻa olomea, waimea	Present in Park	Abundant	N/A	Native
Vascular Plant	Commelinaceae	*Commelina diffusa*	Honohono, honohono wai, makolokolo	Present in Park	Common	N/A	Nonnative
Vascular Plant	Xyridaceae	*Xyris complanata*	Hawai'i yelloweyed grass	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Cyperaceae	*Bulbostylis capillaris*	Densetuft hairsedge, threadleaf beakseed	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Cyperaceae	*Carex alligata*	Hawai'i sedge	Present in Park	Common	N/A	Native
Vascular Plant	Cyperaceae	*Carex echinata*	Prickly sedge, star sedge	Present in Park	Rare	N/A	Native
Vascular Plant	Cyperaceae	*Carex macloviana* ssp. *subfusca*	Brown sedge	Present in Park	Uncommon	N/A	Native
Vascular Plant	Cyperaceae	*Carex meyenii*	Meyen's sedge	Present in Park	Uncommon	N/A	Native
Vascular Plant	Cyperaceae	*Carex wahuensis* ssp. *rubiginosa*	O‘ahu sedge	Present in Park	Common	N/A	Native
Vascular Plant	Cyperaceae	*Carex wahuensis* ssp. *wahuensis*	O‘ahu sedge	Present in Park	Common	N/A	Native
Vascular Plant	Cyperaceae	*Cyperus compressus*	Poorland flatsedge	Probably Present	N/A	N/A	Nonnative
Vascular Plant	Cyperaceae	*Cyperus difformis*	Dmallflower Umbrella sedge, Variable flatsedge	Present in Park	Uncommon	N/A	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Cyperaceae	*Cyperus haspan*	Haspan flatsedge	Present in Park	Common	N/A	Nonnative
Vascular Plant	Cyperaceae	*Cyperus hillebrandii* var. *hillebrandii*	Hillebrand's flatsedge	Present in Park	Common	N/A	Native
Vascular Plant	Cyperaceae	*Cyperus javanicus*	\`Ahu\`awa, \`Ehu\`awa, Ahuawa	Present in Park	Uncommon	N/A	Native
Vascular Plant	Cyperaceae	*Cyperus laevigatus*	Ehu\`awa, makaloa, makoloa	Present in Park	Rare	N/A	Native
Vascular Plant	Cyperaceae	*Cyperus meyenianus*	Meyen's flatsedge	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Cyperaceae	*Cyperus phleoides* var. *hawaiensis*	Molokai flatsedge	Present in Park	Rare	N/A	Native
Vascular Plant	Cyperaceae	*Cyperus polystachyos*	Manyspike flatsedge	Present in Park	Abundant	N/A	Native
Vascular Plant	Cyperaceae	*Cyperus rotundus*	Kili\`o\`opu, mau\`u mokae, nut grass	Probably Present	N/A	N/A	Nonnative
Vascular Plant	Cyperaceae	*Cyperus sanquinolentus*	–	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Cyperaceae	*Cyperus trinervis*	Australian flatsedge	Present in Park	Common	N/A	Nonnative
Vascular Plant	Cyperaceae	*Cyperus virens*	Green flatsedge	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Cyperaceae	*Eleocharis obtusa*	Kohekohe, pipiwai, spikerush	Present in Park	Rare	N/A	Native
Vascular Plant	Cyperaceae	*Fimbristylis cymosa* ssp. *spathacea*	Mau‘u ‘aki‘aki	Present in Park	Common	N/A	Native
Vascular Plant	Cyperaceae	*Fimbristylis cymosa* ssp. *umbellatacapitata*	Tropical fimbry, mau‘u ‘aki‘aki	Present in Park	Common	N/A	Native
Vascular Plant	Cyperaceae	*Fimbristylis dichotoma*	Forked fimbry	Present in Park	Common	N/A	Native
Vascular Plant	Cyperaceae	*Fimbristylis hawaiiensis*	Hawai'i fimbry	Present in Park	Uncommon	N/A	Native
Vascular Plant	Cyperaceae	*Kyllinga brevifolia*	Kaluha, kili`o`opu, manunene	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Cyperaceae	*Kyllinga nemoralis*	Kili`o`pu, mau`u mokae	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Cyperaceae	*Machaerina angustifolia*	‘Uki, uki	Present in Park	Abundant	N/A	Native
Vascular Plant	Cyperaceae	*Machaerina mariscoides* ssp. *meyenii*	‘Ahanui, ‘uki, ahanui	Present in Park	Common	N/A	Native
Vascular Plant	Cyperaceae	*Morelotia gahniiformis*	–	Present in Park	Common	N/A	Native
Vascular Plant	Cyperaceae	*Oreobolus furcatus*	Hawai'i Island sedge	Present in Park	Uncommon	N/A	Native
Vascular Plant	Cyperaceae	*Rhynchospora caduca*	Anglestem beaksedge	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Cyperaceae	*Rhynchospora chinensis* ssp. *spiciformis*	Spiked beaksedge	Probably Present	N/A	N/A	Native
Vascular Plant	Cyperaceae	*Rhynchospora rugosa* ssp. *lavarum*	Pu‘uko‘a, puukoa	Present in Park	Uncommon	N/A	Native
Vascular Plant	Cyperaceae	*Rhynchospora sclerioides*	Kuolohia	Present in Park	Uncommon	N/A	Native
Vascular Plant	Cyperaceae	*Uncinia uncinata*	Hawai'i birdcatching sedge	Present in Park	Common	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Poaceae	*Agrostis avenacea*	He'upueo, heupueo	Present in Park	Uncommon	N/A	Native
Vascular Plant	Poaceae	*Agrostis sandwicensis*	Hawai'i bentgrass	Present in Park	Uncommon	N/A	Native
Vascular Plant	Poaceae	*Agrostis stolonifera*	Marsh bent, redtop bentgrass	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Aira caryophyllea*	Silver hairgrass	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Andropogon glomeratus* var. *pumilus*	Bushy bluestem	Present in Park	Occasional	N/A	Nonnative
Vascular Plant	Poaceae	*Andropogon virginicus*	Yellow bluestem, broomsedge	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Poaceae	*Anthoxanthum odoratum*	Sweet vernalgrass	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Poaceae	*Arundo donax* var. *versicolor*	Giantreed	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Poaceae	*Avena fatua*	Flaxgrass, oatgrass, wheat oats	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Poaceae	*Avena sativa*	‘Oka, cultivated oat, oka	Probably Present	NA	N/A	Nonnative
Vascular Plant	Poaceae	*Axonopus compressus*	Carpet grass	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Poaceae	*Axonopus fissifolius*	Narrow-leaved carpetgrass	Present in Park	Common	N/A	Nonnative
Vascular Plant	Poaceae	*Bothriochloa barbinodis*	Fuzzy top	Present in Park	Common	N/A	Nonnative
Vascular Plant	Poaceae	*Bothriochloa pertusa*	Pitted beardgrass	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Brachiaria mutica*	California grass	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Briza minor*	Little quakinggrass	Present in Park	Common	N/A	Nonnative
Vascular Plant	Poaceae	*Bromus catharticus*	Rescue brome, rescue grass, rescuegras	Present in Park	Common	N/A	Nonnative
Vascular Plant	Poaceae	*Bromus diandrus*	Ripgut brome	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Poaceae	*Bromus rubens*	Foxtail brome, red brome	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Poaceae	*Bromus sterilis*	Barren bromegrass, Poverty brome, Sterile brome	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Cenchrus clandestinus*	Kikuyu grass	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Poaceae	*Cenchrus echinatus*	\`Ume\`alu, Common sandbur, Mau\`u kuku	Present in Park	Common	N/A	Nonnative
Vascular Plant	Poaceae	*Cenchrus purpureus*	Napier grass	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Cenchrus setaceus*	Fountain grass	Present in Park	Common	N/A	Nonnative
Vascular Plant	Poaceae	*Chloris barbata*	Mau\`u lei	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Chloris gayana*	Rhodes grass, rhodesgrass	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Chrysopogon aciculatus*	Golden beardgrass, manienie \`ula, pi\`ipi\`i	Present in Park	Common	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Poaceae	*Cymbopogon refractus*	Soap grass	Present in Park	Common	N/A	Nonnative
Vascular Plant	Poaceae	*Cynodon dactylon*	Manienie, manienie haole	Present in Park	Common	N/A	Nonnative
Vascular Plant	Poaceae	*Dactylis glomerata*	Cocksfoot	Present in Park	Common	N/A	Nonnative
Vascular Plant	Poaceae	*Dactyloctenium aegyptium*	Beach wiregrass	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Deschampsia nubigena*	Hairgrass	Present in Park	Abundant	N/A	Native
Vascular Plant	Poaceae	*Dichanthium aristatum*	Wilder grass	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Poaceae	*Digitaria ciliaris*	Henry's crabgrass, kukaepua`a, kukaepuaa	Present in Park	Common	N/A	Nonnative
Vascular Plant	Poaceae	*Digitaria eriantha*	Pangolagrass	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Digitaria fuscescens*	Creeping kukaepua`a	Present in Park	Common	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Poaceae	*Digitaria insularis*	Sourgrass	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Poaceae	*Digitaria setigera*	East Indian crabgrass	Present in Park	Uncommon	N/A	Native
Vascular Plant	Poaceae	*Digitaria* sp.[1]	–	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Digitaria violascens*	Kukaepua`a `uka, smooth crabgrass	Present in Park	Common	N/A	Nonnative
Vascular Plant	Poaceae	*Ehrharta stipoides*	Meadow ricegrass	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Poaceae	*Eleusine indica*	Manienie ali`I, wiregrass	Present in Park	Common	N/A	Nonnative
Vascular Plant	Poaceae	*Eragrostis amabilis*	–	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Eragrostis atropioides*	Lovegrass	Present in Park	Uncommon	N/A	Native
Vascular Plant	Poaceae	*Eragrostis brownei*	Sheepgrass	Present in Park	Common	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Poaceae	*Eragrostis cilianensis*	Candy grass, lovegrass, Stink grass	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Eragrostis elongata*	Long lovegrass	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Eragrostis grandis*	Large Hawai'i lovegrass	Present in Park	Rare	N/A	Native
Vascular Plant	Poaceae	*Eragrostis pectinacea*	Carolina lovegrass	Present in Park	Common	N/A	Nonnative
Vascular Plant	Poaceae	*Eragrostis* sp. [1]	Lovegrass	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Poaceae	*Eragrostis variabilis*	`Emoloa, kalamalo, kawelu	Present in Park	Uncommon	N/A	Native
Vascular Plant	Poaceae	*Festuca arundinacea*	Reed fescue	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Poaceae	*Festuca rubra*	Ravine fescue, Red fescue	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Gastridium ventricosum*	Nitgrass	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Poaceae	*Heteropogon contortus*	Lule, Pili, Pili grass	Present in Park	Common	N/A	Native
Vascular Plant	Poaceae	*Holcus lanatus*	Yorkshire fog	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Poaceae	*Hyparrhenia rufa*	Thatching grass	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Poaceae	*Isachne distichophylla*	`Ohe, ohe	Present in Park	Common	N/A	Native
Vascular Plant	Poaceae	*Ischaemum byrone*	Hilo ischaemum	Present in Park	Rare	N/A	Native
Vascular Plant	Poaceae	*Lolium multiflorum*	Italian ryegrass	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Melinis minutiflora*	Molasses grass	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Poaceae	*Melinis repens*	Natal grass, natal redtop	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Poaceae	*Oplismenus hirtellus*	Nasketgrass, honohono, honohono kukui	Present in Park	Common	N/A	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Poaceae	*Panicum konaense*	Kona panicgrass	Present in Park	Rare	N/A	Native
Vascular Plant	Poaceae	*Panicum maximum*	Guinea grass	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Panicum nephelophilum*	Konakona	Present in Park	Rare	N/A	Native
Vascular Plant	Poaceae	*Panicum repens*	Quack grass	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Panicum tenuifolium*	Mountain pili	Present in Park	Common	N/A	Native
Vascular Plant	Poaceae	*Panicum xerophilum*	He`upueo	Probably Present	N/A	N/A	Native
Vascular Plant	Poaceae	*Paspalum conjugatum*	Hilo grass, mau`u Hilo, sour paspalum	Present in Park	Common	N/A	Nonnative
Vascular Plant	Poaceae	*Paspalum dilatatum*	Dallis grass	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Poaceae	*Paspalum notatum*	Bahia grass, bahiagrass	Present in Park	Rare	N/A	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Poaceae	*Paspalum paniculatum*	Panic grass	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Poaceae	*Paspalum scrobiculatum*	Mau`u laiki	Present in Park	Common	N/A	Native
Vascular Plant	Poaceae	*Paspalum urvillei*	Vasey grass	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Poaceae	*Phleum pratense*	Common timothy, Timothy	Probably Present	NA	N/A	Nonnative
Vascular Plant	Poaceae	*Phyllostachys nigra*	Black bamboo	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Poaceae	*Poa annua*	Annual blue grass, Annual bluegrass, Walkgrass	Present in Park	Common	N/A	Nonnative
Vascular Plant	Poaceae	*Poa pratensis*	Kentucky bluegrass	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Polypogon monspeliensis*	Montpelier Beardgrass, Rabbitfoot grass	Probably Present	N/A	N/A	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Poaceae	*Rytidosperma semiannulare*	Tasmanian wallaby grass	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Sacciolepis indica*	Glenwood grass	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Schizachyrium condensatum*	Beardgrass, Bush beardgrass, Little bluestem	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Poaceae	*Setaria palmifolia*	Palm grass	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Poaceae	*Setaria parviflora*	Mau`u Kaleponi, perennial foxtail, yellow foxtail	Present in Park	Common	N/A	Nonnative
Vascular Plant	Poaceae	*Setaria sphacelata*	African bristlegrass	Probably Present	N/A	N/A	Nonnative
Vascular Plant	Poaceae	*Sorghum bicolor*	Black amber, Broomcorn, Broom-corn	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Poaceae	*Sorghum drummondii*	–	Present in Park	Rare	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Poaceae	*Sporobolus africanus*	African dropseed, Smutgrass	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Poaceae	*Sporobolus diander*	Indian dropseed	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Poaceae	*Sporobolus indicus*	Indian dropseed	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Poaceae	*Sporobolus*	Dropseed	Present in Park	Unknown	N/A	Nonnative
Vascular Plant	Poaceae	*Stenotaphrum secundatum*	\`Aki\`aki haole, buffalo grass, manienie \`aki\`aki	Present in Park	Common	N/A	Nonnative
Vascular Plant	Poaceae	*Trisetum glomeratum*	He\`upueo, mountain pili	Present in Park	Uncommon	N/A	Native
Vascular Plant	Poaceae	*Vulpia bromoides*	Brome fescue, Brome six-weeks grass, Desert fescue	Present in Park	Common	N/A	Nonnative
Vascular Plant	Poaceae	*Vulpia myuros*	Foxtail fescue, Rattail fescue, Rat-tail fescue	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Caprifoliaceae	*Abelia X grandiflora*	Glossy abelia	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Caprifoliaceae	*Lonicera japonica*	Honekakala	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Caprifoliaceae	*Lonicera periclymenum*	Woodpine	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Caprifoliaceae	*Sambucus mexicana*	Mexican elder	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Ebenaceae	*Diospyros kaki*	Japanese persimmon	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Ebenaceae	*Diospyros sandwicensis*	Lama	Present in Park	Uncommon	N/A	Native
Vascular Plant	Ebenaceae	*Diospyros virginiana*	Common persimmon, Eastern persimmon	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Sapotaceae	*Mimusops elengi*	Spanish cherry	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Sapotaceae	*Pouteria sandwicensis*	\`Ala\`a, \`aulu, \`ela\`a	Present in Park	Rare	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Epacridaceae	*Leptecophylla tameiameiae*	Pūkiawe	Present in Park	Abundant	N/A	Native
