Species Report of *Huperzia stemmermanniae* (no common name)
Version 1.0

Huperzia stemmermanniae on underside of tree. Photo credit: Hawai‘i Plant Extinction Prevention Program staff.

September 2022
Pacific Islands Fish and Wildlife Office
U.S. Fish and Wildlife Service
Honolulu, Hawai‘i

This document was prepared by the staff at the Pacific Islands Fish and Wildlife Office, Honolulu, Hawaiʻi. We received valuable input and assistance from the following experts: Lyman Perry, Hawaiʻi District Botanist for State of Hawai'i Division of Forestry and wildlife (DOFAW); Josh VanDeMark (Plant Extinction Prevention Program and DOFAW), and Jaime Enoka (Horticulturist, Volcano Rare Plant Facility). We greatly appreciate their guidance and support, which resulted in a more robust report.

Suggested reference:
U.S. Fish and Wildlife Service. 2022. Species Report for *Huperzia stemmermanniae* (no common name). Pacific Islands Fish and Wildlife Office, Pacific Islands Interior Region 12, Portland OR. 24 pages.

EXECUTIVE SUMMARY

Huperzia stemmermanniae (no common name) is a perennial epiphytic hanging fir-moss (lycophyte) in the club moss family (Lycopodiaceae) and is part of the Phlegmaria group (Palmer 2003, pp. 254–255). It is currently only found within the Laupāhoehoe Natural Area Reserve (NAR) on the island of Hawaiʻi.

Huperzia stemmermanniae is found in the wet montane forest at elevations around 3,500 to 4,000 feet (ft.) (1070 to 1220 meters [m]) in areas dominated by *Metrosideros polymorpha* and *Acacia koa* (ʻōhiʻa and koa). The habitat is characterized by annual rainfall of 60 to 100 inches (in) (157 to 261 centimeters [cm]) (DLNR 2016, p. 24).

There have only been three populations of *Huperzia stemmermanniae* ever recorded since its discovery in 1981. One population, consisting of three individuals, was found on east Maui in 1995, but has not been relocated since. The other two populations were recorded on the island of Hawaiʻi in the Laupāhoehoe Natural Area Reserve (NAR). The populations are located on the windward slope of Mauna Kea. One population that is closer to the sea (makai) while the other is more inland (mauka). Currently there are only six individuals within the mauka population that have been documented in the wild (PEPP 2019) and while spores have been collected, there have been challenges propagating new individuals (PEPP 2013, p. 5). The main threats to this species are habitat modification and herbivory by ungulates, habitat modification and competition by nonnative plants, genetic and ecological consequences of limited numbers, drought, inadequate regulatory measures, and impacts due to climate change. Conservation efforts include spore collection, fencing and ungulate removal, and storage and annual monitoring.

We are measuring the species overall viability by assessing the three conservation principles of resiliency, redundancy, and representation. In this report, we identify resiliency as the capacity of a species to survive stochastic events and use population size as our measurement of that ability. Redundancy is defined as having enough resilient populations distributed across the landscape to survive catastrophic events. For redundancy, we will use the number of distinct populations over the habitat range. Finally, representation is defined as maintaining genetic diversity by having more than one resilient population representing all known genetic and habitat diversity, thereby increasing the ability to survive changing environmental conditions over time. We will use habitat variability of *Huperzia stemmermanniae* to measure representation.

Considering the limited number of recently observed populations and individuals (fewer than 10), minimal habitat protection, and partial threat control, we have assessed the overall viability of *Huperzia stemmermanniae* as very low.

TABLE OF CONTENTS

List of Tables

List of Figures

INTRODUCTION

Huperzia stemmermanniae (no common name) is an endangered epiphytic hanging fir-moss (fern ally) in the club moss family (Lycopodiaceae) and is part of the Phlegmaria group (Palmer 2003, pp. 254–255). It is endemic to the islands of Hawaiʻi and Maui in the Hawaiian Islands and occurs in wet to mesic forests (Palmer 2003, pp. 257–259).

Species Report Overview

This Species Report summarizes the biology and current status of *Huperzia stemmermanniae* and was conducted by Pacific Islands Fish and Wildlife Office. It is a biological report that provides an in-depth review of the species' biology, factors influencing viability (threats and conservation actions), and an evaluation of its current status and viability.

The intent is for the Species Report to be easily updated as new information becomes available, and to support the functions of the Service's Endangered Species Program. As such, the Species Report will be a living document and biological foundation for other documents such as recovery plans, status in biological opinions, and 5-year reviews.

Regulatory History

Huperzia stemmermanniae was listed as an endangered species on September 30, 2016, along with ten other plant and animal species (USFWS 2016a, p. 67,786). Critical habitat has yet to be designated, and a recovery plan is currently being prepared. The Recovery Outline for Hawaiian Multi-Island Species was released by the U.S. Fish and Wildlife Service (Service) on July 30, 2020, and addresses this species (USFWS 2020a).

Methodology

We used the best scientific and commercial data available to us, including peer-reviewed literature, grey literature (government, academic, business, and industry reports), and expert elicitation. To the best of our ability, we used the current taxonomy at the time this report was drafted (see Taxonomy section below).

To assess the current status and viability of *Huperzia stemmermanniae*, we identified population units. The classic definition of a population is a self-reproducing group of conspecific individuals that occupies a defined area over a span of evolutionary time, an assemblage of genes (the gene pool) of its own, and has its own ecological niche. However, due to information gaps, we could not assess the viability of *H. stemmermanniae* using this definition. The Hawaiʻi and Pacific Plants Recovery Coordinating Committee revised its recovery objectives guidelines in 2011 and included a working definition of a population for plants: "a group of conspecific individuals that are in close spatial proximity to each other (i.e., less than 1,000 meters apart), and are presumed to be genetically similar and capable of sexual (recombinant) reproduction" (HPPRCC 2011, p. 1).

Based on this working definition, maps were created to display population units. In an effort to protect the sensitivity of species data, we created maps with symbol markers rather than displaying species points or polygons. We created the symbols in steps. First, we added a 500-meter buffer around each individual species point and polygon. We then dissolved all buffer areas intersecting each other into a single shape. Next, we created a centroid (i.e., point representing the center of a polygon) within each dissolved buffer area. The symbol marker represents the centroid. Finally, the Disperse Marker tool in ArcGIS Pro was used shift symbol markers that were overlapping so they would all be visible at the scale of the map. All points and polygons were used in this process, regardless of observation date or current status (historical, current, extant, or extirpated), to represent the known range of the species.

Species Viability

The Species Report assesses the ability of *Huperzia stemmermanniae* to maintain viability over time. Viability is the ability or likelihood of the species to maintain populations over time (i.e., likelihood of avoiding extinction). To assess the viability of *H. stemmermanniae*, we used the three conservation biology principles of resiliency, redundancy, and representation, or the "3Rs" (Figure 1; USFWS 2016b, entire). We will evaluate the viability of a species by describing what the species needs to be resilient, redundant, and represented, and compare that to the status of the species based on the most recent information available to us.

