Species Report for *Phyllostegia pilosa* (no common name)

Version 1.0

Phyllostegia pilosa (Photo: Kim Starr and Forest Starr)

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EXECUTIVE SUMMARY

This document presents the species report (SR) for *Phyllostegia pilosa* (no common name), completed to assess the species' overall viability. To assess viability we used the three conservation biology principles of resiliency, representation, and redundancy. We identified the species' ecological requirements for survival and reproduction at the individual, population, and species levels, and described risk factors influencing the species' current and future condition.

Phyllostegia pilosa has a restricted range in the Hawaiian islands with a known range on both Molokaʻi and Maui. The species was extirpated from Molokaʻi in the early 1900s (TNC 2007; HBMP 2008). The last two wild individuals of this species were known from The Nature Conservancy (TNC) Waikamoi Preserve of Haleakalā on Maui, but both have died (PEPP 2014-2015) and now the species is believed to be extinct in the wild (Oppenheimer pers. comm. 2019; Wood et al. 2019, p. 3). However, the species is represented in 7 reintroduced locations totaling 81 or fewer individuals, none of which are naturally recruiting. All of the reintroduced individuals occur on Haleakalā in the wet forests of Honomanū and Haipuaʻena, and mesic forests of TNC Waikamoi Preserve in Makawao Forest Reserve (PEPP 2016-2019). Very little is known about *P. pilosa*; much of the information presented in this SR is inferred from closely-related *Phyllostegia* species, and we rely heavily on information from species experts. We focused our analysis on eight primary intrinsic and extrinsic stressors that either significantly or potentially negatively affect the species – introduced ungulates, competition with alien plants, loss of substrate, predation (rodents and slugs), infection by fungal pathogens (powdery mildew), limited numbers (small population dynamics), human disturbance, and climate change. The synergistic effects of multiple stressors on this species have likely exacerbated declines.

Despite the fact that some high quality habitat exists within the historic range of *Phyllostegia pilosa*, no new wild populations have been discovered since 2015, and therefore, we cannot identify any reasonable measure of resiliency for the species. Furthermore, no additional wild populations of *P. pilosa*, distributed across any level of ecological conditions or spatial extent, are known to exist. Therefore we cannot identify any reasonable measure of genetic or ecological representation or redundancy for the species. Despite conservation efforts, there are currently only 2 founder lines (TNC Waikamoi Preserve in Makawao Forest Reserve source populations) represented in *ex situ* populations for this species. These founder lines have been reintroduced into four areas on Haleakalā from Makawao FR to Honomanū (PEPP 2019). However, almost half of the remaining reintroduced individuals are from one location, only seven reintroduced locations remain and a majority have not been monitored in the past seven years, and none of the individuals are reproducing naturally (PEPP 2019). Additionally, *Phyllostegia pilosa* is a short-lived species, and most reintroduced individuals have died (Oppenheimer 2022, pers. comm.) This results in extremely low redundancy, resiliency, and representation for the species. Therefore, the current viability of *P. pilosa* is assessed as <u>extremely low.</u>

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INTRODUCTION

Phyllostegia pilosa (no common name), an upright, unbranched to few branched shrub in the mint family (Lamiaceae), was historically known from Molokaʻi and Maui, and occurred in both mesic and wet forest ecosystems (Figures 3-4). The individuals identified as *P. pilosa* on Molokaʻi, at Kamoku Flats (wet forest ecosystem) and at Moʻoloa (mesic forest ecosystem), have not been observed since the early 1900s (TNC 2007; HBMP 2008). *Phyllostegia pilosa* was also known from the mesic forests of TNC Waikamoi Preserve in Makawao Forest Reserve (Puʻu o Kākaʻe) on Haleakalā as recently as 2015 (Wagner 1999, p. 274; Lowe et al. 2019; HBMP 2010).

Species Report Overview

This biological report summarizes the biology and current status of *Phyllostegia pilosa* and was conducted by Pacific Islands Fish and Wildlife Office. The biological report 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 upon which other documents such as recovery plans and 5-year reviews will be based.

Regulatory History

Endangered Species Act

In 2013 the Service determined the endangered status under the Endangered Species Act of 1973 (Act), as amended, for 38 plants and animals, including *Phyllostegia pilosa*, on Maui, Molokaʻi, and Lānaʻi (USFWS 2013).