Vascular Plant	Ericaceae	*Rhododendron laetum*	Vireya rhododendron	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Ericaceae	*Rhododendron macrosepalum*	Indian azalea	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Ericaceae	*Rhododendron scabrum* ssp.*amanoi*	–	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Ericaceae	*Vaccinium calycinum*	‘Ohelo, ohelo, ohelo kau laau	Present in Park	Common	N/A	Native
Vascular Plant	Ericaceae	*Vaccinium dentatum*	Ohelo	Probably Present	N/A	N/A	Native
Vascular Plant	Ericaceae	*Vaccinium reticulatum*	‘Ohelo, ohelo, ohelo ai	Present in Park	Abundant	N/A	Native
Vascular Plant	Buxaceae	*Buxus sempervirens*	Common box	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Euphorbiaceae	*Aleurites moluccana*	Candlenut, kuikui, kukui	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Euphorbiaceae	*Antidesma platyphyllum* var. *platyphyllum*	Haʻamaile, Hame, Hamehame	Present in Park	Uncommon	N/A	Native
Vascular Plant	Euphorbiaceae	*Antidesma pulvinatum*	Haʻa, haʻamaile, hamehame	Present in Park	Rare	N/A	Native
Vascular Plant	Euphorbiaceae	*Chamaesyce celastroides* var. *amplectens*	ʻAkoko, koko	Present in Park	Rare	N/A	Native
Vascular Plant	Euphorbiaceae	*Chamaesyce hirta*	Garden spurge, Hairy spurge, Koko kahiki	Present in Park	Common	N/A	Nonnative
Vascular Plant	Euphorbiaceae	*Chamaesyce hypericifolia*	Graceful spurge	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Euphorbiaceae	*Chamaesyce hyssopifolia*	Spurge	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Euphorbiaceae	*Chamaesyce prostrata*	Prostrate spurge	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Euphorbiaceae	*Chamaesyce thymifolia*	Gulf sandmat	Present in Park	Common	N/A	Nonnative
Vascular Plant	Euphorbiaceae	*Euphorbia peplus*	Petty spurge	Present in Park	Rare	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Euphorbiaceae	*Euphorbia pulcherrima*	Poinsetta, poinsettia	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Euphorbiaceae	*Macaranga tanarius*	Bingabing	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Euphorbiaceae	*Phyllanthus debilis*	Niruri	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Euphorbiaceae	*Ricinus communis*	Ka`apeha, kamakou, koli	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Abrus precatorius*	Bead vine, Black-eyed susan, Pukiawe	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Acacia confusa*	Formosa koa	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Acacia koa*	Koa	Present in Park	Abundant	N/A	Native
Vascular Plant	Fabaceae	*Acacia mearnsii*	Black wattle	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Acacia melanoxylon*	Australian blackwood, Blackwood acacia	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Fabaceae	*Caesalpinia bonduc*	Gray nickers, hihikolo, Kakalaioa	Present in Park	Uncommon	N/A	Native
Vascular Plant	Fabaceae	*Canavalia cathartica*	Maunaloa	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Canavalia hawaiiensis*	‘Awikiwiki, awikiwiki	Present in Park	Rare	N/A	Native
Vascular Plant	Fabaceae	*Ceratonia siliqua*	St. John's bread	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Fabaceae	*Chamaecrista nictitans* ssp. *patellaria* var. *glabrata*	Lauki	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Fabaceae	*Crotalaria assamica*	Rattlepod	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Crotalaria incana*	Fuzzy rattlepod, Kolomona, Kukaehoki	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Crotalaria lanceolata*	Rattlepod	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Fabaceae	*Crotalaria micans*	Caracas rattlebox	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Fabaceae	*Crotalaria pallida*	Kolomona, Pikakani, Smooth rattlepod	Present in Park	Common	N/A	Nonnative
Vascular Plant	Fabaceae	*Crotalaria retusa*	Rattleweed	Present in Park	Common	N/A	Nonnative
Vascular Plant	Fabaceae	*Crotalaria spectabilis*	Kolomona	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Fabaceae	*Desmodium cajanifolium*	Tropical ticktrefoil	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Desmodium incanum*	Ka`imi, kaimi, Spanish clover	Probably Present	N/A	N/A	Nonnative
Vascular Plant	Fabaceae	*Desmodium intortum*	Greenleaf tick trefoil, greenleaf ticktrefoil	Present in Park	Common	N/A	Nonnative
Vascular Plant	Fabaceae	*Desmodium sandwicense*	Chili clover, Kikania pipili, Pilipili `ula	Present in Park	Common	N/A	Nonnative
Vascular Plant	Fabaceae	*Desmodium* sp.[1]	–	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Desmodium tortuosum*	Florida beggarweed	Present in Park	Uncommon	N/A	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Fabaceae	*Desmodium triflorum*	Threeflower ticktrefoil	Present in Park	Common	N/A	Nonnative
Vascular Plant	Fabaceae	*Dioclea wilsonii*	Maunaloa, Sea bean	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Erythrina sandwicensis*	Wiliwili	Present in Park	Rare	N/A	Native
Vascular Plant	Fabaceae	*Falcataria moluccana*	Peacocksplume	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Fabaceae	*Indigofera suffruticosa*	\`Iniko, \`inikoa, iniko	Present in Park	Common	N/A	Nonnative
Vascular Plant	Fabaceae	*Lathyrus odoratus*	Sweetpea	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Leucaena leucocephala*	Ekoa, koa haole, lilikoa	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Lotus subbiflorus*	Hairy bird's-foot trefoil	Present in Park	Common	N/A	Nonnative
Vascular Plant	Fabaceae	*Lotus uliginosus*	–	Present in Park	Uncommon	N/A	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Fabaceae	*Lupinus hybridus*	Lupine	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Fabaceae	*Macroptilium atropurpureum*	Purple bushbean, Purple bush-bean	Present in Park	Common	N/A	Nonnative
Vascular Plant	Fabaceae	*Macroptilium lathyroides*	Cow pea, Wild bean	Present in Park	Common	N/A	Nonnative
Vascular Plant	Fabaceae	*Medicago lupulina*	Black medic, black medic clover, black medick	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Medicago polymorpha*	Bur clover, burclover, California burclover	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Melilotus indica*	Clover	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Mimosa pudica* var. *unijuga*	Shameplant	Present in Park	Common	N/A	Nonnative
Vascular Plant	Fabaceae	*Mucuna gigantea* ssp. *gigantea*	Ka\`e\`e, Ka\`e\`e\`e, Kaee	Present in Park	Rare	N/A	Native
Vascular Plant	Fabaceae	*Neonotonia wightii*	Perennial soybean	Present in Park	Common	N/A	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Fabaceae	*Pithecellobium dulce*	`Opiuma, Manila tamarind	Probably Present	N/A	N/A	Nonnative
Vascular Plant	Fabaceae	*Prosopis pallida*	Algaroba, mesquite	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Fabaceae	*Pueraria montana*var. *lobata*	Acha, aka, Japanese arrowroot	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Fabaceae	*Samanea saman*	‘Ohai, Monkeypod, Ohai	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Fabaceae	*Senna gaudichaudii*	Heuhiuhi, Kalamona, Kolomona	Present in Park	Rare	N/A	Native
Vascular Plant	Fabaceae	*Senna occidentalis*	`Au`auko‘i, ‘Auko‘i, Coffee senna	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Senna pendula* var. *advena*	Valamuerto	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Senna septemtrionalis*	Kalamona, Kolomona	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Sesbania tomentosa*	‘Ohai, Ohai	Present in Park	Rare	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Fabaceae	*Sophora chrysophylla*	Māmane	Present in Park	Common	N/A	Native
Vascular Plant	Fabaceae	*Stylosanthes scabra*	Pencilflower	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Stylosanthes viscosa*	Poorman's friend	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Tephrosia purpurea* var. *purpurea*	‘Ahuhu, ‘Auhola, ‘Auhuhu	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Trifolium arvense* var. *arvense*	Rabbit-foot clover	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Trifolium dubium*	Small hop-clover	Present in Park	Common	N/A	Nonnative
Vascular Plant	Fabaceae	*Trifolium pratense var. sativum*	Red clover	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Trifolium repens* var. *repens*	White clover	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Fabaceae	*Vicia sativa* ssp. *nigra*	Common vetch, Spring vetch	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Fabaceae	*Vigna marina*	Beach pea, Lemuomakili, Mohihihi	Present in Park	Common	N/A	Native
Vascular Plant	Fabaceae	*Vigna speciosa*	Snail maunaloa	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Fabaceae	*Wisteria sinensis*	Chinese wisteria	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Fagaceae	*Castanea dentata*	American chestnut	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Fagaceae	*Quercus agrifolia*	California live oak	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Fagaceae	*Quercus suber*	Cork oak	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Apocynaceae	*Alyxia stellata*	–	Present in Park	Common	N/A	Native
Vascular Plant	Apocynaceae	*Catharanthus roseus*	kihapai	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Apocynaceae	*Ochrosia haleakalae*	Holei	Present in Park	Rare	NA	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Apocynaceae	*Rauvolfia sandwicensis*	Hao	Present in Park	Rare	NA	Native
Vascular Plant	Asclepiadaceae	*Asclepias curassavica*	Butterfly weed, Lauhele, Laulele	Present in Park	Common	NA	Nonnative
Vascular Plant	Asclepiadaceae	*Asclepias physocarpa*	Balloon plant	Present in Park	Common	NA	Nonnative
Vascular Plant	Gentianaceae	*Centaurium erythraea* ssp. *erythraea*	Bitter herb, European centaury	Present in Park	Common	NA	Nonnative
Vascular Plant	Loganiaceae	*Labordia hedyosmifolia*	Kamakahala	Present in Park	Uncommon	NA	Native
Vascular Plant	Loganiaceae	*Labordia hirtella*	Kamakahala	Present in Park	Rare	NA	Native
Vascular Plant	Balsaminaceae	*Impatiens walleriana*	Impatiens, Patient Lucy	Present in Park	Uncommon	NA	Nonnative
Vascular Plant	Geraniaceae	*Erodium cicutarium*	Alfilaria, pin clover	Present in Park	Uncommon	NA	Nonnative
Vascular Plant	Geraniaceae	*Geranium cuneatum* ssp. *cuneatum*	Nohoanu	Present in Park	Rare	NA	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Geraniaceae	*Geranium cuneatum* ssp. *hypoleucum*	Hinahina, nohoanu	Present in Park	Rare	NA	Native
Vascular Plant	Geraniaceae	*Geranium homeanum*	Australasian geranium	Present in Park	Common	NA	Nonnative
Vascular Plant	Geraniaceae	*Pelargonium graveolens*	Sweet scented geranium	Present in Park	Uncommon	NA	Nonnative
Vascular Plant	Geraniaceae	*Pelargonium X hortorum*	Zonal geranium	Present in Park	Uncommon	NA	Nonnative
Vascular Plant	Oxalidaceae	*Oxalis corniculata*	`Ihi `ai, `Ihi `awa, `Ihi maka `ula	Present in Park	Common	NA	Nonnative
Vascular Plant	Oxalidaceae	*Oxalis debilis*	`Ihi pehu, Pink wood sorrel	Present in Park	Rare	NA	Nonnative
Vascular Plant	Tropaeolaceae	*Tropaeolum majus*	Pohe haole	Present in Park	Uncommon	NA	Nonnative
Vascular Plant	Haloragaceae	*Gonocarpus chinensis* ssp. *verrucosus*	Chinese raspwort	Present in Park	Rare	NA	Nonnative
Vascular Plant	Hamamelidaceae	*Liquidambar styraciflua*	Sweetgum	Present in Park	Rare	NA	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Juncaceae	*Juncus bufonius*	Common rush	Present in Park	Common	NA	Nonnative
Vascular Plant	Juncaceae	*Juncus effusus*	Japanese mat rush	Present in Park	Uncommon	NA	Nonnative
Vascular Plant	Juncaceae	*Juncus ensifolius*	Dwordleaf rush, Three-stamened rush	Present in Park	Common	NA	Nonnative
Vascular Plant	Juncaceae	*Juncus planifolius*	Rush	Present in Park	Common	NA	Nonnative
Vascular Plant	Juncaceae	*Juncus polyanthemos*	Manyflower rush	Present in Park	Common	NA	Nonnative
Vascular Plant	Juncaceae	*Juncus tenuis*	Field rush, Path rush, Poverty rush	Present in Park	Common	NA	Nonnative
Vascular Plant	Juncaceae	*Luzula hawaiiensis* var. *hawaiiensis*	Wood rush	Present in Park	Common	NA	Native
Vascular Plant	Boraginaceae	*Cordia subcordata*	Kou	Present in Park	Uncommon	NA	Native
Vascular Plant	Boraginaceae	*Cynoglossum amabile*	Chinese forget-me-not	Present in Park	Rare	NA	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Boraginaceae	*Heliotropium amplexicaule*	Clasping heliotrope	Present in Park	Rare	NA	Nonnative
Vascular Plant	Boraginaceae	*Heliotropium curassavicum*	Kipukai, Nena, Po`opo`ohina	Present in Park	Rare	NA	Native
Vascular Plant	Boraginaceae	*Myosotis azorica*	Forget-me-not	Present in Park	Uncommon	NA	Nonnative
Vascular Plant	Boraginaceae	*Tournefortia argentea*	Tree heliotrope	Present in Park	Uncommon	NA	Nonnative
Vascular Plant	Lamiaceae	*Hyptis pectinata*	Comb hyptis	Present in Park	Common	NA	Nonnative
Vascular Plant	Lamiaceae	*Lavandula angustifolia*	English lavender	Present in Park	Rare	NA	Nonnative
Vascular Plant	Lamiaceae	*Leonurus sibiricus*	Lion's tail	Present in Park	Rare	NA	Nonnative
Vascular Plant	Lamiaceae	*Marrubium vulgare*	Common horehound	Present in Park	Unknown	NA	Nonnative
Vascular Plant	Lamiaceae	*Mentha X spicata*	Kepemineka, Spearmint	Present in Park	Uncommon	NA	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Lamiaceae	*Ocimum basilicum*	Common basil, Ki 'a'ala, Ki paoa	Present in Park	Rare	NA	Nonnative
Vascular Plant	Lamiaceae	*Phyllostegia ambigua*	Mountain phyllostegia	Present in Park	Rare	NA	Native
Vascular Plant	Lamiaceae	*Phyllostegia floribunda*	Hawai'i phyllostegia	Present in Park	Rare	NA	Native
Vascular Plant	Lamiaceae	*Phyllostegia macrophylla*	Largeleaf phyllostegia	Probably Present	NA	NA	Native
Vascular Plant	Lamiaceae	*Phyllostegia parviflora* var. *glabriuscula*	Smallflower phyllostegia	Present in Park	Rare	NA	Native
Vascular Plant	Lamiaceae	*Phyllostegia* sp.[1]	–	Present in Park	Rare	NA	Native
Vascular Plant	Lamiaceae	*Phyllostegia vestita*	Streambed phyllostegia	Present in Park	Rare	NA	Native
Vascular Plant	Lamiaceae	*Plectranthus parviflorus*	\`Ala\`ala wai nui, \`Ala\`ala wai nui pua ki, \`Ala\`ala wai nui wahine	Present in Park	Uncommon	NA	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Lamiaceae	*Prunella vulgaris*	Heal-all	Present in Park	Uncommon	NA	Nonnative
Vascular Plant	Lamiaceae	*Rosmarinus officinalis*	Rosemary	Present in Park	Rare	NA	Nonnative
Vascular Plant	Lamiaceae	*Salvia coccinea*	Lililehua, Scarlet sage, Texas sage	Present in Park	Uncommon	NA	Nonnative
Vascular Plant	Lamiaceae	*Salvia occidentalis*	West Indian sage	Present in Park	Uncommon	NA	Nonnative
Vascular Plant	Lamiaceae	*Stachys arvensis*	Staggerweed	Present in Park	Rare	NA	Nonnative
Vascular Plant	Lamiaceae	*Stenogyne calaminthoides*	Bog stenogyne	Present in Park	Common	NA	Native
Vascular Plant	Lamiaceae	*Stenogyne macrantha*	Hawai'i stenogyne	Present in Park	Rare	NA	Native
Vascular Plant	Lamiaceae	*Stenogyne rugosa*	Maohiohi	Present in Park	Common	NA	Native
Vascular Plant	Lamiaceae	*Stenogyne scrophularioides*	Mohihi	Present in Park	Rare	NA	Native