Definitions

Resiliency is the capacity of a population or a species to withstand the more extreme limits of normal year-to-year variation in environmental conditions such as temperature and rainfall extremes, and unpredictable but seasonally frequent perturbations such as fire, flooding, and storms (i.e., environmental stochasticity). Quantitative information on the resiliency of a population or species is often unavailable. However, in the most general sense, a population or species that can be found within a known area over an extended period of time (e.g., seasons or years) is likely to be resilient to current environmental stochasticity. If quantitative information is available, a resilient population or species will show enough reproduction and recruitment to maintain or increase the numbers of individuals in the population or species, and possibly expand the range of occupancy. Thus, resiliency is positively related to population size and growth rate, and may also influence the connectivity among populations.

Redundancy is having more than one resilient population distributed across the landscape, thereby minimizing the risk of extinction of the species. To be effective at achieving redundancy, the distribution of redundant populations across the geographic range should exceed the area of impact of a catastrophic event that would otherwise overwhelm the resilient capacity of the populations of a species. In the report, catastrophic events are distinguished from environmental stochasticity in that they are relatively unpredictable and infrequent events that exceed the more extreme limits of normal year-to-year variation in environmental conditions (i.e., environmental stochasticity), and thus expose populations or species to an elevated extinction risk within the area of impact of the catastrophic event. Redundancy is conferred upon a species when the geographic range of the species exceeds the area of impact of any anticipated catastrophic event. In general, a wider range of habitat types, a greater geographic distribution, and connectivity across the geographic range will increase the redundancy of a species and its ability to survive a catastrophic event.

Representation is having more than one population of a species occupying the full range of habitat types used by the species. Alternatively, representation can be viewed as maintaining the breadth of genetic diversity within and among populations, in order to allow the species to adapt to changing environmental conditions over time. The diversity of habitat types, or the breadth of the genetic diversity of a species, is strongly influenced by the current and historic biogeographical range of the species. Conserving this range should take into account historic latitudinal and longitudinal ranges, elevation gradients, climatic gradients, soil types, habitat types, seasonal condition, etc. Connectivity among populations and habitats is also an important consideration in evaluating representation.

The viability of a species is derived from the combined effects of the 3Rs. A species is considered viable when there are a sufficient number of self-sustaining populations (resiliency) distributed over a large enough area across the range of the species (redundancy) and occupying a range of habitats to maintain environmental and genetic diversity (representation) to allow the species to persist indefinitely when faced with annual environmental stochasticity and infrequent catastrophic events. Common ecological features are part of each of the 3Rs. This is especially true of connectivity among habitats across the range of the species. Connectivity sustains dispersal of individuals, which in turn greatly affects genetic diversity within and among populations. Connectivity also sustains access to the full range of habitats normally used by the species, and is essential for re-establishing occupancy of habitats following severe environmental stochasticity or catastrophic events (see Figure 1 for more examples of overlap among the 3Rs). Another way the three principles are inter-related is through the foundation of population resiliency. Resiliency is assessed at the population level, while redundancy and representation are assessed at the species level. Resilient populations are the necessary foundation needed to attain sustained or increasing representation and redundancy within the species. For example, a species cannot have high redundancy if the populations have low resiliency. The assessment of viability is not binary, in which a species is either viable or not, but rather on a continual scale of degrees of viability, from low to high. The health, number and distribution of populations were analyzed to determine the 3Rs and viability. In broad terms, the more resilient, represented, and redundant a species is, the more viable the species is. The current understanding of factors, including threats and conservation actions, will influence how the 3Rs and viability are interpreted for *Huperzia stemmermanniae.*

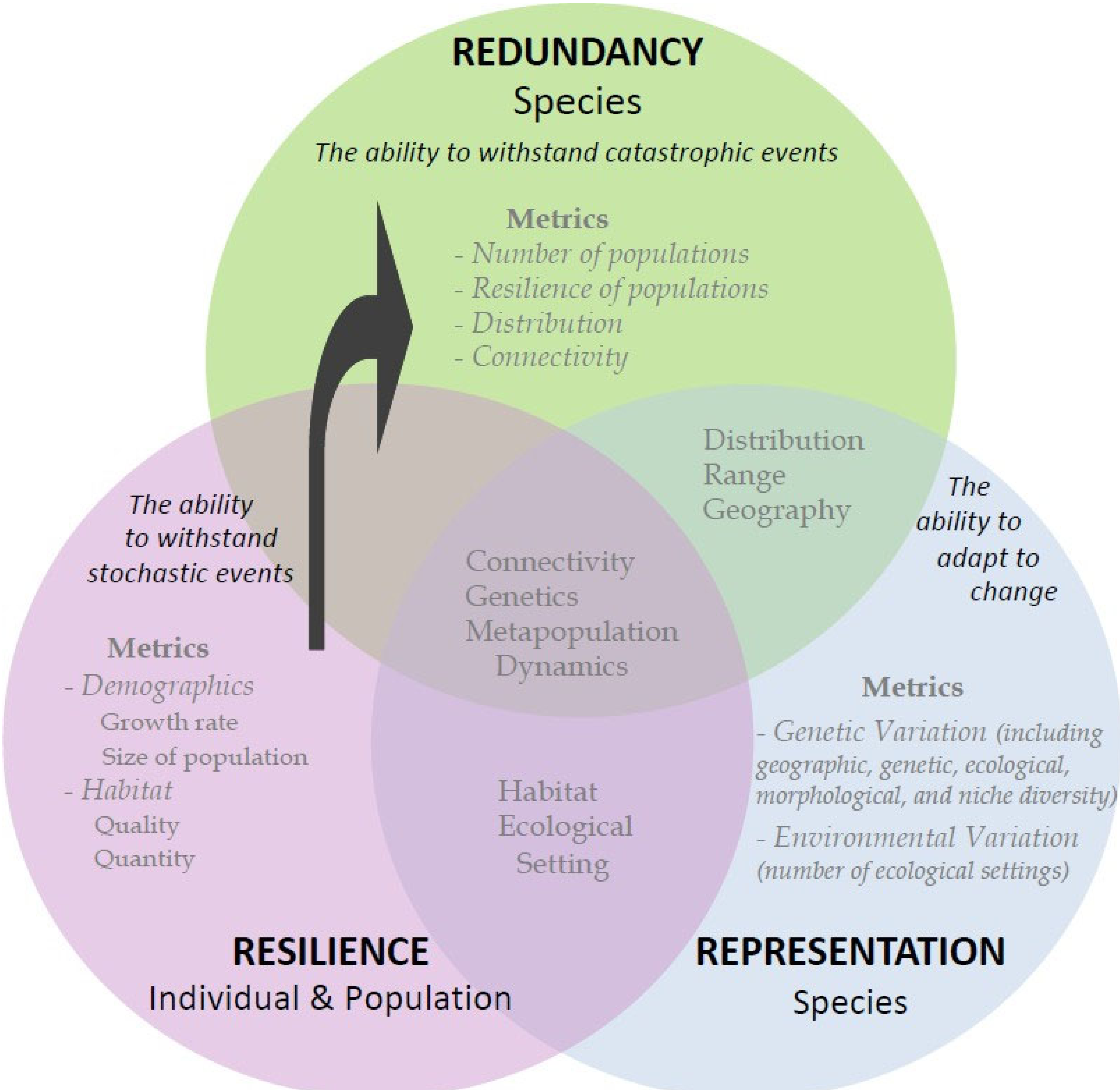

Figure 1. The three conservation biology principles of resiliency, redundancy, and representation, or the "3Rs".