Critical habitat

Under section 4(a)(3)(A) of the Act the Service is required to designate critical habitat to the maximum extent prudent and determinable concurrently with the publication of a final determination that a species is endangered or threatened. The final rule designating critical habitat for 135 species on Molokaʻi, Lānaʻi, Maui, and Kahoʻolawe, including *Phyllostegia pilosa*, was published in 2016 (USFWS 2016a). In this rule, a total of 35,021 acres (14,172 ha) of critical habitat was designated for *P. pilosa* on Maui and Molokaʻi (USFWS 2016a). Ecosystem units for this species in unoccupied designated critical habitat include montane wet forest and lowland mesic forest (Figure 1: all ecosystem critical habitat units are displayed, not only the units for *Phyllostegia pilosa*).

Critical habitat for *Phyllostegia pilosa* contains the elevation, moisture regime, substrate, and canopy, subcanopy, and understory native plant species (primary constituent elements (PCEs)), identified as physical or biological features needed for species survival and recovery (USFWS 2016a).

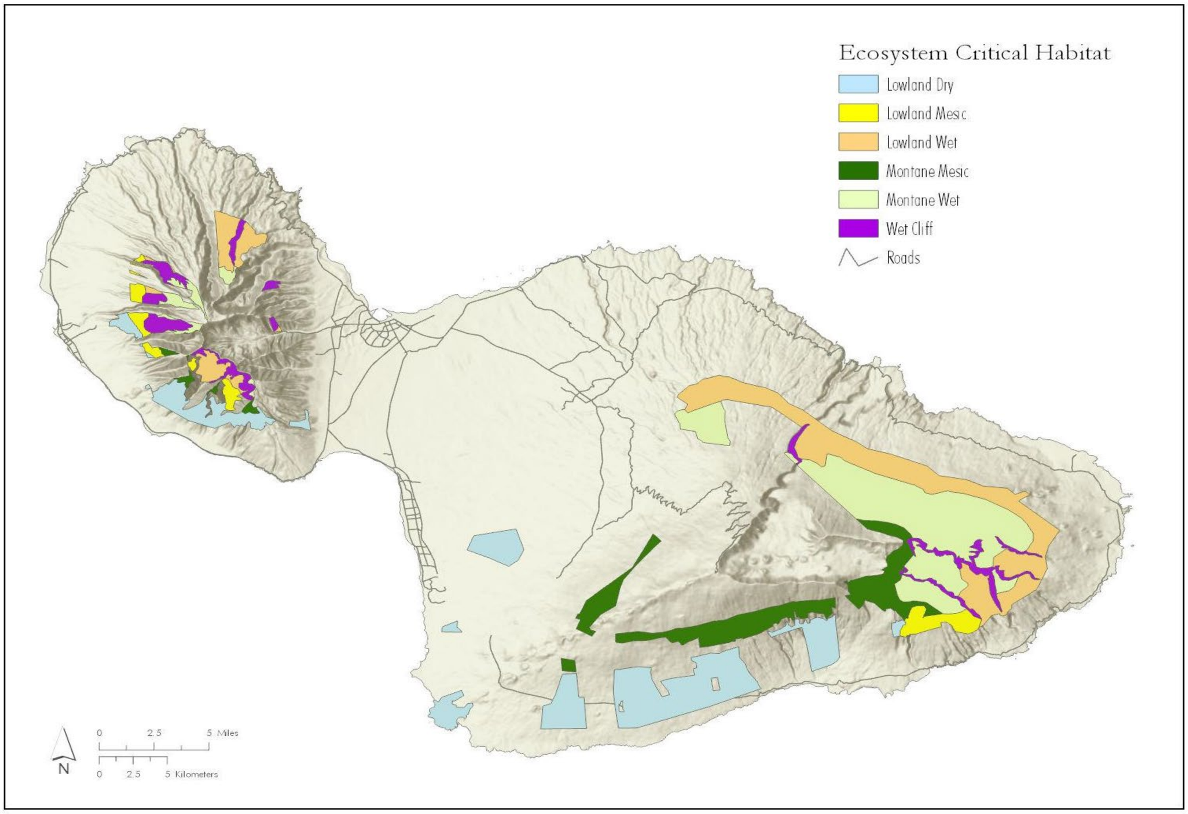

Figure 1. Critical habitat on the island of Maui.