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Lamiaceae	*Stenogyne sessilis*	Fuzzyflower stenogyne	Present in Park	Uncommon	NA	Native
Vascular Plant	Lamiaceae	*Stenogyne* sp. [1]	–	Present in Park	Unknown	NA	Native
Vascular Plant	Verbenaceae	*Lantana camara*	La‘a kalakala, Lakala, Lantana, Lanakanamikinolia hihiu	Present in Park	Common	N/A	Nonnative
Vascular Plant	Verbenaceae	*Stachytarpheta australis*	Oi, Owi	Present in Park	Common	N/A	Nonnative
Vascular Plant	Verbenaceae	*Stachytarpheta cayennensis*	Blue snakeweed, Bluetop, Cayenne porterweed	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Verbenaceae	*Stachytarpheta jamaicensis*	Jamaica vervain, Oi, owi	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Verbenaceae	*Verbena litoralis*	Ha`uoi, Ha`uowi, Oi	Present in Park	Common	N/A	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Lauraceae	*Cassytha filiformis*	Kauna`oa malolo, kauna`oa pehu, kauna`oa uka	Present in Park	Common	N/A	Native
Vascular Plant	Lauraceae	*Persea americana*	Avocado	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Agavaceae	*Agave americana*	Centuryplant	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Agavaceae	*Agave sisalana*	Malina, sisal	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Agavaceae	*Furcraea foetida*	Mauritius hemp	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Agavaceae	*Yucca smalliana*	Spanish dagger, yucca	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Aloeaceae	*Aloe vera*	Aloe	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Dioscoreaceae	*Dioscorea alata*	Uhi	Present in Park	Rare	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Dioscoreaceae	*Dioscorea pentaphylla*	Pi`a, pi`a Hawai`I, pi`ia	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Iridaceae	*Aristea gerrardii*	Gerrard's aristea	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Iridaceae	*Crocosmia X crocosmiiflora*	Montbretia	Present in Park	Common	N/A	Nonnative
Vascular Plant	Iridaceae	*Dietes iridioides*	–	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Iridaceae	*Sisyrinchium acre*	Mau`u ho`ula `ili, mau`u la`ili	Present in Park	Rare	N/A	Native
Vascular Plant	Iridaceae	*Sisyrinchium exile*	–	Present in Park	Common	N/A	Nonnative
Vascular Plant	Liliaceae	*Asparagus densiflorus*	Asparagus fern	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Liliaceae	*Asparagus* sp.[1]	Asparagus fern	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Liliaceae	*Astelia menziesiana*	Kaluaha, pa`iniu, painiu	Present in Park	Common	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Liliaceae	*Chlorophytum comosum*	–	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Liliaceae	*Clivia miniata*	Clivia, kaffir lily	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Liliaceae	*Cordyline fruticosa*	Ki, ti	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Liliaceae	*Crinum X powellii*	Powell's swamp lily	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Liliaceae	*Dianella sandwicensis*	`Uki, uki	Present in Park	Uncommon	N/A	Native
Vascular Plant	Liliaceae	*Dracaena fragrans*	Fragrant dracaena	Probably Present	N/A	N/A	Nonnative
Vascular Plant	Liliaceae	*Dracaena marginata*	Money tree	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Liliaceae	*Hemerocallis aurantiaca*	Day lily	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Liliaceae	*Hemerocallis fulva*	Orange day lily, orange daylily, tawny daylily	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Liliaceae	*Hippeastrum* x *johnsonii*	St. Joseph's lily	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Liliaceae	*Pleomele hawaiiensis*	Hala pepe, ie‘ie	Present in Park	Rare	N/A	Native
Vascular Plant	Liliaceae	*Zephyranthes grandiflora*	Rosepink zephyrlily	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Smilacaceae	*Smilax melastomifolia*	Aka‘awa, hoi kuahiwi, pi`oi	Present in Park	Uncommon	N/A	Native
Vascular Plant	Lycopodiaceae	*Huperzia erosa*	Fir moss	Present in Park	Rare	N/A	Native
Vascular Plant	Lycopodiaceae	*Huperzia filiformis*	Stringleaf clubmoss	Present in Park	Rare	N/A	Native
Vascular Plant	Lycopodiaceae	*Huperzia phyllantha*	Daggerleaf clubmoss	Present in Park	Uncommon	N/A	Native
Vascular Plant	Lycopodiaceae	*Lycopodiella cernua*	Wawae`iole	Present in Park	Common	N/A	Native
Vascular Plant	Lycopodiaceae	*Lycopodium venustulum*	Hairtip clubmoss	Present in Park	Uncommon	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Lycopodiaceae	*Lycopodium venustulum* var. *verticale*	Wawae`iole	Present in Park	Uncommon	N/A	Native
Vascular Plant	Annonaceae	*Annona cherimola*	Cherimoya	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Magnoliaceae	*Magnolia grandiflora*	Southern magnolia	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Malvaceae	*Abutilon grandifolium*	Hairy abutilon, ma`o, mao	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Malvaceae	*Hibiscadelphus giffardianus*	Hau kuahiwi	Present in Park	Rare	N/A	Native
Vascular Plant	Malvaceae	*Hibiscadelphus X puakuahiwi*	Hau kuahiwi	Present in Park	Rare	N/A	Native
Vascular Plant	Malvaceae	*Hibiscus brackenridgei*	Ma‘o hau hele	Present in Park	Rare	N/A	Native
Vascular Plant	Malvaceae	*Hibiscus rosa-sinensis*	Red hibiscus	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Malvaceae	*Hibiscus tiliaceus*	Hau	Present in Park	Uncommon	N/A	Native
Vascular Plant	Malvaceae	*Kokia drynarioides*	Hau-hele`ula, hau-hele'ula, hawaii tree cotton	Present in Park	Rare	N/A	Native
Vascular Plant	Malvaceae	*Malva parviflora*	Cheese weed	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Malvaceae	*Malvastrum coromandelianum* ssp. *coromandelianum*	False mallow	Present in Park	Common	N/A	Nonnative
Vascular Plant	Malvaceae	*Modiola caroliniana*	Carolina bristlemallow, Carolina modiola	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Malvaceae	*Sida acuta* ssp. *carpinifolia*	–	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Malvaceae	*Sida fallax*	‘Ilima, ilima	Present in Park	Uncommon	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Malvaceae	*Sida rhombifolia*	Arrowleaf sida, cuban jute, Cuban-jute	Present in Park	Common	N/A	Nonnative
Vascular Plant	Malvaceae	*Thespesia populnea*	Milo	Present in Park	Uncommon	N/A	Native
Vascular Plant	Sterculiaceae	*Melochia umbellata*	Hierba del soldado, melochia	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Sterculiaceae	*Waltheria indica*	\`Ala\`ala pu loa, \`uhaloa, hi\`aloa	Present in Park	Common	N/A	Native
Vascular Plant	Tiliaceae	*Triumfetta semitriloba*	Sacramento burr	Present in Park	Unknown	N/A	Nonnative
Vascular Plant	Marattiaceae	*Marattia douglasii*	Kapua\`ilio, pala	Present in Park	Rare	N/A	Native
Vascular Plant	Myricaceae	*Morella faya*	Firetree, faya tree	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Lythraceae	*Cuphea carthagenensis*	Colombian cuphea, tarweed	Present in Park	Common	N/A	Nonnative
Vascular Plant	Lythraceae	*Cuphea hyssopifolia*	False heather	Present in Park	Rare	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Lythraceae	*Lagerstroemia indica*	Crapemyrtle	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Lythraceae	*Lythrum maritimum*	Ninika, pukamole lau li`I, pukamole lau nui	Present in Park	Common	N/A	Nonnative
Vascular Plant	Melastomataceae	*Clidemia hirta*	Kaurasiga, Koster's curse, kui	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Melastomataceae	*Heterocentron subtriplinervium*	Pearlflower	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Melastomataceae	*Melastoma candidum*	Asian melastome, Indian rhododendron, Malabar melastome	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Melastomataceae	*Tibouchina herbacea*	Cane ti, glorybush, herbaceous glorytree	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Melastomataceae	*Tibouchina urvilleanavar. urvilleana*	Lasiandra, princess flower, Tibouchina	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Myrtaceae	*Eucalyptus globulus*	Blue gum	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Myrtaceae	*Eucalyptus robusta*	Robust eucalyptus, swampmahogany	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Myrtaceae	*Feijoa sellowiana*	Feijoa	Probably Present	NA	N/A	Nonnative
Vascular Plant	Myrtaceae	*Melaleuca quinquenervia*	Paperbark	Probably Present	NA	N/A	Nonnative
Vascular Plant	Myrtaceae	*Metrosideros polymorpha*	‘Ohi‘a	Present in Park	Common	N/A	Native
Vascular Plant	Myrtaceae	*Metrosideros polymorpha* var. *glaberrima*	‘Ohi‘a, ‘ōhi‘a lehua, lehua	Present in Park	Common	N/A	Native
Vascular Plant	Myrtaceae	*Metrosideros polymorpha* var. *incana*	‘Ohi‘a, ‘ōhi‘a lehua, lehua	Present in Park	Abundant	N/A	Native
Vascular Plant	Myrtaceae	*Metrosideros polymorpha* var. *macrophylla*	‘Ohi‘a, ‘ōhi‘a lehua, lehua	Present in Park	Abundant	N/A	Native
Vascular Plant	Myrtaceae	*Metrosideros polymorpha* var. *polymorpha*	‘Ohi‘a, ‘ōhi‘a lehua, lehua	Present in Park	Abundant	N/A	Native
Vascular Plant	Myrtaceae	*Psidium cattleianum*	Guava, waiawi, waiawi \`ula\`ula	Present in Park	Abundant	N/A	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Myrtaceae	*Psidium guajava*	Guava, kuawa, puawa	Present in Park	Common	N/A	Nonnative
Vascular Plant	Myrtaceae	*Syzygium cumini*	Jambolan plum	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Myrtaceae	*Syzygium jambos*	‘Ohi‘a loke, rose apple	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Onagraceae	*Epilobium billardierianum* ssp. *cinereum*	Aboriginal willowherb	Present in Park	Common	N/A	Nonnative
Vascular Plant	Onagraceae	*Epilobium ciliatum*	Willowherb	Present in Park	Common	N/A	Nonnative
Vascular Plant	Onagraceae	*Fuchsia magellanica*	Earring flower, kulapepeiao	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Onagraceae	*Fuchsia paniculata*	Shrubby fuchsia	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Onagraceae	*Ludwigia palustris*	Marsh purslane	Present in Park	Common	N/A	Nonnative
Vascular Plant	Onagraceae	*Oenothera laciniata*	Evening primrose	Present in Park	Uncommon	N/A	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Onagraceae	*Oenothera stricta* ssp. *stricta*	Chilean evening primrose, evening primrose	Present in Park	Common	N/A	Nonnative
Vascular Plant	Thymelaeaceae	*Wikstroemia phillyreifolia*	‘Akia, akia, kauhi	Present in Park	Common	N/A	Native
Vascular Plant	Thymelaeaceae	*Wikstroemia pulcherrima*	‘Akia, akia, kauhi	Present in Park	Uncommon	N/A	Native
Vascular Plant	Thymelaeaceae	*Wikstroemia sandwicensis*	‘Akia, akia, kauhi	Present in Park	Common	N/A	Native
Vascular Plant	Ophioglossaceae	*Ophioderma pendulum* ssp. *falcatum*	–	Present in Park	Uncommon	N/A	Native
Vascular Plant	Ophioglossaceae	*Ophioglossum nudicaule*	Least adderstongue	Present in Park	Rare	N/A	Native
Vascular Plant	Ophioglossaceae	*Ophioglossum petiolatum*	Longstem adderstongue	Present in Park	Rare	N/A	Native
Vascular Plant	Ophioglossaceae	*Ophioglossum polyphyllum*	–	Present in Park	Rare	N/A	Native
Vascular Plant	Orchidaceae	*Anoectochilus sandvicensis*	Jewel orchid	Present in Park	Rare	N/A	Native