SPECIES ECOLOGY

Species Description

Huperzia stemmermanniae is a short-lived epiphytic (growing on another plant) hanging fir-moss (not a true fern) in the club moss family (Lycopodiaceae) (Palmer 2003, pp. 257–259). The sterile stem bases are usually unforked or 1-forked, short and usually smaller than 15 centimeters (cm) long, and are pale yellow with fertile terminal strobili (cone like structures of small leaves). The sterile leaves are elliptic, five to twelve by two to four millimeters (mm) long and separated. The transition to fertile leaves is somewhat gradual. The fertile leaves are ovate (egg shaped) to lanceolate (oval tapering to a point), and as long as or longer than the sporangia (enclosure in which spores are formed), which is about 1.5 to 5 mm long. Strobili are much larger and longer than the sterile basal stem and are up to 30 cm long and 1.5 to 2.2 mm in diameter and are unforked or forking (up to six times) at acute (define) angles of 10 to 50 degrees. The branches of the strobili are usually straight (Palmer 2003, pp. 257–259).

Taxonomy
Huperzia stemmermanniae is very similar to *Huperzia mannii*. It can be distinguished from this species by its thicker and straighter strobili. Additionally, it has narrower angles of strobilus forkings (Palmer 2003, p. 259).

In his 2003 review of Hawaiian ferns and fern allies, Palmer recognized the taxonomy of Øllgaard (1987) for the Hawaiian *Phlegmariurus* as a group within the genus *Huperzia* (Palmer 2003, pp. 257–259). Later, Ranker et al. (2019, p. 55), recognized the genus *Phlegmariurus*. The new status of *Phlegmariurus stemmermanniae* is in the most recent taxonomic treatment in the checklist of Hawaiian flora (Smithsonian Institution 2021). This taxonomic change does not affect the range or status of this species. We will refer to this species as *Phlegmariurus stemmermanniae* throughout the following sections of this document, and recommend updating the list of Threatened and Endangered Species in the Federal Register through a technical revision in the future.

Individual Needs
Phlegmariurus stemmermanniae is an epiphytic lycophyte that is reliant on a healthy *Metrosideros polymorpha* (ʻōhiʻa) and *Acacia koa* (koa) forest to survive and reproduce (Lynch 2019, p. 2). While specifics about reproduction, such as life cycle and reproduction timing, aren't known, we can do know that *P. stemmermanniae* reproduces by spores. *Phlegmariurus stemmermanniae* is a fern ally, now identified as lycophytes (Lynch 2019, p. 2). *Phlegmariurus stemmermanniae* germinates from spores, and may need darkness for spore germination (Mehltreter et al. 2010). *Phlegmariurus stemmermanniae* (no common name) is a perennial epiphytic hanging fir- moss (lycophyte) in the club moss family (Lycopodiaceae) and is part of the Phlegmaria group (Palmer 2003, pp. 254–255).

Habitat
Phlegmariurus stemmermanniae is a narrow endemic species that is known only from the Laupāhoehoe Natural Area Reserve (NAR) on the island of Hawaiʻi. Three individuals occurred at Kaʻāpahu on east Maui, but has not been relocated since 1995 (USFWS 2016a, p.67,797). The species is typically found in the wet montane forests at elevations between 3,000 to 4,000 ft (914 to 1219 m).

The Laupāhoehoe NAR is located on the windward slopes of Mauna Kea, in the North Hilo District. It stretches from 1,600 ft to about 4,600 ft (490 to 1400 m) in elevation and is adjacent to Hakalau Forest National Wildlife Refuge. The Laupāhoehoe NAR is also part of the Hawaiʻi Experimental Tropical Forest, which is co-managed by the U.S. Forest Service and Hawaii Division of Department of Land and Natural Resources; Division of Forestry and Wildlife (DOFAW). Experimental forests, such as the Laupāhoehoe NAR, focus on six primary research themes: (1) Understanding the composition, structure, and function of all components, (2) Determining how the function and health of the ecosystem is influenced by biological and physical factors, (3) Developing models and tools for predicting ecosystem responses to impacts, (4) Identifying conditions needed to: support biodiversity, reduce ecological impacts of nonnative species, and restore ecosystems, (5) Improving wildland fire management strategies, modeling, and predictions, and (6) Integrating research local communities with research.

The Laupāhoehoe NAR is described as a wet montane forest and occurs on a variety of substrates from older weathered soils to young lava flows and is considered species rich with a diverse array of trees, shrubs, and ferns (Clark et al. 2019, p. 2). Average annual rainfall at this site ranges from 60 to 100 in (157 to 261 cm) (DLNR 2016, p. 24). The understory of this area has many common species that are normally found within wet forests except it lacks the *Cibotium menziesii* (hāpu'u tree fern) layer and resembles assemblages from drier areas on the island. Native species include but are not limited to: *Dryopteris wallichiana* (laukahi), *Cheirodendron trigynum* (ʻōlapa), *Coprosma rhynchocarpa* (pilo), *Kadua centranthoides* (manono), *Zanthoxylum dipetalum* (kāwa'u), *Myoporum sandwicense* (naio), *Myrsine lessertiana* (kōlea), *Melicope clusiifolia* (alani), *Ranunculus hawaiensis* (makou; recently extirpated), *Sophora chrysophylla* (māmane), *Leptecophylla tameiameiae* (pūkiawe), and *Vaccinium reticulatum* (ʻōhelo) (DLNR 2016, p. 33).

Phlegmariurus stemmermanniae is an epiphytic lycophyte that is reliant on a healthy *Metrosideros polymorpha* (ʻōhiʻa) and *Acacia koa* (koa) forest to survive and reproduce. In most observances, *P. stemmermanniae* was found about 10 ft (3 m) off the ground (USFWS 2020b).

Population Needs

Populations are more resilient when there are abundant individuals representing all age classes (seedlings, immature plants, and mature plants) within suitable habitat that can continue surviving despite stochastic events and disturbances. As resiliency is the capacity of a population or a species to withstand the more extreme limits of normal year-to-year variation in environmental conditions, robust populations that are dispersed throughout the ecosystem, contain genetic variability and connectivity increase their resiliency to survive environmental stochasticity. For this Species Report, we will measure the resiliency of *Phlegmariurus stemmermanniae* by population size, as higher resiliency is demonstrated when there are enough individuals to survive stochastic events.

Phlegmariurus stemmermanniae occurs or occurred in the wet montane forest on the islands of Hawaiʻi and Maui as described in the Habitat section above. Initial surveys indicate that the only populations in existence are comprised of low numbers of individuals and the species occurs in one habitat type, which is wet montane forest. Populations comprised of low numbers may show little recruitment and therefore are more vulnerable. For this Species Report, we will be using the latest information available, which includes the 2019 survey for *P. stemmermanniae* in the Laupāhoehoe NAR and *ex situ* propagation and storage efforts at the Lyon Arboretum.