Methodology
We used the best scientific data available to us, including peer-reviewed literature, grey literature (government, academic, and technical reports), and expert elicitation. To the best of our ability we used the current taxonomy at the time this report was drafted. Because little information is available about *Phyllostegia pilosa*, we also used reference material for closely related *Phyllostegia* species to fill in data gaps as well as using basic plant and animal biology to identify needs of individuals, populations, and species.

To assess the current status and viability of *Phyllostegia pilosa*, 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 *Phyllostegia pilosa* 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.

The biological report assesses the ability of *Phyllostegia pilosa* 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 *P. pilosa*, we used the three conservation biology principles of resiliency, redundancy, and representation, or the "3Rs" (Figure 2; USFWS 2016b). We will evaluate the viability of our species by describing what our species needs to be resilient, redundant, and represented, and compare that to the status of our 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.

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.

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.

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 2 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. Resiliency 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 *Phyllostegia pilosa*.

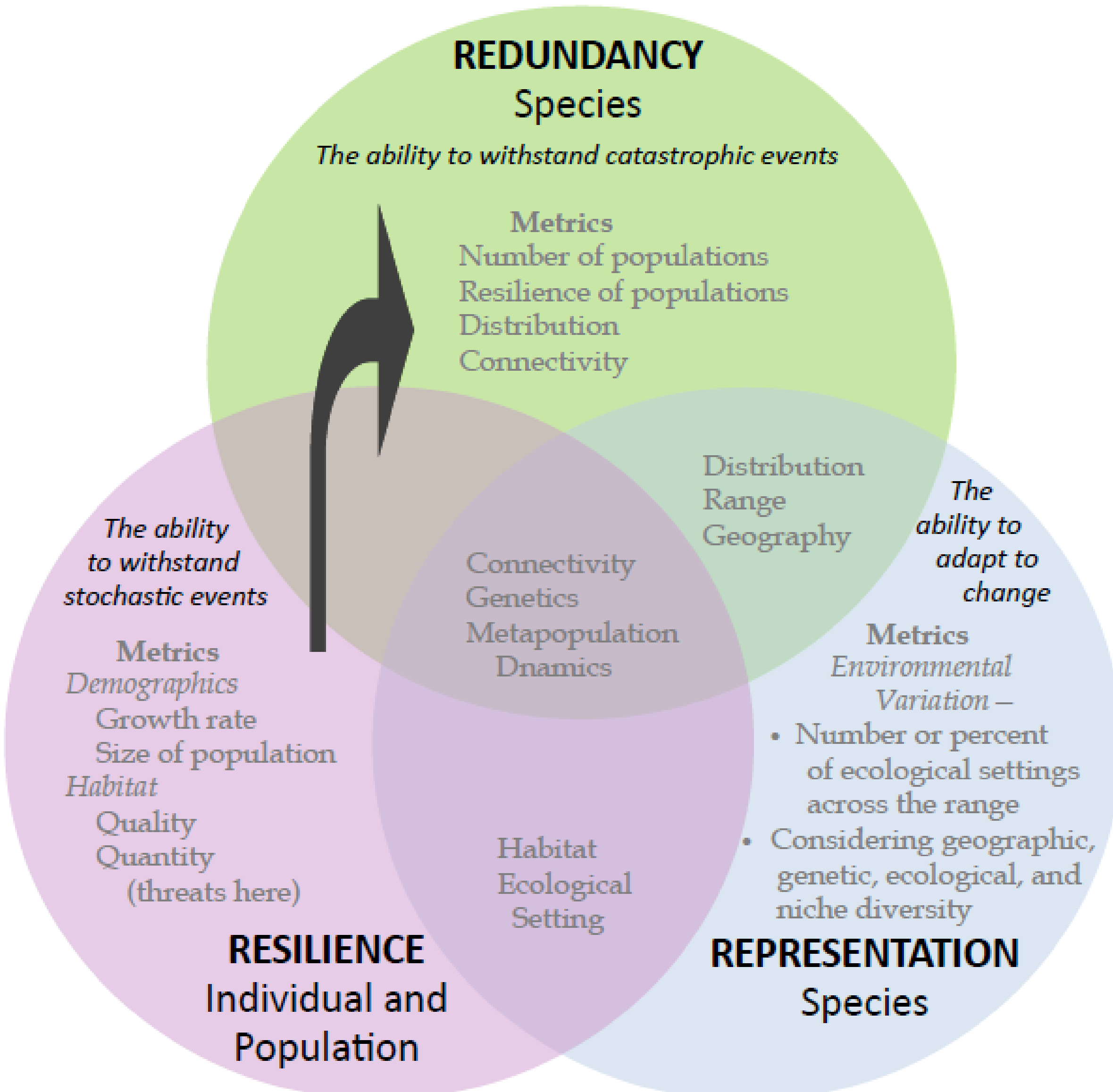

Figure 2. The three conservation biology principles of resiliency, redundancy, and representation, or the "3Rs."

SPECIES NEEDS/ECOLOGY

Species Description

Phyllostegia pilosa (no common name) is an upright, unbranched to few branched shrub in the mint family (Lamiaceae) and was historically known from the mesic forest ecosystem of Haleakalā and likely Mauna Kahālāwai on Maui (Lowe et al. 2019; Wagner 1999, p. 274; Oppenheimer 2022, pers. comm.). It was also found historically in the mesic and wet forests on Molokaʻi (Lowe et al. 2019; Clark et al. 2019; TNC 2007; HBMP 2008). *Phyllostegia* spp. are dicots and are often found growing as scandent (climbing) perennial herbs in the forest understory (Wagner et al. 1999a).

Taxonomy