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Orchidaceae	*Arundina graminifolia*	Bamboo orchid	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Orchidaceae	*Cymbidium* sp.[1]	–	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Orchidaceae	*Cymbidium* sp.[2]	–	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Orchidaceae	*Epidendrum X obrienianum*	O'brien's star orchid	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Orchidaceae	*Liparis hawaiensis*	‘Awapuhi a kanaloa, awapuhiakanaloa	Present in Park	Rare	N/A	Native
Vascular Plant	Orchidaceae	*Phaius tankarvilleae*	Chinese ground, nun's hood, nun's orchid	Present in Park	Common	N/A	Nonnative
Vascular Plant	Orchidaceae	*Spathoglottis plicata*	Malayan ground orchid	Present in Park	Common	N/A	Nonnative
Vascular Plant	Pandanaceae	*Freycinetia arborea*	\`Ie, \`ie\`ie, ieie	Present in Park	Common	N/A	Native
Vascular Plant	Pandanaceae	*Pandanus tectorius*	Hala, pu hala	Present in Park	Uncommon	N/A	Native

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Papaveraceae	*Argemone glauca* var. *decipiens*	Kala, naule, pokalakala	Present in Park	Uncommon	N/A	Native
Vascular Plant	Papaveraceae	*Argemone glauca* var. *glauca*	Pua kala	Present in Park	Rare	N/A	Native
Vascular Plant	Papaveraceae	*Eschscholzia californica*	California goldenpoppy, California poppy	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Araucariaceae	*Agathis macrophylla*	Fiji kauri	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Araucariaceae	*Agathis* sp.[1]	Kauri	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Araucariaceae	*Araucaria columnaris*	Cook pine	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Araucariaceae	*Araucaria heterophylla*	Norfolk island pine	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Cupressaceae	*Cupressus macrocarpa*	Monterey cypress	Present in Park	Rare	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Cupressaceae	*Cupressus* sp.[1]	–	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Cupressaceae	*Juniperus bermudiana*	–	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Cupressaceae	*Platycladus orientalis*	Oriental arborvitae	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Pinaceae	*Pinus caribaea*	Slash pine	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Pinaceae	*Pinus patula*	Mexican weeping pine	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Pinaceae	*Pinus pinea*	Italian stone pine	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Pinaceae	*Pinus radiata*	Insignis pine, Monterey pine	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Pinaceae	*Pinus* sp.[1]	Pine	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Pinaceae	*Pinus taeda*	Loblolly pine	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Podocarpaceae	*Dacrycarpus imbricatus*	–	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Taxodiaceae	*Cryptomeria japonica*	Japanese cedar	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Taxodiaceae	*Cunninghamia lanceolata*	Chinese fir	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Taxodiaceae	*Metasequoia glyptostroboides*	Dawn redwood	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Taxodiaceae	*Sequoia sempervirens*	California redwood, coast redwood, redwood	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Piperaceae	*Peperomia blanda var. floribunda*	–	Present in Park	Common	N/A	Native
Vascular Plant	Piperaceae	*Peperomia cookiana*	Weakstem peperomia	Present in Park	Common	N/A	Native
Vascular Plant	Piperaceae	*Peperomia hypoleuca*	\`Ala\`alawainui	Present in Park	Common	N/A	Native
Vascular Plant	Piperaceae	*Peperomia latifolia*	Hawai'i peperomia	Probably Present	N/A	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Piperaceae	*Peperomia macraeana*	Pinninerve peperomia	Present in Park	Uncommon	N/A	Native
Vascular Plant	Piperaceae	*Peperomia membranacea*	Woodland peperomia	Present in Park	Uncommon	N/A	Native
Vascular Plant	Piperaceae	*Peperomia remyi*	Valley peperomia	Present in Park	Rare	N/A	Native
Vascular Plant	Piperaceae	*Peperomia* sp.1	–	Present in Park	Unknown	N/A	Native
Vascular Plant	Piperaceae	*Peperomia tetraphylla*	Acorn peperomia	Present in Park	Uncommon	N/A	Native
Vascular Plant	Plantaginaceae	*Plantago aristata*	Bracted plantain	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Plantaginaceae	*Plantago australis* ssp. *hirtella*	Dwarf plantain	Present in Park	Common	N/A	Nonnative
Vascular Plant	Plantaginaceae	*Plantago hawaiensis*	Laukahi, laukahi kuahiwi	Present in Park	Rare	N/A	Native
Vascular Plant	Plantaginaceae	*Plantago lanceolata*	Buckhorn, English plantain	Present in Park	Abundant	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Plantaginaceae	*Plantago major*	Broad-leaved plantain, kuhekilil, laukahi	Present in Park	Common	N/A	Nonnative
Vascular Plant	Plumbaginaceae	*Plumbago auriculata*	Cape leadwort	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Plumbaginaceae	*Plumbago zeylanica*	\`Ilie\`e, \`ilihe\`e, hilie\`e	Present in Park	Rare	N/A	Native
Vascular Plant	Polygalaceae	*Polygala paniculata*	Milkwort	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Polygonaceae	*Persicaria capitata*	–	Present in Park	Common	N/A	Nonnative
Vascular Plant	Polygonaceae	*Persicaria punctata*	–	Present in Park	Common	N/A	Nonnative
Vascular Plant	Polygonaceae	*Rumex acetosella*	Sheep sorrel	Present in Park	Common	N/A	Nonnative
Vascular Plant	Polygonaceae	*Rumex giganteus*	Uhauhako	Present in Park	Rare	N/A	Native
Vascular Plant	Polygonaceae	*Rumex obtusifolius ssp. obtusifolius*	Bitter dock	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Polygonaceae	*Rumex skottsbergii*	Pawale	Present in Park	Uncommon	N/A	Native
Vascular Plant	Aspleniaceae	*Asplenium adiantum-nigrum*	\`Iwa\`iwa, iwa iwa	Present in Park	Common	N/A	Native
Vascular Plant	Aspleniaceae	*Asplenium aethiopicum*	\`Iwa\`iaw a Kane	Present in Park	Uncommon	N/A	Native
Vascular Plant	Aspleniaceae	*Asplenium contiguum* var. *contiguum*	Pamoho	Present in Park	Uncommon	N/A	Native
Vascular Plant	Aspleniaceae	*Asplenium excisum*	Pamoho	Present in Park	Rare	N/A	Native
Vascular Plant	Aspleniaceae	*Asplenium insiticium*	Pi\`ipi\`i lau manamana	Present in Park	Uncommon	N/A	Native
Vascular Plant	Aspleniaceae	*Asplenium kaulfussii* f. *kaulfussii*	Kuau	Present in Park	Uncommon	N/A	Native
Vascular Plant	Aspleniaceae	*Asplenium lobulatum*	Pi\`ipi\`i lau manamana	Present in Park	Common	N/A	Native
Vascular Plant	Aspleniaceae	*Asplenium macraei*	\`Iwa\`iwa lau li\`i	Present in Park	Rare	N/A	Native