Species Needs

We will measure the needs of *Phlegmariurus stemmermanniae* by the metrics of redundancy and representation. Redundancy is the capacity of a species to withstand catastrophic events. We will measure the redundancy of this species by the number of resilient populations and their proximity to one another. We will measure the representation of *P. stemmermanniae* by the number of resilient populations occupying the full range of habitat types used by the species and representing all genetic structure of the species in order to adapt to changing environmental conditions over time. A summary of these metrics is displayed below in Table 1.

Table 1. Metrics for assessing resiliency, redundancy, and representation.

Conservation Biology Principle	Metrics
Resiliency	Population size
Redundancy	Number of resilient populations and their proximity to each other
Representation	Number of resilient populations representing genetic and habitat variation throughout the species' range

FACTORS INFLUENCING VIABILITY

Threats and Conservation Efforts

Immediate threats facing the survival of *Phlegmariurus stemmermanniae* include habitat destruction and degradation by introduced ungulates, nonnative plants, and drought, herbivory by introduced ungulates, inadequate existing regulatory mechanisms, consequences from low numbers of populations and small population sizes, and climate change (Table 2) (USFWS 2016a, p. 67,824). Currently there are a number of organizations and state agencies that are working on the various conservation efforts such as the Department of Forestry and Wildlife (DOFAW) is a division of the Hawaii Department of Land and Natural Resources (DLNR), Haleakala National Park, the State of Hawaii Plant Extinction Prevention Program (PEPP), the Lyon Arboretum and Seed Bank, and the Volcano Rare Plant Facility (VRPF).

Ungulates

Ungulates, specifically feral pigs (*Sus scrofa*), goats (*Capra hircus*), deer (*Axis axis*), and cattle (*Bos* sp.), have been listed as one of the main threats to *Phlegmariurus stemmermanniae* (USFWS 2016a, p. 67,824). They may threaten *P. stemmermanniae* directly and indirectly. Indirect impacts are through habitat degradation and destruction through digging and spreading invasive plants. They directly impact the species through trampling and herbivory. (Cuddihy and Stone 1990, pp. 70–74). Nonnative ungulates are particularly a problem in Hawaiʻi as there are no natural predators and hence, no real control on population growth (USGS 2020). The 2016 Laupāhoehoe NAR management plan states that the main ungulate species in the Laupāhoehoe Forest is feral pigs. Although feral cattle are also stated as a threat, all feral cattle were removed from the area by 2003. However, there is always potential for impacts as cattle are found in the adjacent Waipunalei and Hūmuʻula forests, which are adjacent to the Laupāhoehoe NAR (DLNR 2016, p. 44).

Conservation Actions: Approximately 35 acres (ac) (0.1416 square kilometers [km^2]) of the Laupāhoehoe NAR has been fenced (DLNR 2016, p. 49). Unfortunately, the known populations of *Phlegmariurus stemmermanniae* do not fall within these areas and they remain unfenced. As the species is epiphytic, most of the population is naturally protected from direct impacts such as trampling and herbivory, but at least one individual in the population is closer to the ground, underneath a koa log, and therefore susceptible to direct impacts from feral ungulates (PEPP 2019).

Nonnative Plants
Invasive plants have the ability to outcompete native plant species for water, nutrients, and light (Lowe et al. 2019, pp. 14–15). These competitive advantages adversely affect the microhabitat by modifying plant communities, decreasing biological diversity, and preventing reproduction of native species. The Laupāhoehoe NAR Management Plan identifies invasive nonnative plants that have a higher potential for spreading and causing modifications to the native forest. Invasive plants observed in Laupāhoehoe NAR include but are not limited to: *Sphaeropteris cooperi* (Australian tree fern), *Passiflora tarminiana* (banana poka), *Rubus argutus* (Florida blackberry), *Tibouchina herbacea* (cane tibouchina), *Miconia crenata* (Koster's curse), *Ficus* spp., *Hedychium gardnerianum* (Himalayan ginger), *Angiopteris evecta* (mules foot fern), *Setaria palmifolia* (palm grass), *Passiflora edulis* (passion fruit), *Polygonum chinensis*, *Psidium cattleianum* (strawberry guava), *Fraxinus uhdei* (tropical ash), *Rubus ellipticus* (yellow Himalayan raspberry), and *Delairea odorata* (German ivy) (DLNR 2016, pp. 43–44). During the 2009 survey of the area where Population C was last recorded in Ka'āpahu, nonnative plants that were near the population of *P. stemmermanniae* included *Paspalum conjugatum* (Hilo grass), *Psidium cattleianum*, and *Sphaeropteris cooperi* (Australian tree fern) (Welton 2008, in litt.).

Conservation Actions: While surveys for nonnative plants are conducted on only a small portion of Laupāhoehoe NAR, nonnative plant control is conducted throughout the year (DLNR 2016, p. 43). Nonnative plant surveys and control within the Laupāhoehoe NAR are conducted by DOFAW staff and members of the Youth Conservation Corps (YCC) (when available) (DLNR 2016, p. 49).

Drought
Phlegmariurus stemmermanniae has proven to be susceptible to drought (USFWS 2016a, p. 67,797). Drought causes death and degradation due to loss of moisture and may add to loss of habitat due to increase occurrences of fire. It may also exacerbate the impacts of trampling by ungulates, increasing erosion, and destabilizing substrate (Cuddihy and Stone 1990, pp. 63–34). During a survey in 2013 of the Laupāhoehoe population, it was noted that most of the individuals of *P. stemmermanniae* had died. This was attributed to the severe drought conditions that the island was experiencing at the time (PEPP 2013, p. 5).

Conservation Actions: One method of counteracting the effects of drought is by propagating plants to supplement current populations or reintroduce plants into historically known areas. Currently, the VRPF has one live plant within its collection. However, all efforts at creating supplemental populations of *Phlegmariurus stemmermanniae* have been unsuccessful (PEPP 2010, p. 24). Until successful propagation of plants can be achieved, continuing to monitor plants and collect genetic material is the only way to address death and declining population numbers due to drought.

Inadequate existing regulatory mechanisms
Inadequate Habitat Protection: Nonnative feral ungulates pose a threat to *Phlegmariurus stemmermanniae* through destruction and degradation of the species' habitat and herbivory, but regulatory mechanisms are inadequate to address this threat (USFWS 2016a, p. 67,843). The State of Hawai'i provides game mammal (feral pigs and goats, and axis deer) hunting opportunities on 38 State-designated public hunting areas on the island of Hawai'i (HDLNR 2015, pp. 19–21 and 66–77). However, the State's management objectives for game animals

range from maximizing public hunting opportunities (e.g., "sustained yield") in some areas to removal by State staff, or their designees, in other areas (HDLNR 2015, entire).