Phyllostegia pilosa was first described by H. St. John (1987). It is an endemic species of Molokaʻi and Maui was formerly treated within *Phyllostegia mollis* (Wagner et al. 1990; Kartez 1994; 1999). It was recognized as *P. haliakalae* in Wagner and Herbst's 1999 Supplement, with *P. mollis* considered endemic to Oʻahu only. However, Wagner (1999, Novon 9:265-279) has subsequently decided that *P. pilosa* is the correct name for plants called "*P. haliakalae"* with the latter name actually applying to the species previously known as *P. imminuta.* This species is recognized as a distinct taxon in Wagner et al. (1999a) and Wagner and Herbst (2003), the most recently accepted Hawaiian plant taxonomy.

Distribution

Historic Distribution and Assessment of Viability

Phyllostegia pilosa was first described by St. John in 1987. *Phyllostegia pilosa* was documented in historic records from Kamoku Flats (wet forest ecosystem) and Moʻoloa (mesic forest ecosystem), on Molokaʻi in the early 1900s (TNC 2007; HBMP 2008; Lowe et al. 2019; Clark et al. 2019). It was also known from Haleakalā in mesic forests, and historically, likely from Mauna Kahālāwai as well (Oppenheimer 2022, pers. comm.). The last two occurrences of two total individuals, (originally totaling 8 individuals) occurred west of Puʻu o Kākaʻe on Haleakalā (Table 1; Figure 3) (TNC 2007; HBMP 2010; Oppenheimer 2022, pers. comm.). In the absence of the threats introduced such as invasive species, that are current threats to *P. pilosa*, the species likely had more resilient populations.

We currently do not have information on the role of insect pollinators and seed dispersing native birds associated with *Phyllostegia pilosa* in Hawai'i. Several species of now extinct flightless birds likely overlapped the range of *P. pilosa* and may have been important in seed dispersal of the species. The species may have always had relatively low genetic variation, regardless of the number of populations and individuals, due to pollination and seed dispersal mechanisms. The current lack of genetic diversity and high levels of inbreeding expected for rare *Phyllostegia* species may be partly due to few founders and isolated populations due to the topography of Maui and Moloka'i, with many watersheds separated by cliffs and other steep terrain, resulting in low representation. These factors may have increased the species' vulnerability to stochastic events (reduced redundancy), including catastrophic rainfall, storms, and flooding.

Table 1. Known range and locations of *Phyllostegia pilosa* populations.