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Aspleniaceae	*Asplenium monanthes*	Singlesorus spleenwort, single-sorus spleenwort	Present in Park	Rare	N/A	Native
Vascular Plant	Aspleniaceae	*Asplenium nidus*	Bird's nest fern	Present in Park	Uncommon	N/A	Native
Vascular Plant	Aspleniaceae	*Asplenium normale*	Rainforest spleenwort	Present in Park	Uncommon	N/A	Native
Vascular Plant	Aspleniaceae	*Asplenium peruvianum* var. *insulare*	–	Present in Park	Rare	N/A	Native
Vascular Plant	Aspleniaceae	*Asplenium polyodon*	Punana manu	Present in Park	Common	N/A	Native
Vascular Plant	Aspleniaceae	*Asplenium sphenotomum*	–	Present in Park	Uncommon	N/A	Native
Vascular Plant	Aspleniaceae	*Asplenium trichomanes* ssp. *densum*	\`Oali\`i	Present in Park	Common	N/A	Native
Vascular Plant	Aspleniaceae	*Asplenium unilaterale*	Pamoho	Present in Park	Uncommon	N/A	Native
Vascular Plant	Blechnaceae	*Blechnum appendiculatum*	–	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Blechnaceae	*Sadleria cyatheoides*	‘Ama‘u	Present in Park	Common	N/A	Native
Vascular Plant	Blechnaceae	*Sadleria pallida*	‘Ama‘u	Present in Park	Common	N/A	Native
Vascular Plant	Blechnaceae	*Sadleria souleyetiana*	‘Ama‘u	Present in Park	Uncommon	N/A	Native
Vascular Plant	Cyatheaceae	*Sphaeropteris cooperi*	Australian Tree Fern	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Dennstaedtiaceae	*Hypolepis hawaiiensis* var. *hawaiiensis*	Olua	Probably Present	N/A	N/A	Native
Vascular Plant	Dennstaedtiaceae	*Lindsaea ensifolia*	Graceful necklace fern	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Dennstaedtiaceae	*Microlepia speluncae*	Palapalai	Present in Park	Rare	N/A	Native
Vascular Plant	Dennstaedtiaceae	*Microlepia strigosa*	Palai, palapalai	Present in Park	Common	N/A	Native
Vascular Plant	Dennstaedtiaceae	*Pteridium aquilinum* var. *decompositum*	Kilau	Present in Park	Abundant	N/A	Native