Introduction of Nonnative Plants and Insects: Currently, four agencies are responsible for inspection of goods arriving in Hawaiʻi (USFWS 2016a, p. 67,843). The Hawaiʻi Department of Agriculture (HDOA) inspects domestic cargo and vessels and focuses on pests of concern to Hawaiʻi, especially insects or plant diseases. The U.S. Department of Homeland Security-Customs and Border Protection (CBP) is responsible for inspecting commercial, private, and military vessels and aircraft and related cargo and passengers arriving from foreign locations (USFWS 2016a, p. 67,843). The U.S. Department of Agriculture-Animal and Plant Health Inspection Service-Plant Protection and Quarantine (USDA-APHIS-PPQ) inspects propagative plant material, provides identification services for arriving plants and pests, and conducts pest risk assessments among other activities (HDOA 2009, p. 1). The Service inspects arriving wildlife products, enforces the injurious wildlife provisions of the Lacey Act (18 U.S.C. 42; 16 U.S.C. 3371 *et seq*.), and prosecutes CITES (Convention on International Trade in Wild Fauna and Flora) violations. The State of Hawaiʻi allows the importation of most plant taxa, with limited exceptions (USFWS 2016a, p. 67,845). It is likely that the introduction of most nonnative invertebrate pests to the State has been and continues to be accidental and incidental to other intentional and permitted activities. Many invasive weeds established on Hawaiʻi have currently limited but expanding ranges. Resources available to reduce the spread of these species and counter their negative ecological effects are limited. Control of established pests is largely focused on a few invasive species that cause significant economic or environmental damage to public and private lands, and comprehensive control of an array of invasive pests remains limited in scope (USFWS 2016a, pp. 67,843–67,846).

Conservation Actions: Endangered Species Act: The Service determined endangered status under the Endangered Species Act of 1973 (Act), as amended, for 49 plants and animals on September 30, 2016, including *Phlegmariurus stemmermanniae* (USFWS 2016a, entire). The primary purpose of the Act is the conservation of endangered and threatened species and the ecosystems upon which they depend. The ultimate goal of such conservation efforts is the recovery of these listed species, so that they no longer need the protective measures of the Act. Conservation measures provided to species listed as endangered or threatened under the Act include recognition of threatened or endangered status, recovery planning, requirements for Federal protection, and prohibitions against certain activities. The Act encourages cooperation with the States and requires that recovery actions be carried out for all listed species. The Act and its implementing regulations in addition set forth a series of general prohibitions and exceptions that apply to all endangered wildlife and plants. For plants listed as endangered, the Act prohibits the malicious damage or destruction on areas under Federal jurisdiction and the removal, cutting, digging up, or damaging or destroying of such plants in knowing violation of any State law or regulation, including State criminal trespass law. Certain exceptions to the prohibitions apply to agents of the Service and State conservation agencies. The Service may issue permits to carry out otherwise prohibited activities involving endangered or threatened wildlife and plant species under certain circumstances. With regard to endangered plants, a permit must be issued for scientific purposes or for the enhancement of propagation or survival. For federally listed species unauthorized collecting, handling, possessing, selling, delivering, carrying, or transporting, including import or export across State lines and international boundaries, except for properly documented antique specimens of these taxa at least 100 years old, as defined by section 10(h)(1) of the Act, is prohibited. Damaging or destroying any of the listed plants in addition is violation of the Hawai‘i State law prohibiting the take of listed species. The State of Hawai‘i's endangered species law (HRS, Section 195-D) is automatically invoked when a species is federally listed, and provides supplemental protection, including prohibiting take of listed species and encouraging conservation by State government agencies. *Phlegmariurus stemmermanniae* occurs on non-Federal lands, and may still exist on Federal land.

Low population numbers
Narrowly endemic species are inherently more vulnerable to extinction than widespread species because of suspected limitation in the amount of genetic diversity, as well as increased risk of extinction from localized catastrophes such as hurricanes and landslides, drought, disease, and climate change effects (Pimm et al. 1988, p. 757; Mangel and Tier 1994, p. 607). While populations with larger numbers can absorb these impacts, populations with fewer individuals in a smaller geographic area may not be able to recover from such events. Additionally limited numbers produce reduced levels of genetic variability, which diminishes the species ability to adapt to environmental change, thereby decreasing the resiliency of the species (Barrett and Kohn 1991, p.4; Newman and Pilson 1997, p. 354).

Conservation Actions: In 2006, spores were collected by the PEPP survey team from the Laupāhoehoe makai population and delivered to the Lyon Arboretum micropropagation lab for germination. However, when the plants grew it turned out that they were species other than *Phlegmariurus stemmermanniae*. This is a common issue with spore collection as other nearby species spores may settle on the plant and contaminate the sample (Lyon Arboretum 2019, entire). There is currently one plant at the Volcano Rare Plant Facility. In 2010, two plants were kept as representatives of the species, but one died in 2011. Since then, one specimen has been kept in the collection (VRPF 2019, entire).

Climate Change
Changes in global temperature will result in increases in extreme conditions including warmer temperatures at higher elevations and increasing intensity of storms and droughts (IPCC 2014, pp. 6–11) and is currently listed as a potential threat to *Phlegmariurus stemmermanniae* USFWS 2016a, p. 67,798). Current landscape-based analysis on the vulnerability of native plants of Hawai‘i shows that *P. stemmermanniae* is highly vulnerable, with a vulnerability score of 0.578 (on a scale of 0 being not vulnerable to 1 being extremely vulnerable to climate change). In the study, vulnerability is defined as the relative inability of a species to display the possible responses necessary for persistence under climate change (Fortini et al. 2013, pp. 3 and 90).\

Conservation Actions: Hawai‘i passed the Hawai‘i Climate Adaptation Initiate Act in 2014 (HCAIA 2014). This act established an Interagency Climate Adaptation Committee (ICAC), which is attached to the Hawai‘i Department of Land and Natural Resources (DLNR) to establish a policy framework and requirements to address greenhouse gas emissions. The act will help reduce greenhouse gas emissions on a broad scale and overtime may benefit populations of *P. stemmermanniae*.

Table 2. Factors Influencing Viability.

		Laupāhoehoe mauka (Population A)	**Laupāhoehoe makai (Population B)**	**Population C Kaʻāpahu**
Threats & Conservation Actions	Ungulates	Yes	Yes	Yes
	Conservation Action	None	None	Fencing
	Nonnative Plants	Yes	Yes	Yes
	Conservation Action	Nonnative plant removal in parts of the NAR	Nonnative plant removal in parts of the NAR	Removal when found near surveyed plants
	Drought	Yes	Yes	Yes
	Conservation Action	None	None	None
	Inadequate Existing Regulatory Mechanisms	Yes	Yes	Yes
	Conservation Action	None	None	None
	Low Population Numbers	Yes	Yes	Yes
	Conservation Action	Spore collection and genetic storage	Spore collection and genetic storage	None
	Climate Change	Yes	Yes	Yes
	Conservation Action	Creating a task force to address ways Hawaiʻi can help stop the rise of global temperatures		

CURRENT CONDITION

Historical Condition

Historically, Hawaiian wet forests are thought to have occurred along the windward slopes of Hawaiʻi extending from the coastal zone to the summits of Mauna Kea and Mauna Loa Mountains, this included a narrow band on the windward side of the island of Hawaiʻi. On Maui, the wet forests were also located on the windward slopes. Prior to western contact, these areas likely remained relatively unaffected due to the remote nature of the forests. Although specifics of pre-human ecosystems are unknown, relatively high-elevation wet forests that are still intact can give us clues about the ecology and diversity of these forests. Historically, the wet forested areas were dominated by *Acacia koa* and *Metrosideros polymorpha* forests (Clark et al. 2019, pp. 4–7). Therefore, we might assume that *Phlegmariurus stemmermanniae* could have had a wider distribution across its current range due to the dominant occurrence of *Acacia koa* and *Metrosideros polymorpha* in the wet forest habitats and the direct association of *P. stemmermanniae* to these tree species.