Population ID	**Geographic Location**	**HSA Ecosystem Type**	**Pop. Type**	**Island**	**Individuals when last observed**	**Last observed**
A	Honomanū	Mesic forest	Wild/ Reintro	Maui	1/ 28	1989/ 2015
B	Makawao	Mesic forest	Wild/ Reintro	Maui	1/ 46	2015 (extirpated 2018*)/ 2017
C	Puʻu o Kākaʻe/ Waikamoi	Mesic forest	Wild/ Reintro	Maui	1/7	2015/2014
D	Moʻoloa	Mesic forest	Wild	Molokaʻi	0	Extirpated early 1900ʻs+
E	Kamakou Flats	Wet forest	Wild	Molokaʻi	0	Extirpated early 1900ʻs+

*Hank Oppenheimer 2022, pers. comm.; +TNC 2007; HBMP 2008

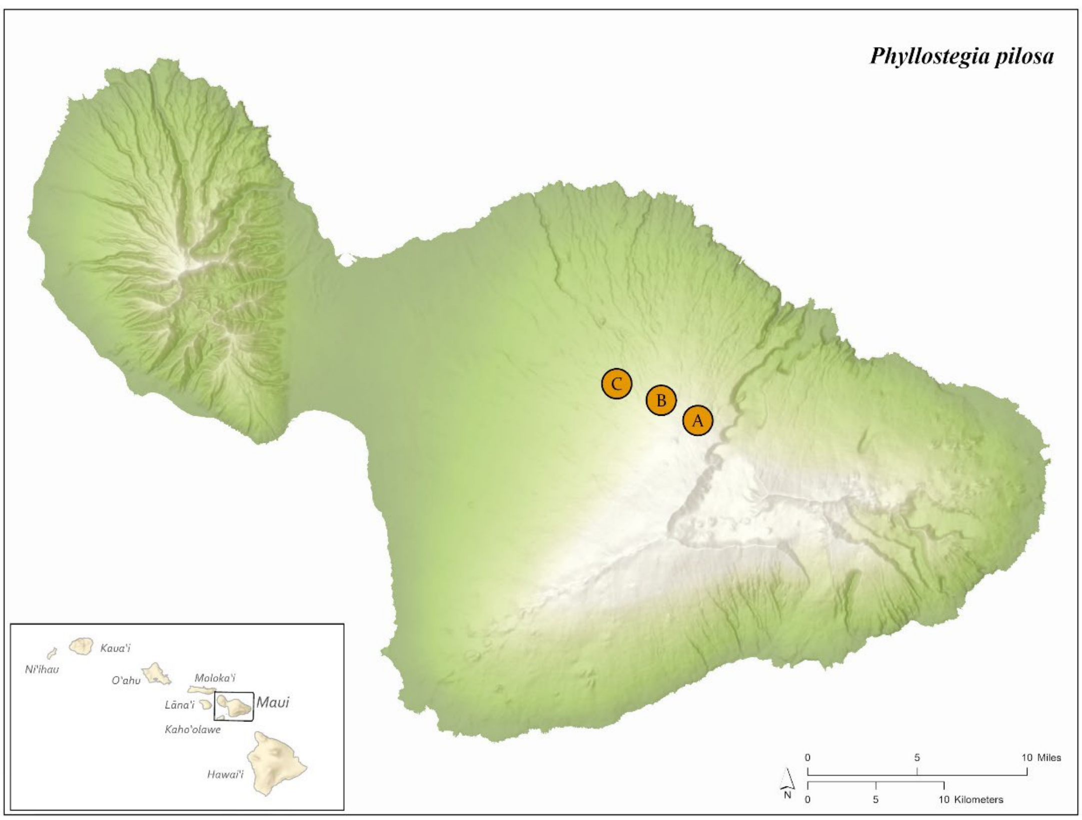

Figure 3. Recent distribution of *Phyllostegia pilosa* on Maui.