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Dennstaedtiaceae	*Sphenomeris chinensis*	Pala`a	Present in Park	Common	N/A	Native
Vascular Plant	Dicksoniaceae	*Cibotium chamissoi*	Meu	Present in Park	Uncommon	N/A	Native
Vascular Plant	Dicksoniaceae	*Cibotium glaucum*	Hāpuʻu pulu	Present in Park	Abundant	N/A	Native
Vascular Plant	Dicksoniaceae	*Cibotium menziesii*	Hāpuʻu ʻiʻi	Present in Park	Common	N/A	Native
Vascular Plant	Dryopteridaceae	*Athyrium microphyllum*	Akolea	Present in Park	Common	N/A	Native
Vascular Plant	Dryopteridaceae	*Cyrtomium caryotideum*	Dwarf netvein hollyfern	Present in Park	Rare	N/A	Native
Vascular Plant	Dryopteridaceae	*Cyrtomium falcatum*	Japanese netvein hollyfern	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Dryopteridaceae	*Diplazium sandwichianum*	Hoʻiʻo	Present in Park	Common	N/A	Native
Vascular Plant	Dryopteridaceae	*Dryopteris fuscoatra* var. *fuscoatra*	–	Present in Park	Uncommon	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Dryopteridaceae	*Dryopteris glabra var. glabra*	Kilau	Present in Park	Common	N/A	Native
Vascular Plant	Dryopteridaceae	*Dryopteris hawaiiensis*	Hawai'i woodfern	Present in Park	Uncommon	N/A	Native
Vascular Plant	Dryopteridaceae	*Dryopteris mauiensis*	–	Present in Park	Rare	N/A	Native
Vascular Plant	Dryopteridaceae	*Dryopteris sandwicensis*	Pacific woodfern	Present in Park	Uncommon	N/A	Native
Vascular Plant	Dryopteridaceae	*Dryopteris subbipinnata*	Ainahou Valley woodfern	Present in Park	Rare	N/A	Native
Vascular Plant	Dryopteridaceae	*Dryopteris unidentata* var. *paleaceae*	–	Present in Park	Rare	N/A	Native
Vascular Plant	Dryopteridaceae	*Dryopteris unidentata* var. *unidentata*	–	Present in Park	Rare	N/A	Native
Vascular Plant	Dryopteridaceae	*Dryopteris wallichiana*	Lau kahi	Present in Park	Common	N/A	Native
Vascular Plant	Dryopteridaceae	*Elaphoglossum aemulum*	Ekaha	Present in Park	Rare	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Dryopteridaceae	*Elaphoglossum crassifolium*	Royal tonguefern	Present in Park	Common	N/A	Native
Vascular Plant	Dryopteridaceae	*Elaphoglossum paleaceum*	Maku‘e	Present in Park	Common	N/A	Native
Vascular Plant	Dryopteridaceae	*Elaphoglossum parvisquameum*	–	Present in Park	Common	N/A	Native
Vascular Plant	Dryopteridaceae	*Elaphoglossum pellucidum*	Jeweled tonguefern	Present in Park	Uncommon	N/A	Native
Vascular Plant	Dryopteridaceae	*Elaphoglossum wawrae*	Laukahi	Present in Park	Common	N/A	Native
Vascular Plant	Dryopteridaceae	*Nephrolepis cordifolia*	Kupukupu	Present in Park	Common	N/A	Native
Vascular Plant	Dryopteridaceae	*Nephrolepis exaltata ssp. hawaiiensis*	Ni`ani`au, okupukupu	Present in Park	Common	N/A	Native
Vascular Plant	Dryopteridaceae	*Nephrolepis multiflora*	Swordfern	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Dryopteridaceae	*Nothoperanema rubiginosum*	Island lacefern	Present in Park	Common	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Dryopteridaceae	*Polystichum hillebrandii*	Ka`upu	Present in Park	Rare	N/A	Native
Vascular Plant	Dryopteridaceae	*Tectaria gaudichaudii*	Gaudichaud's halberd fern	Present in Park	Rare	N/A	Native
Vascular Plant	Gleicheniaceae	*Dicranopteris linearis*	Uluhe	Present in Park	Abundant	N/A	Native
Vascular Plant	Gleicheniaceae	*Dicranopteris linearis* f. *emarginata*	Uluhe	Present in Park	Uncommon	N/A	Native
Vascular Plant	Gleicheniaceae	*Diplopterygium pinnatum*	Uluhe lau nui	Present in Park	Rare	N/A	Native
Vascular Plant	Gleicheniaceae	*Sticherus owhyhensis*	Uluhe, unuhe	Present in Park	Uncommon	N/A	Native
Vascular Plant	Grammitidaceae	*Adenophorus hymenophylloides*	Filmy kihifern	Present in Park	Uncommon	N/A	Native
Vascular Plant	Grammitidaceae	*Adenophorus periens*	Palai lāʻau, pendant kihi fern	Present in Park	Rare	N/A	Native
Vascular Plant	Grammitidaceae	*Adenophorus pinnatifidus var. pinnatifidus*	–	Present in Park	Uncommon	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Grammitidaceae	*Adenophorus tamariscinus*	Wahine noho mauna	Present in Park	Common	N/A	Native
Vascular Plant	Grammitidaceae	*Adenophorus tamariscinus var. montanus*	–	Present in Park	Common	N/A	Native
Vascular Plant	Grammitidaceae	*Adenophorus tripinnatifidus*	Royal kihifern	Present in Park	Uncommon	N/A	Native
Vascular Plant	Grammitidaceae	*Adenophorus X carsonii*	–	Probably Present	N/A	N/A	Native
Vascular Plant	Grammitidaceae	*Grammitis hookeri*	Hooker's dwarf polypody	Present in Park	Common	N/A	Native
Vascular Plant	Grammitidaceae	*Grammitis tenella*	Kolokolo, mahinalua	Present in Park	Common	N/A	Native
Vascular Plant	Grammitidaceae	*Lellingeria saffordii*	Safford's lellingeria	Present in Park	Uncommon	N/A	Native
Vascular Plant	Hymenophyllaceae	*Callistopteris baldwinii*	–	Present in Park	Uncommon	N/A	Native
Vascular Plant	Hymenophyllaceae	*Gonocormus minutus*	Minute fern	Present in Park	Uncommon	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Hymenophyllaceae	*Gonocormus prolifer*	–	Present in Park	Rare	N/A	Native
Vascular Plant	Hymenophyllaceae	*Mecodium recurvum*	–	Present in Park	Common	N/A	Native
Vascular Plant	Hymenophyllaceae	*Sphaerocionium lanceolatum*	Palai hinahina	Present in Park	Common	N/A	Native
Vascular Plant	Hymenophyllaceae	*Sphaerocionium obtusum*	–	Present in Park	Uncommon	N/A	Native
Vascular Plant	Hymenophyllaceae	*Vandenboschia cyrtotheca*	–	Present in Park	Rare	N/A	Native
Vascular Plant	Hymenophyllaceae	*Vandenboschia davallioides*	Creeping palai, kilau, palai hihi	Present in Park	Common	N/A	Native
Vascular Plant	Hymenophyllaceae	*Vandenboschia draytoniana*	Limu kau la'au	Present in Park	Rare	N/A	Native
Vascular Plant	Polypodiaceae	*Lepisorus thunbergianus*	Ekaha akolea, pakahakaha, pua akuhinia	Present in Park	Common	N/A	Native
Vascular Plant	Polypodiaceae	*Phlebodium aureum*	Golden polypody	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Polypodiaceae	*Phymatosorus grossus*	–	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Polypodiaceae	*Polypodium pellucidum* var. *pellucidum*	‘Ae	Present in Park	Common	N/A	Native
Vascular Plant	Polypodiaceae	*Polypodium pellucidum* var. *vulcanicum*	‘Ae	Present in Park	Common	N/A	Native
Vascular Plant	Pteridaceae	*Adiantum capillus-veneris*	Common maidenhair, common maidenhair fern, venus hairfern	Probably Present	N/A	N/A	Native
Vascular Plant	Pteridaceae	*Adiantum hispidulum*	Rough maidenhair	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Pteridaceae	*Adiantum raddianum*	Delta maidenhair	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Pteridaceae	*Cheilanthes viridis*	–	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Pteridaceae	*Coniogramme pilosa*	Loulu	Present in Park	Common	N/A	Native
Vascular Plant	Pteridaceae	*Doryopteris decipiens*	–	Present in Park	Uncommon	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Pteridaceae	*Doryopteris decora*	–	Present in Park	Uncommon	N/A	Native
Vascular Plant	Pteridaceae	*Doryopteris subdecipiens*	Waianae mountain digit fern	Present in Park	Common	N/A	Native
Vascular Plant	Pteridaceae	*Pellaea ternifolia*	Kalamoho lau li`i	Present in Park	Common	N/A	Native
Vascular Plant	Pteridaceae	*Pityrogramma austroamericana*	Leatherleaf goldback fern	Present in Park	Common	N/A	Nonnative
Vascular Plant	Pteridaceae	*Pityrogramma calomelanos*	Silver fern	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Pteridaceae	*Pteris cretica*	`Oali, `owali, `owali`I	Present in Park	Common	N/A	Native
Vascular Plant	Pteridaceae	*Pteris excelsa*	`Iwa, waimakanui	Present in Park	Uncommon	N/A	Native
Vascular Plant	Pteridaceae	*Pteris irregularis*	`Ahewa, iwapuakea, mana	Present in Park	Rare	N/A	Native
Vascular Plant	Pteridaceae	*Pteris vittata*	Chinese brake, ladder brake	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Thelypteridaceae	*Amauropelta globulifera*	Palapalai a Kamapua`a	Present in Park	Uncommon	N/A	Native
Vascular Plant	Thelypteridaceae	*Christella cyatheoides*	Kikawaio, pakikawaio	Present in Park	Uncommon	N/A	Native
Vascular Plant	Thelypteridaceae	*Christella dentata*	–	Present in Park	Common	N/A	Nonnative
Vascular Plant	Thelypteridaceae	*Christella parasitica*	–	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Thelypteridaceae	*Macrothelypteris torresiana*	Swordfern	Present in Park	Common	N/A	Nonnative
Vascular Plant	Thelypteridaceae	*Pneumatopteris hudsoniana*	Hudson's air fern	Present in Park	Rare	N/A	Native
Vascular Plant	Thelypteridaceae	*Pneumatopteris pendens*	–	Present in Park	Rare	N/A	Native
Vascular Plant	Thelypteridaceae	*Pneumatopteris sandwicensis*	Hoʻiʻo kula	Present in Park	Abundant	N/A	Native
Vascular Plant	Thelypteridaceae	*Pseudophegopteris keraudreniana*	`Akolea, ala`alai, waimakanui	Present in Park	Uncommon	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Vittariaceae	*Haplopteris elongata*	Mana, 'ohe'ohe	Present in Park	Rare	N/A	Native
Vascular Plant	Myrsinaceae	*Embelia pacifica*	Kilioe	Present in Park	Rare	N/A	Native
Vascular Plant	Myrsinaceae	*Myrsine lanaiensis*	Kolea	Present in Park	Rare	N/A	Native
Vascular Plant	Myrsinaceae	*Myrsine lessertiana*	Kolea	Present in Park	Common	N/A	Native
Vascular Plant	Myrsinaceae	*Myrsine sandwicensis*	Kolea, kolea lau lii	Present in Park	Common	N/A	Native
Vascular Plant	Primulaceae	*Anagallis arvensis*	Pimpernel, scarlet pimpernel	Present in Park	Common	N/A	Nonnative
Vascular Plant	Proteaceae	*Banksia integrifolia*	Coast Banksia	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Proteaceae	*Grevillea banksii*	\`Oka pua \`ula\`ula, ha\`iku, kahili	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Proteaceae	*Grevillea robusta*	\`Oka kalika, ha\`iku ke\`oke\`o, he oak	Present in Park	Uncommon	N/A	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Proteaceae	*Macadamia integrifolia*	Macadamia nut	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Psilotaceae	*Psilotum complanatum*	Moa, pipi	Present in Park	Common	N/A	Native
Vascular Plant	Psilotaceae	*Psilotum complanatum X nudum*	–	Present in Park	Rare	N/A	Native
Vascular Plant	Psilotaceae	*Psilotum nudum*	Moa	Present in Park	Common	N/A	Native
Vascular Plant	Menispermaceae	*Cocculus orbiculatus*	`Inalua, hue, hue`ie	Present in Park	Common	N/A	Native
Vascular Plant	Ranunculaceae	*Anemone hupehensis* var. *japonica*	Japanese anemone	Present in Park	Common	N/A	Nonnative
Vascular Plant	Ranunculaceae	*Ranunculus hawaiensis*	Hawai'ian buttercup	Present in Park	Rare	N/A	Native
Vascular Plant	Ranunculaceae	*Ranunculus muricatus*	Spring buttercup	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Ranunculaceae	*Ranunculus plebeius*	Common Australian buttercup	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Ranunculaceae	*Ranunculus repens*	Butter daisy	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Joinvilleaceae	*Joinvillea ascendens* ssp. *ascendens*	`Ohe	Present in Park	Rare	N/A	Native
Vascular Plant	Rhamnaceae	*Alphitonia ponderosa*	Kauila, kauwila, o'a	Present in Park	Rare	N/A	Native
Vascular Plant	Vitaceae	*Vitis* sp.[1]	–	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Vitaceae	*Vitis vinifera*	Wine grape	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Vitaceae	*Vitis X prolifera*	Labruscan grape	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Crassulaceae	*Crassula multicava*	Cape Province pygmyweed	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Crassulaceae	*Crassula ovata*	Jade plant	Present in Park	Unknown	N/A	Nonnative
Vascular Plant	Crassulaceae	*Kalanchoe beharensis*	Felt bush, velvet leaf	Present in Park	Rare	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Crassulaceae	*Kalanchoe pinnata*	`Oliwa ku kahakai, air plant, life plant	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Crassulaceae	*Kalanchoe pumila*	–	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Crassulaceae	*Kalanchoe tubiflora*	Chandelier plant	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Crassulaceae	*Kalanchoe waldheimii*	–	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Hydrangeaceae	*Broussaisia arguta*	Pu`ahanui, puahanui	Present in Park	Common	N/A	Native
Vascular Plant	Hydrangeaceae	*Hydrangea aspera*	–	Probably Present	N/A	N/A	Nonnative
Vascular Plant	Hydrangeaceae	*Hydrangea macrophylla ssp.macrophylla*	–	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Hydrangeaceae	*Philadelphus* sp.[1]	–	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Pittosporaceae	*Pittosporum confertiflorum*	Ha`awa, ho`awa, hoawa	Present in Park	Rare	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Pittosporaceae	*Pittosporum glabrum*	Ha`awa, ho`awa, hoawa	Present in Park	Rare	N/A	Native
Vascular Plant	Pittosporaceae	*Pittosporum hawaiiense*	Ha`awa, haawa, hōʻawa	Present in Park	Uncommon	N/A	Native
Vascular Plant	Pittosporaceae	*Pittosporum hosmeri*	`A`awa, `a`awa hua kukui, ha`awa	Present in Park	Rare	N/A	Native
Vascular Plant	Pittosporaceae	*Pittosporum* sp.[1]	–	Present in Park	Unknown	N/A	Native
Vascular Plant	Pittosporaceae	*Pittosporum terminalioides*	Ha`awa, ho`awa, hoawa	Present in Park	Uncommon	N/A	Native
Vascular Plant	Pittosporaceae	*Pittosporum tobira*	Japanese cheesewood	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Pittosporaceae	*Pittosporum undulatum*	Orange pittosporum, Victorian box, Victorian laurel	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Rosaceae	*Cotoneaster pannosus*	Firethorn, silverleaf cotoneaster	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Rosaceae	*Eriobotrya japonica*	Loquat	Present in Park	Rare	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Rosaceae	*Fragaria chiloensis ssp. sandwicensis*	ʻOhelo papa	Present in Park	Rare	N/A	Native
Vascular Plant	Rosaceae	*Fragaria vesca*	Woodland strawberry	Present in Park	Common	N/A	Nonnative
Vascular Plant	Rosaceae	*Malus pumila*	Domestic apple	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Rosaceae	*Osteomeles anthyllidifolia*	ʻUlei, eluehe, uʻūlei	Present in Park	Common	N/A	Native
Vascular Plant	Rosaceae	*Prunus cerasifera X salicina*	–	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Rosaceae	*Prunus cerasus*	Sour cherry	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Rosaceae	*Prunus persica*	Peach	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Rosaceae	*Prunus serrulata*	Japanese flowering cherry	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Rosaceae	*Prunus* sp. [1]	–	Present in Park	Rare	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Rosaceae	*Pyracantha crenatoserrata*	–	Present in Park	Common	N/A	Nonnative
Vascular Plant	Rosaceae	*Pyrus kawakami*	Ornamental pear	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Rosaceae	*Pyrus pyrifolia*	Sand pear	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Rosaceae	*Rosa laevigata*	Cherokee rose	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Rosaceae	*Rosa multiflora*	Multiflora rose	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Rosaceae	*Rosa* sp.[1]	Rose	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Rosaceae	*Rubus argutus*	\`Ohelo \`ele\`ele, blackberry, ohelo eleele	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Rosaceae	*Rubus ellipticus* var. *obcordatus*	Yellow Himalayan raspberry	Present in Park	Common	N/A	Nonnative
Vascular Plant	Rosaceae	*Rubus glaucus*	Andes berry, raspberry	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Rosaceae	*Rubus hawaiensis*	‘Akala, akala, akalakala	Present in Park	Common	N/A	Native
Vascular Plant	Rosaceae	*Rubus macraei*	‘Akala, akala, akalakala	Present in Park	Rare	N/A	Native
Vascular Plant	Rosaceae	*Rubus rosifolius*	‘Akala, ‘akalakala, Mauritius raspberry	Present in Park	Common	N/A	Nonnative
Vascular Plant	Rosaceae	*Spiraea cantoniensis*	Reeves' meadowsweet	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Rubiaceae	*Bobea timonioides*	‘Ahakea, ahakea	Present in Park	Rare	N/A	Native
Vascular Plant	Rubiaceae	*Coffea arabica*	Arabian coffee	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Rubiaceae	*Coprosma ernodeoides*	Aiakanene, kukaenene, leponene	Present in Park	Abundant	N/A	Native
Vascular Plant	Rubiaceae	*Coprosma granadensis*	Makole	Present in Park	Uncommon	N/A	Native
Vascular Plant	Rubiaceae	*Coprosma menziesii*	Pilo	Present in Park	Common	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Rubiaceae	*Coprosma montana*	Hupilo, pilo	Present in Park	Uncommon	N/A	Native
Vascular Plant	Rubiaceae	*Coprosma ochracea*	Maui mirrorplant	Present in Park	Common	N/A	Native
Vascular Plant	Rubiaceae	*Coprosma ochracea X rhynchocarpa*	–	Present in Park	Uncommon	N/A	Native
Vascular Plant	Rubiaceae	*Coprosma pubens*	Pilo	Present in Park	Common	N/A	Native
Vascular Plant	Rubiaceae	*Coprosma repens*	Looking glass plant	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Rubiaceae	*Coprosma rhynchocarpa*	Pilo	Present in Park	Common	N/A	Native
Vascular Plant	Rubiaceae	*Galium* sp.[1]	Bedstraw	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Rubiaceae	*Hedyotis centranthoides*	Forest starviolet	Present in Park	Common	N/A	Native
Vascular Plant	Rubiaceae	*Hedyotis corymbosa*	–	Present in Park	Uncommon	N/A	Nonnative