Current Condition
Currently there is only one known wild population of *Phlegmariurus stemmermanniae* which is located within the Laupāhoehoe NAR (Population A). Initially there were two populations within this area. These population units are called Laupāhoehoe mauka and Laupāhoehoe makai. This species was first collected in 1981 from two occurrences, with approximately 10 individuals total, in Laupāhoehoe NAR (Medeiros et al. 1996, p. 93). In 1995, three plants were located on a single tree in the Kaʻāpahu area of Haleakalā National Park on the island of Maui (Table 3, Figure 4). Unfortunately, the individuals at Kaʻāpahu have not been seen since 1995 (Palmer 2003, p. 259) and the status of these individuals are unknown. A survey in 2006 found approximately 20 individuals in Laupāhoehoe NAR; however, by 2013 this number dropped to just a few individuals in the mauka population (A) and to zero in the makai population (B), possibly due to a severe drought (Perry 2006, in litt.; PEPP 2013, p. 5). The latest survey in 2018 of Laupāhoehoe NAR noted six mature individuals in the mauka population (PEPP 2018) (Figure 3, Table 3).

While spores and one plant have been collected from the Laupāhoehoe makai population unit in 2010, there has been no success in propagating them to viable plants for reintroduction. Additionally, that collected individual died in 2018. There are currently no translocated populations of *Phlegmariurus stemmermanniae* (VRPF 2019).

Table 3. Current and Historic Populations Units of *Phlegmariurus stemmermanniae.*

Population Unit Name	**Laupāhoehoe mauka**	**Laupāhoehoe makai**	**Kaʻāpahu**
Population Unit Letter	A	B	C
Habitat Type	Wet montane forest	Wet montane forest	Wet montane forest
Last Observation Date	2018	2008	1995
Extant?	Yes	Unknown	Unknown
Population Type (Wild; Reintroduction; Augmentation; Introduction)	Wild	Wild	Wild
Population Trend	Decreasing	Decreasing	Decreasing
Estimated Number of Sites	1	1	1
Estimated Number of Individuals	6	Unknown	0

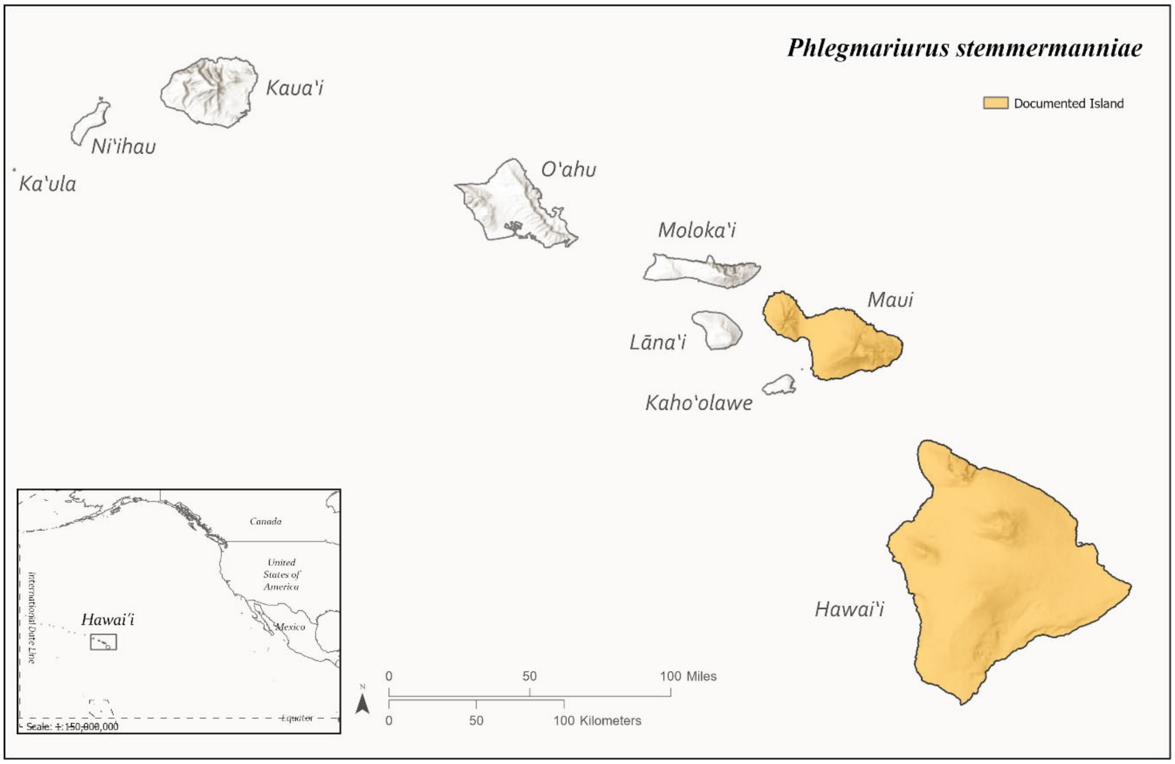

Figure 2. Known range of *Phlegmariurus stemmermanniae* (USFWS 2020b).

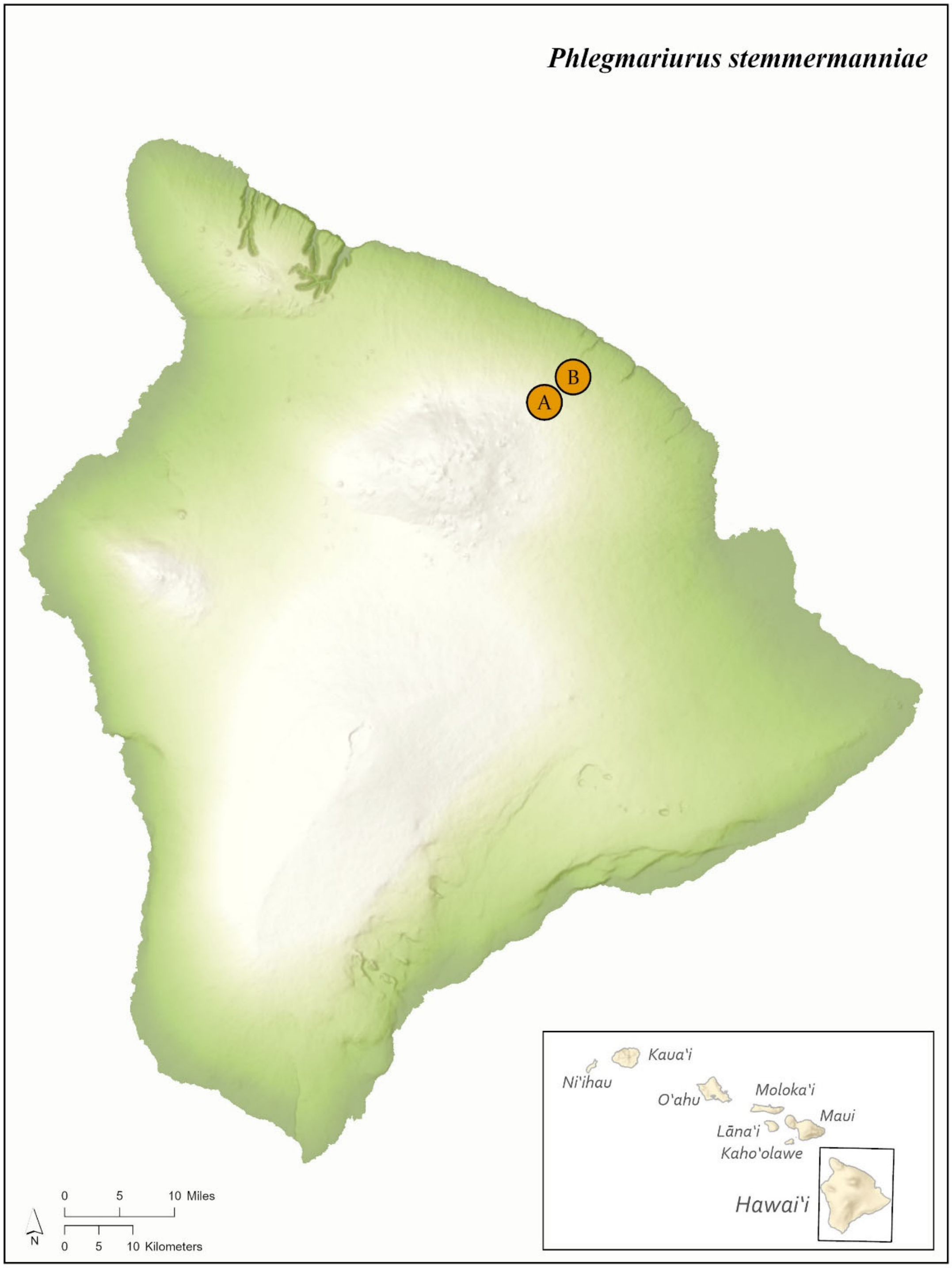

Figure 3. Known populations of *Phlegmariurus stemmermanniae* on the island of Hawai‘i (USFWS 2020b).

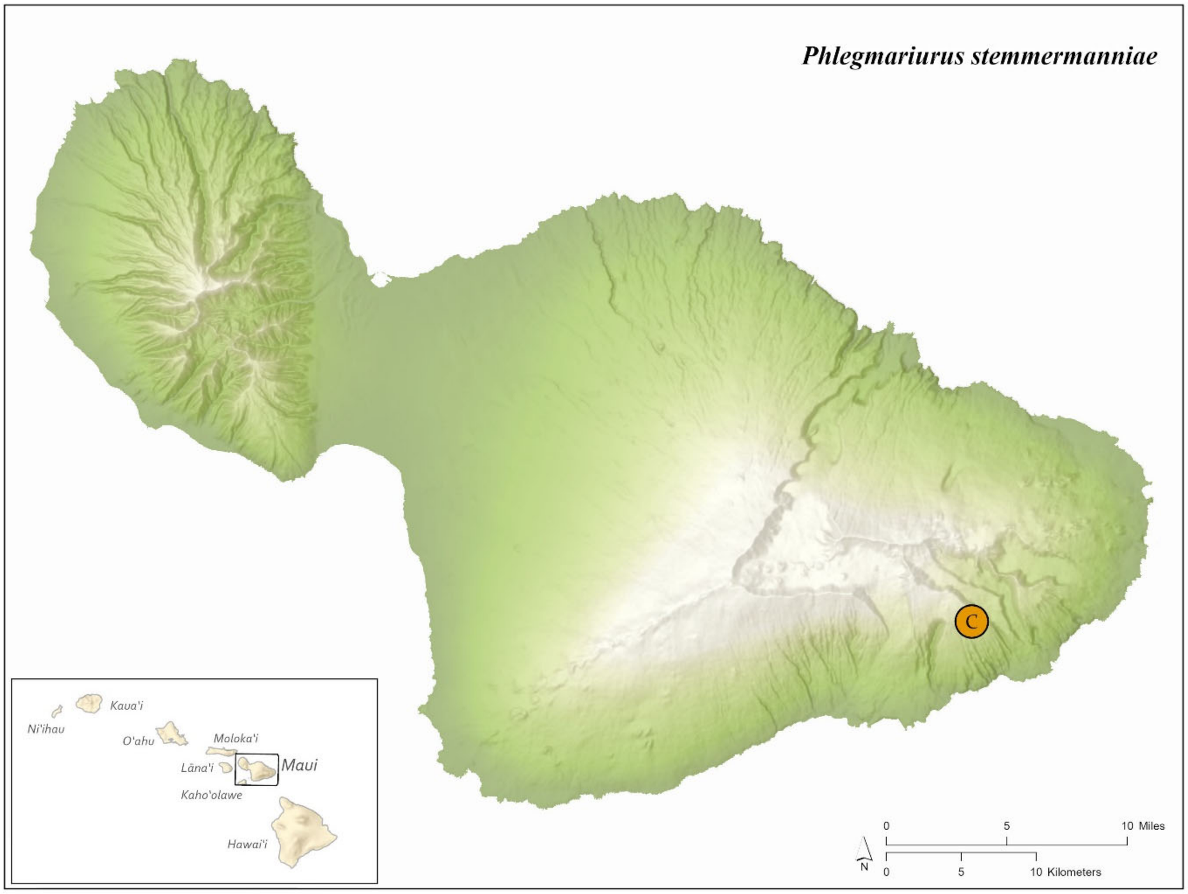

Figure 4. Population of *Phlegmariurus stemmermanniae* on Maui, last seen in 1995 (USFWS 2020b).

SPECIES VIABILITY SUMMARY

To assess species viability we must again look at the 3Rs, resiliency, redundancy, and representation. For this analysis, we will only assess the viability of *Phlegmariurus stemmermanniae* using the Laupāhoehoe mauka and Laupāhoehoe makai population units, as these populations are the only populations that have been observed within the last 15 years.

Resiliency

Resiliency is the capacity of a population to withstand the more extreme limits of normal year-to-year variation in environmental conditions (environmental stochasticity). Numbers of individuals in the wild populations have declined from 20 to 6 individuals. Some conservation measures have been implemented, such as cattle exclusions; however, the populations are exposed to the majority of the threats listed above. Small population size decreases the chances of surviving a single stochastic event. The population and numbers of individuals have not recovered since the severe drought in 2013. Since the populations have not recovered or shown substantial growth since the end of the drought, and there are currently only 6 known individuals of this species, we consider the resiliency of *Phlegmariurus stemmermanniae* to be very low for all populations (Table 4).

Table 4. Resiliency of Populations of *Phlegmariurus stemmermanniae*.

Population Unit Letter	Population Unit Name	Resiliency	Justification
A	Laupāhoehoe mauka	Very Low	Low number of individuals and declining population trend.
B	Laupāhoehoe makai	Very Low	

Redundancy
Redundancy is having more than one resilient population distributed across the landscape, thereby minimizing the risk of extinction of the species. While this species was originally known on two islands, the Maui population has not been observed since 1995. The remaining two populations are only located within the Laupāhoehoe NAR, one of which currently has no known individuals (Laupāhoehoe makai). Finally, there has been no success to date with spore germination from propagules collected from wild individuals, which impacts the ability to reintroduce individuals and bolster population numbers. We therefore conclude that *Phlegmariurus stemmermanniae* is at risk of extinction due to catastrophic events, such as drought, and have very low redundancy.