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Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Rubiaceae	*Hedyotis hillebrandii*	Manono	Present in Park	Uncommon	N/A	Native
Vascular Plant	Rubiaceae	*Hedyotis terminalis*	Manono	Present in Park	Common	N/A	Native
Vascular Plant	Rubiaceae	*Hedyotis terminalis X hillebrandii*	–	Probably Present	NA	N/A	Native
Vascular Plant	Rubiaceae	*Luculia gratissima*	–	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Rubiaceae	*Morinda citrifolia*	Noni	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Rubiaceae	*Paederia foetida*	Maile ka kahiki, maile pilau	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Rubiaceae	*Psychotria hawaiiensis* var. *hawaiiensis*	‘Opiko, kopiko	Present in Park	Common	N/A	Native
Vascular Plant	Rubiaceae	*Psychotria hawaiiensis* var. *hillebrandii*	Kopiko	Present in Park	Common	N/A	Native
Vascular Plant	Rubiaceae	*Psychotria mauiensis*	‘Opiko	Present in Park	Rare	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Rubiaceae	*Psydrax odorata*	‘Ohe‘e, alahe‘e, alahee	Present in Park	Common	N/A	Native
Vascular Plant	Rubiaceae	*Richardia brasiliensis*	Tropical Mexican clover	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Rubiaceae	*Spermacoce assurgens*	Buttonweed	Probably Present	N/A	N/A	Nonnative
Vascular Plant	Rubiaceae	*Spermacoce latifolia*	Oval-leaf false buttonweed	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Santalaceae	*Exocarpos gaudichaudii*	Kaumahana	Present in Park	Rare	N/A	Native
Vascular Plant	Santalaceae	*Exocarpos menziesii*	Menzies' ballart	Present in Park	Rare	N/A	Native
Vascular Plant	Santalaceae	*Santalum paniculatum* var. *paniculatum*	‘Iliahi, iliahi	Present in Park	Uncommon	N/A	Native
Vascular Plant	Santalaceae	*Santalum paniculatum* var. *pilgeri*	Pilger's sandalwood	Present in Park	Rare	N/A	Native
Vascular Plant	Viscaceae	*Korthalsella complanata*	Hulumoa	Present in Park	Uncommon	N/A	Native

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Viscaceae	*Korthalsella remyana*	Bog korthal mistletoe	Present in Park	Rare	N/A	Native
Vascular Plant	Anacardiaceae	*Mangifera indica*	Mango	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Anacardiaceae	*Rhus sandwicensis*	Neleau	Present in Park	Rare	N/A	Native
Vascular Plant	Anacardiaceae	*Schinus molle*	California pepper tree, pepper tree	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Anacardiaceae	*Schinus terebinthifolius*	Christmas berry, naniohilo, wilelaiki	Present in Park	Common	N/A	Nonnative
Vascular Plant	Rutaceae	*Citrus aurantifolia*	Lime	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Rutaceae	*Citrus limon*	Lemon, rough lemon	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Rutaceae	*Citrus reticulata*	Tangerine	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Rutaceae	*Citrus sinensis*	Orange	Present in Park	Rare	N/A	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Rutaceae	*Citrus X paradisi*	Grapefruit	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Rutaceae	*Fortunella japonica*	Marumi kumquat	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Rutaceae	*Melicope clusiifolia*	Kolokolo mokihana	Present in Park	Common	N/A	Native
Vascular Plant	Rutaceae	*Melicope hawaiensis*	Mokihana kūkae moa, manena, alani	Present in Park	Rare	N/A	Native
Vascular Plant	Rutaceae	*Melicope pseudoanisata*	Alani	Present in Park	Uncommon	N/A	Native
Vascular Plant	Rutaceae	*Melicope radiata*	Alani	Present in Park	Common	N/A	Native
Vascular Plant	Rutaceae	*Melicope* sp.[1]	–	Present in Park	Unknown	N/A	Native
Vascular Plant	Rutaceae	*Melicope zahlbruckneri*	Alani, Zahlbruckner's pelea	Present in Park	Rare	N/A	Native
Vascular Plant	Rutaceae	*Platydesma spathulata*	Pilo kea	Present in Park	Rare	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Rutaceae	*Zanthoxylum dipetalum* var. *dipetalum*	Kāwaʻu, kawaʻu kua kuku kapa, kawau	Present in Park	Rare	N/A	Native
Vascular Plant	Rutaceae	*Zanthoxylum kauaense*	Aʻe, ae, heaʻe	Present in Park	Rare	N/A	Native
Vascular Plant	Sapindaceae	*Dodonaea viscosa*	ʻAʻaliʻI, kumakani	Present in Park	Abundant	N/A	Native
Vascular Plant	Sapindaceae	*Sapindus saponaria*	Aʻe, mānele	Present in Park	Uncommon	N/A	Native
Vascular Plant	Acanthaceae	*Justicia betonica*	Shrimp tail, white shrimp plant	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Acanthaceae	*Thunbergia alata*	Blackeyed Susan vine	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Bignoniaceae	*Jacaranda mimosifolia*	Jacaranda	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Bignoniaceae	*Spathodea campanulata*	African tuliptree	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Bignoniaceae	*Tecoma stans*	Yellow elder	Present in Park	Rare	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Buddlejaceae	*Buddleja asiatica*	Butterfly bush, huelo ʻilio	Present in Park	Common	N/A	Nonnative
Vascular Plant	Buddlejaceae	*Buddleja davidii*	Orange eye butterflybush	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Buddlejaceae	*Polypremum procumbens*	Juniper leaf	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Gesneriaceae	*Cyrtandra giffardii*	Haʻiwale, kanawao keʻokeʻo	Present in Park	Rare	N/A	Native
Vascular Plant	Gesneriaceae	*Cyrtandra giffardii X platyphylla*	–	Present in Park	Rare	N/A	Native
Vascular Plant	Gesneriaceae	*Cyrtandra lysiosepala*	Oppositeleaf cyrtandra	Present in Park	Uncommon	N/A	Native
Vascular Plant	Gesneriaceae	*Cyrtandra lysiosepala X paludosa*	–	Present in Park	Uncommon	N/A	Native
Vascular Plant	Gesneriaceae	*Cyrtandra lysiosepala X platyphylla*	–	Present in Park	Uncommon	N/A	Native
Vascular Plant	Gesneriaceae	*Cyrtandra menziesii*	Haʻiwale	Present in Park	Rare	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Gesneriaceae	*Cyrtandra paludosa var. paludosa*	Hahala, moa	Present in Park	Uncommon	N/A	Native
Vascular Plant	Gesneriaceae	*Cyrtandra platyphylla*	‘Ilihia, ilihia	Present in Park	Common	N/A	Native
Vascular Plant	Gesneriaceae	*Cyrtandra* sp.[1]	–	Present in Park	Uncommon	N/A	Native
Vascular Plant	Gesneriaceae	*Cyrtandra tintinnabula*	Ha‘iwale, Laupahoehoe cyrtandra	Present in Park	Rare	N/A	Native
Vascular Plant	Myoporaceae	*Myoporum sandwicense*	Bastard sandalwood, naeo, naiep	Present in Park	Common	N/A	Native
Vascular Plant	Oleaceae	*Fraxinus uhdei*	Tropical ash	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Oleaceae	*Jasminum humile*	–	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Oleaceae	*Ligustrum ovalifolium*	California privet	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Oleaceae	*Ligustrum sinense*	Privet	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Oleaceae	*Nestegis sandwicensis*	Olopua, pua, ulupua	Present in Park	Uncommon	N/A	Native
Vascular Plant	Oleaceae	*Olea europaea* ssp. *cuspidata*	Russian olive	Present in Park	Common	N/A	Nonnative
Vascular Plant	Oleaceae	*Olea europaea* ssp. *europaea*	Russian olive	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Scrophulariaceae	*Castilleja arvensis*	Indian paintbrush, painted-cup	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Scrophulariaceae	*Hebe X andersonii*	Hebe	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Scrophulariaceae	*Hebe X franciscana*	Francisco hebe	Probably Present	N/A	N/A	Nonnative
Vascular Plant	Scrophulariaceae	*Linaria canadensis* var. *texana*	Blue toadflax	Present in Park	Common	N/A	Nonnative
Vascular Plant	Scrophulariaceae	*Lindernia crustacea*	False pimpernel	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Scrophulariaceae	*Lophospermum erubescens*	Creeping gloxinia, larger roving sailor	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Scrophulariaceae	*Torenia glabra*	–	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Scrophulariaceae	*Verbascum thapsus*	Mullein, woolly mullein	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Scrophulariaceae	*Verbascum virgatum*	Virgate mullein	Probably Present	N/A	N/A	Nonnative
Vascular Plant	Scrophulariaceae	*Veronica peregrine* ssp. *xalapensis*	Necklace weed, purselane speedwell	Present in Park	Unknown	N/A	Nonnative
Vascular Plant	Scrophulariaceae	*Veronica plebeia*	Common speedwell, trailing speedwell	Present in Park	Common	N/A	Nonnative
Vascular Plant	Scrophulariaceae	*Veronica serpyllifolia*	Thymeleaf speedwell, thyme-leaf speedwell	Present in Park	Common	N/A	Nonnative
Vascular Plant	Selaginellaceae	*Selaginella arbuscula*	Lepelepe a moa	Present in Park	Uncommon	N/A	Native
Vascular Plant	Selaginellaceae	*Selaginella kraussiana*	Spreadling selaginella	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Selaginellaceae	*Selaginella* sp.[1].	–	Probably Present	N/A	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Convolvulaceae	*Ipomoea batatas*	\`Uala, \`uwala, uala	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Convolvulaceae	*Ipomoea indica*	Koali, koali \`awa, koali \`awahia	Present in Park	Abundant	N/A	Native
Vascular Plant	Convolvulaceae	*Ipomoea pes-caprae* ssp. *brasiliensis*	Beach morning glory, pōhuehue, puhuehue	Present in Park	Uncommon	N/A	Native
Vascular Plant	Convolvulaceae	*Ipomoea tuboides*	Hawaiian moon flower	Present in Park	Rare	N/A	Native
Vascular Plant	Convolvulaceae	*Ipomoea violacea*	Heavenlyblue morningglory, heavenlyblue morning-glory	Probably Present	N/A	N/A	Nonnative
Vascular Plant	Convolvulaceae	*Jacquemontia ovalifolia* ssp. *sandwicensis*	Kakuaohi\`iaka, kaupoʻo, paʻuohiʻiaka	Present in Park	Uncommon	N/A	Native
Vascular Plant	Convolvulaceae	*Merremia aegyptia*	Hairy merremia, koali kua hulu, kuahulu	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Convolvulaceae	*Stictocardia tiliifolia*	Pilikai	Probably Present	N/A	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Cuscutaceae	*Cuscuta sandwichiana*	Kauna'oa kahakai, kauna'oa lei, kaunaoa	Present in Park	Rare	N/A	Native
Vascular Plant	Solanaceae	*Brugmansia candida*	Angel's-trumpet	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Solanaceae	*Capsicum frutescens*	Bird pepper	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Solanaceae	*Cestrum nocturnum*	'Ala aumoe, kupaoa, night cestrum	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Solanaceae	*Nicotiana tabacum*	Paka, tobacco	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Solanaceae	*Nothocestrum breviflorum*	'Aiea, smallflower aiea	Present in Park	Rare	N/A	Native
Vascular Plant	Solanaceae	*Nothocestrum longifolium*	'Aiea, aiea, halena	Present in Park	Rare	N/A	Native
Vascular Plant	Solanaceae	*Physalis peruviana*	Cape gooseberry, pa'ina, poha	Present in Park	Common	N/A	Nonnative
Vascular Plant	Solanaceae	*Solanum americanum*	'Olohua, glossy nightshade, popolo	Present in Park	Common	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Solanaceae	*Solanum linnaeanum*	Apple of Sodom	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Solanaceae	*Solanum lycopersicum* var. *cerasiforme*	Garden tomato	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Solanaceae	*Solanum pseudocapsicum*	Jerusalem cherry	Present in Park	Common	N/A	Nonnative
Vascular Plant	Solanaceae	*Solanum seaforthianum*	Brazilian nightshade	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Clusiaceae	*Hypericum kouytchense*	–	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Clusiaceae	*Hypericum mutilum ssp. mutilum*	Dwarf St. John's wort	Present in Park	Common	N/A	Nonnative
Vascular Plant	Clusiaceae	*Hypericum parvulum*	Sierra Madre St. Johnswort	Present in Park	Common	N/A	Nonnative
Vascular Plant	Theaceae	*Camellia japonica*	Camellia	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Theaceae	*Camellia sasanqua*	Sasanqua camellia	Present in Park	Rare	N/A	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Moraceae	*Artocarpus altilis*	Breadfruit	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Moraceae	*Ficus carica*	Common fig, edible fig, fiku	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Moraceae	*Ficus macrophylla*	–	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Moraceae	*Ficus palmata*	Punjab fig	Present in Park	Unknown	N/A	Nonnative
Vascular Plant	Moraceae	*Ficus pumila*	Climbing fig	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Moraceae	*Morus alba*	Mulberry, white mulberry	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Ulmaceae	*Trema orientale*	Gunpowder tree	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Ulmaceae	*Ulmus parvifolia*	Chinese elm, lacebark elm	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Urticaceae	*Hesperocnide sandwicensis*	Hawai'i stingingnettle	Present in Park	Rare	N/A	Native

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Urticaceae	*Neraudia ovata*	Big Island ma'oloa	Present in Park	Rare	N/A	Native
Vascular Plant	Urticaceae	*Pilea microphylla*	Artillery plant	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Urticaceae	*Pilea peploides*	Pacific Island clearweed	Present in Park	Rare	N/A	Native
Vascular Plant	Urticaceae	*Pipturus albidus*	Mamake, mamaki	Present in Park	Abundant	N/A	Native
Vascular Plant	Urticaceae	*Touchardia latifolia*	Olona	Present in Park	Uncommon	N/A	Native
Vascular Plant	Urticaceae	*Urera glabra*	Hopue	Present in Park	Uncommon	N/A	Native
Vascular Plant	Begoniaceae	*Begonia coccinea*	Scarlet begonia	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Begoniaceae	*Begonia rex*	King begonia, rex begonia	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Begoniaceae	*Begonia semperflorens*	Bedding begonia, wax begonia	Present in Park	Uncommon	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Begoniaceae	*Begonia* sp.[1]	Unidentified begonia	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Cucurbitaceae	*Sechium edule*	Pipinella	Probably Present	N/A	N/A	Nonnative
Vascular Plant	Cucurbitaceae	*Sicyos alba*	–	Present in Park	Rare	N/A	Native
Vascular Plant	Cucurbitaceae	*Sicyos macrophyllus*	‘Anunu	Present in Park	Rare	N/A	Native
Vascular Plant	Flacourtiaceae	*Xylosma hawaiiense*	Ae, a‘e, maua	Present in Park	Rare	N/A	Native
Vascular Plant	Passifloraceae	*Passiflora edulis*	Liliko‘i, lilikoi, passionfruit	Present in Park	Common	N/A	Nonnative
Vascular Plant	Passifloraceae	*Passiflora foetida*	Lani wai, love-in-a-mist, pohapoha	Present in Park	Common	N/A	Nonnative
Vascular Plant	Passifloraceae	*Passiflora ligularis*	Lani wai, lemi wai, lemona	Present in Park	Uncommon	N/A	Nonnative
Vascular Plant	Passifloraceae	*Passiflora tarminiana*	Banana poka	Present in Park	Abundant	N/A	Nonnative

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Violaceae	*Viola hederacea* ssp. *hederacea*	Australian violet	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Violaceae	*Viola odorata*	Sweet violet	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Cannaceae	*Canna X generalis*	Canna lily	Present in Park	Unknown	N/A	Nonnative
Vascular Plant	Costaceae	*Costus speciosus*	Crepe ginger, Malay ginger	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Heliconiaceae	*Heliconia* sp.[1]	–	Probably Present	N/A	N/A	Nonnative
Vascular Plant	Marantaceae	*Calathea makoyana*	–	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Musaceae	*Musa* sp.	Banana, maia	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Strelitziaceae	*Strelizia reginae*	–	Present in Park	Rare	N/A	Nonnative
Vascular Plant	Zingiberaceae	*Hedychium coronarium*	`Awapuhi ke`oke`o, common ginger lily, white ginger	Present in Park	Common	N/A	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Table A-1 (continued). Certified Species List for all Taxonomic Categories in HAVO (IRMA 2012b).

Grouping	Family	Scientific Name	Common and Hawaiian Name(s)	Occurrence	Abundance	Residency	Nativity
Vascular Plant	Zingiberaceae	*Hedychium flavescens*	`Awapuhi melemele, yellow ginger, yellow ginger lily	Present in Park	Common	N/A	Nonnative
Vascular Plant	Zingiberaceae	*Hedychium gardnerianum*	`Awapuhi kahili, kahili, kahili ginger	Present in Park	Abundant	N/A	Nonnative
Vascular Plant	Zingiberaceae	*Zingiber zerumbet*	`Awapuhi, `awapuhi kuahiwi, awapuhi	Present in Park	Uncommon	N/A	Nonnative

[1] Date Certified: Mammal = September 08, 2005; Bird = December 21, 2010; Fish = October 12, 2005; Reptile = September 27, 2005; Amphibian = September 27, 2005; Vascular Plant = February 08, 2011

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Appendix B. Federally and State Listed and SOC Plants and Animals Known to Currently or Historically Occur at HAVO (Pratt et al. 2011, R. Loh unpublished).

Table B-1. Federally and state listed and SOC plants and animals known to currently or historically occur at HAVO (Pratt et al. 2011, R. Loh unpublished).

Species Order	Scientific Name	Common Name	Date Listed	Status*
Flora	*Adenophorus periens*	Palai lāʻau, pendant kihi fern	11/10/1994	E
	Alphitonia ponderosa	Kauila, kauwila	–	SOC
	Anoectochilus sandvicensis	Jewel orchid	–	SOC
	Argyroxiphium kauense	Kaʻū, MaunaLoa silversword	4/7/1993	E
	Argyroxiphium sandwicense ssp. *macrocephalum*	ʻAhinahina, Haleakalā silversword, Hawaiian catchfly	5/15/1992	T
	Argyroxiphium sandwicense ssp. *sandwicense*	ʻAhinahina, MaunaKea silversword	3/21/1986	E
	Asplenium peruvianum var. *insulare*	–	9/26/1994	E
	Asplenium schizophyllum	–	–	SOC
	Bobea timonioides	ʻAhakea	–	SOC
	Caesalpinia kavaiensis	Uhiuhi	7/8/1986	E
	Capparis sandwichiana	Maipilo	–	SOC
	Clermontia lindseyana	ʻOhā wai, Lindsey's ʻōhā	3/4/1994	E
	Clermontia peleana	ʻOhā wai, Pele's ʻōhā	3/4/1994	E
	Cyanea shipmanii	Hāhā	3/4/1994	E
	Cyanea stictophylla	Hāhā, haʻiwale, kanawao keʻokeʻo	3/4/1994	E
	Cyanea tritomantha	ʻAkū	11/29/2013	E
	Cyrtandra giffardii	Haʻiwale	3/4/1994	E
	Cyrtandra menziesii	Haʻiwale	–	SOC
	Cyrtandra tintinnabula	Haʻiwale	3/4/1994	E
	Embelia pacifica	Kilioe	–	SOC
	Eurya sandwicensis	Anini	–	SOC
	Exocarpos gaudichaudii	Hulumoa, kaumahana	–	SOC
	Fimbristylis hawaiiensis	–	–	SOC
	Fragaria chiloensis subsp. *sandwicensis*	ʻOhelo papa	–	SOC
	Haplostachys haplostachya	Honohono	11/29/1979	E
	Hibiscadelphus giffardianus	Hau kuahiwi	10/10/1996	E

* Status: E = Federal and state endangered; T = Federal and state threatened; PE = Proposed endangered; C = Candidate for listing.

Table B-1 (continued). Federally and state listed and SOC plants and animals known to currently or historically occur at HAVO (Pratt et al. 2011, R. Loh unpublished).

Species Order	Scientific Name	Common Name	Date Listed	Status*
Flora (cont'd)	*Hibiscus brackenridgei* subsp. *brackenridgei*	Maʻo hau hele	11/10/1994	E
	Ischaemum byrone	Hilo ischaemum	3/4/1994	E
	Joinvillea ascendens ssp. *ascendens*	ʻOhe	–	C
	Kokia drynarioides	Kokiʻo	12/4/1994	E
	Liparis hawaiensis	ʻAwapuhiakanaloa	–	SOC
	Melicope hawaiensis	Mokihanakūkae moa, manena, alani	–	SOC
	Melicope zahlbruckneri	Alani, Zahlbruckner's pelea	10/10/1996	E
	Neraudia ovata	Maʻaloa	10/10/1996	E
	Nothocestrum breviflorum	ʻAiea	3/4/1994	E
	Ochrosia haleakalae	Hōlei	–	C
	Ochrosia kilaueaensis	Hōlei	3/4/1994	E
	Phyllostegia floribunda	Many-flowered phyllostegia	11/29/2013	E
	Phyllostegia stachyoides	–	–	SOC
	Phyllostegia velutina	–	10/10/1996	E
	Pittosporum hawaiiense	Hōʻawa	11/29/2013	E
	Plantago hawaiensis	Laukahi kuahiwi	3/4/1994	E
	Pleomele hawaiiensis	Hawaiʻi hala pepe	10/10/1996	E
	Polyscias sandwicensis	ʻOhe, ʻohe kukuluaeʻo, ʻohe makai	–	SOC
	Portulaca sclerocarpa	Poʻe, ʻihi mākole	3/4/1994	E
	Portulaca villosa	ʻIhi	–	SOC
	Pritchardia affinis	Loulu	3/4/1994	E
	Pritchardia lanigera	–	11/29/2013	E
	Ranunculus hawaiensis	Makou, large-flower native buttercup	–	C
	Rubus macraei	ʻAkala	–	SOC
	Sanicula sandwicensis	–	–	SOC
	Scaevola kilaueae	Huahekili uka,Kīlauea naupaka, naupaka kuahiwi	–	SOC
	Schiedea diffusa subsp. *macraei*	–	11/29/2013	E
	Sesbania tomentosa	ʻOhai	11/10/1994	E
	Sicyos alba	ʻAnunu; white-bur cucumber	10/10/1996	E

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Table B-1 (continued). Federally and state listed and SOC plants and animals known to currently or historically occur at HAVO (Pratt et al. 2011, R. Loh unpublished).

Species Order	Scientific Name	Common Name	Date Listed	Status*
Flora (cont'd)	*Sicyos macrophyllus*	ʻAnunu, large-leaved ʻānunu, large leaf bur cucumber	–	C
	Silene hawaiiensis	–	3/4/1994	T
	Sisyrinchium acre	Mauʻu lāʻili, mauʻu hōʻula ʻili	–	SOC
	Spermolepis hawaiiensis	–	11/10/1994	E
	Stenogyne angustifolia	–	11/29/1979	E
	Stenogyne macrantha	–	–	SOC
	Trematolobelia wimmeri	Koliʻi	–	SOC
	Zanthoxylum dipetalum var. *dipetalum*	Kāwaʻu	–	SOC
	Zanthoxylum hawaiiense	Aʻe, Hawaiʻi pricklyash	3/4/1994	E
Mammals	*Lasiurus cinereus semotus*	Hawaiian hoary bat, ʻopeʻapeʻa	10/13/1970	E
	Monachus schauinslandi	Hawaiian monk seal	12/23/1976	E
Reptiles	*Chelonia mydas*	Honu, green sea turtle	7/28/1978	T
	Eretmochelys imbricata	Hawksbill sea turtle	6/2/1970	E
Birds	*Branta sandvicensis*	Hawaiian goose, nēnē	3/11/1967	E
	Buteo solitarius	ʻIo, Hawaiian hawk	3/11/1967	E
	Corvus hawaiiensis	ʻAlala	3/11/1967	E
	Falco peregrinus tundrius	Peregrine falcon	–	SOC
	Hemignathus munroi	ʻAkiapōlāʻau	3/11/1967	E
	Loxops coccineus coccineus	ʻAkepa, honeycreeper	10/13/1970	E
	Numenius tahitiensis	Bristle-thighed curlew	–	SOC
	Oceanodroma castro	ʻAkē ʻakē, band-rumped storm petrel	–	C
	Oreomystis mana	Hawaiʻi creeper	10/28/1975	E
	Psittirostra psittacea	ʻOʻū	3/11/1967	E
	Pterodroma sandwichensis	ʻUaʻu, Hawaiian petrel	3/11/1967	E
	Puffinus auricularis newelli	ʻAʻo, Newell's shearwater	10/28/1975	T
Insects	*Drosophila digressa*	Pomace fly, pāpala picture-wing	11/29/2013	E
	Drosophila heteroneura	Pomace fly, hammerhead picture-wing	5/9/2006	E
	Drosophila mulli	Pomace fly, Mull's picture-wing	5/9/2006	T
	Drosophila ochrobasis	Pomace fly	5/9/2006	E
	Megalagrion nesiotes	Flying earwig Hawaiian damselfly	7/26/2010	E

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Table B-1 (continued). Federally and state listed and SOC plants and animals known to currently or historically occur at HAVO (Pratt et al. 2011, R. Loh unpublished).

Species Order	Scientific Name	Common Name	Date Listed	Status*
Insects (continued)	*Megalagrion xanthomelas*	Orangeblack Hawaiian damselfly	–	C
Crustaceans	*Metabetaeus lohena*	Anchialine pool shrimp	–	C

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