Representation
Representation is having more than one resilient population of a species occupying the full range of habitat types used by the species and representing all genetic diversity within the species. *Phlegmariurus stemmermanniae* is found only within one habitat type and has one population with currently known, extant individuals that have very low resiliency. While PEPP has been able to collect propagules, no individuals have been produced from spores or cloned vegetatively to allow propagation of new individuals *ex situ* for translocations to occur. We therefore consider this species to have very low representation.

Species Viability Summary
Phlegmariurus stemmermanniae has very low resiliency, redundancy, and representation. Therefore, we consider the overall viability to be very low under its current condition (Table 5).

Table 5. Viability of Current Condition of *Phlegmariurus stemmermanniae*

Species Name	Overall Resiliency	Redundancy	Representation	Viability
Phlegmariurus stemmermanniae	Very Low	Very Low	Very Low	Very Low

LITERATURE CITED

Barrett S.C.H., Kohn J.R. 1991. Genetic and evolutionary consequences of small population size in plants: implications for conservation. In Genetics and Conservation of Rare Plants, ed. D.A. Falk, KE Holsinger, pp. 3–30. New York: Oxford Univ. Press.

Clark, M., M.K. Reeves, F. Amidon, and S.E. Miller. 2020. Hawaiian Islands wet forests. Pages 328–345. In Encyclopedia of the Worlds Biomes. M.I. Goldstein and D.A. DellaSala (Eds.). Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.11920-7.

Cuddihy, L. W. and C.P. Stone. 1990. Alteration of native Hawaiian vegetation: Effects of humans, their activities, and introductions. University of Hawaiʻi Press, Honolulu, Hawaiʻi. p.138.

Fortini, L., J. Price, J. Jacobi, A. Vorsino, J. Burgett, K. Brinck, F. Amidon, S. Miller, S. Gon II, G. Koob, and E. Paxton. 2013. A landscape-based assessment of climate change vulnerability for all native Hawaiian plants. Technical report HCSU-044. Hawaiʻi Cooperative Studies Unit, University of Hawaiʻi at Hilo, Hawaiʻi. 134 pp.

[DLNR] Hawaiʻi Department of Land and Natural Resources, Division of Forestry and Wildlife. 2016. Laupāhoehoe Forest Management Plan. 110 pp.

[HDLNR] Hawaiʻi Department of Land and Natural Resources. 2015. STATE OF HAWAII DEPARTMENT OF LAND AND NATURAL RESOURCES Division of Forestry and Wildlife Title 13 Chapter 123 Rules Regulating Game Mammal Hunting. https://dlnr.hawaii.gov/dofaw/files/2013/09/HAR-123-Game-Mammals.pdf. 78 pages.

[HDOA] Hawaiʻi Department of Agriculture. 2009. Plant guidelines for importation to Hawaii. Available online at: http://hawaii.gov/hdoa/pi/pq/plants.

[HPPRCC] Hawaiʻi and Pacific Plants Recovery Coordinating Committee. 2011. Revised recovery objective guidelines. 8 pp.

[IUCN] International Union for Conservation of Nature. 2013. IUCN Guidelines for Reintroductions and Other Conservation Translocations. Version 1.0. Gland, Switzerland: IUCN Species Survival Commission, viiii + 57 pp.

[IPCC] Intergovernmental Panel on Climate Change. 2014. Fifth assessment report: climate change 2014, synthesis report, summary for policymakers.

Lowe, S., D.L. Ball, M.K. Reeves, F. Amidon, and S.E. Miller. 2020. Hawaiʻi mesic forests. Pages 346–372. In Encyclopedia of the Worlds Biomes. M.I. Goldstein and D.A. DellaSala. Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.11930-X.

Lyon Arboretum. 2019. Lyon Arboretum Hawaiian Rare Plant Program. Report on controlled propagation of listed and candidate species, as designated under the U.S. Endangered Species Act. Unpublished report submitted to the U.S. Fish and Wildlife Service, Pacific

Islands Fish and Wildlife office, Honolulu, Hawai‘i.

Mangel, M. and Tier, C. 1994. Four Facts Every Conservation Biologists Should Know about Persistence. Ecology 75: Issue 3, pp. 607–614.

Medeiros, A.C., Wagner Jr., W.H., and Hobdy, R.W. 1996. A new hanging firmoss (Lycopodiaceae: *Phlegmariurus*) from the eastern Hawaiian Islands. American Fern Journal 86(3):89–97.

Mehltreter, K., Walker, L., Sharpe, J. 2010. Fern Ecology. Cambridge University Press. 429 pp.

Newman, D. and Pilson, D. (1997), Increased probability of extinction due to decreased genetic effective population size: experimental populations of Clarkia pulchella. Evolution, 51: 354–362. DOI:10.1111/j.1558-5646.1997.tb02422.x

[PEPP] Plant Extinction Prevention Program. 2010. Annual Report for Fiscal Year 2010. 120 pp.

[PEPP] Plant Extinction Prevention Program. 2013. Progress Report for Fiscal Year 2013, Quarter 1–2. 23 pp.

[PEPP] Plant Extinction Prevention Program. 2016. Annual Report for Fiscal Year 2016. 241 pp.

Palmer, D. 2003. Hawai‘i’s Ferns and Fern Allies. University of Hawai‘i Press, Honolulu.

[PEPP] 2019. Plant Extinction Prevention Program FY 2019 annual report (Oct 1, 2018–Sep 30, 2019), US FWS CFDA program #15.657; Endangered species conservation-recovery implementation funds, Cooperative Agreement F18AC00502 & F14AC00174, December 31, 2019, UH Manoa, Pacific Cooperative Studies Unit. 53 pp.

Pimm, S. L., H. Lee Jones, and Jared Diamond. 1988. The American Naturalist 132:6, 757–785.

Ranker, T.A., Imada, C.T., Lynch, K., Palmer, D. D., and Vernon, A. 2019. Taxonomic and Nomenclatural Updates to the Fern and Lycopyte Flora of the Hawaiian Islands. American Fern Journal 109(1):54–72.

[USFWS] U.S. Fish and Wildlife Service. 2016a. Endangered and threatened wildlife and plants; Endangered status for 49 species from the Hawaiian Islands. Federal Register 7(190): 67786–67860.

[USFWS] U.S. Fish and Wildlife Service. 2016b. USFWS Species Status Assessment Framework. Version 3.4 dated August 2016.

[USFWS] U.S. Fish and Wildlife Service. 2020a. Recovery Outline for Hawaiian Multi-Island Species. Portland, Oregon. 36 pp.

[USFWS] U.S. Fish and Wildlife Service. 2020b. Unpublished data. U.S. Fish and Wildlife Service, Pacific Islands Field Office, Honolulu, Hawai‘i.

[VRPF] Volcano Rare Plant Facility. 2019. Report on controlled propagation of listed and candidate species, as designated under the U.S. Endangered Species Act. Unpublished report submitted to the U.S. Fish and Wildlife Service, Pacific Islands Fish and Wildlife Office, Honolulu, Hawaii.