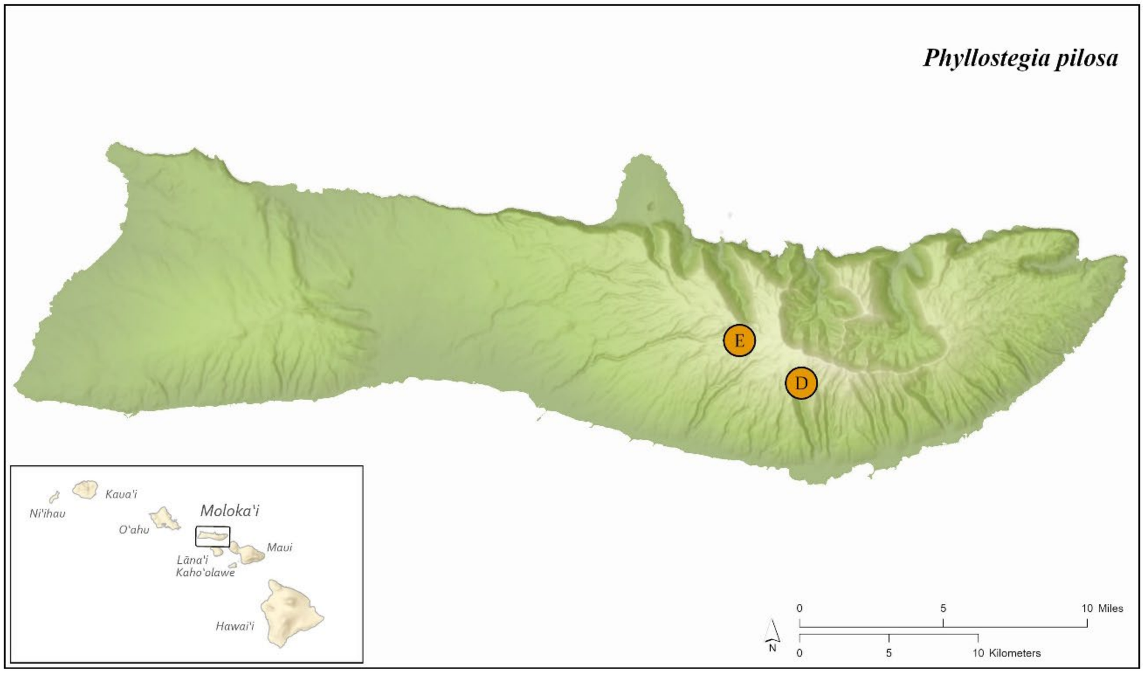

Figure 4. Historically known distribution of *Phyllostegia pilosa* on Molokaʻi.

Individual Ecology/Needs

Phenology and Reproduction

The specific life history characteristics of *Phyllostegia pilosa* has not been studied. It is a short-lived species (Oppenheimer 2022, pers. comm.) and little is known about its reproduction except time of flowering and fruiting. Flowers has been observed between February and April and fruiting observed between April and June (PEPP 2010-2018; Oppenheimer pers comm. 2019).

The fragrant flowers of *Phyllostegia* spp. have prominent lower-lipped, usually white, and rarely pink-tinged corollas, and are associated with insect pollination (Lindqvist and Albert 2002, p. 3; Wood et al. 2019, p. 1). *Phyllostegia* species have well-developed fleshy fruits, a feature commonly associated with bird dispersal of seeds (Carlquist 1980, p. 96).

Population Ecology/Needs

Population size affects population viability through genetic health. Small populations have lower levels of genetic diversity (heterozygosity), which reduces the capacity of a population to respond to environmental change. Inbreeding depression may result, leading to reduced longevity and fecundity and overall population fitness (Darvill et al. 2006, p. 602).

Thus, population viability requires occupying areas with a diversity of environmental conditions (spatial heterogeneity) to ensure populations are secure despite year-to-year variations in climatic variables, such as temperature and precipitation. Similarly, spatial heterogeneity increases the likelihood of long-term metapopulation persistence (Hanski 1999, p. 28). In spatially heterogeneous populations, it is unlikely that the entire population will contemporaneously experience the same environmental conditions, thus ensuring that not all individuals comprising a population will fail due to unfavorable conditions.

Historically, populations of *Phyllostegia pilosa* occurred in both mesic and wet forests on Haleakalā, and likely from Mauna Kahālāwai on Maui, and on Molokaʻi between 4265-6004 feet (ft) (1300-1830 meters (m)) (Wagner et al. 1999a). Characteristics of these ecosystems are described in Table 2 and are further described in the Hawaiʻi Habitat Status Assessments (HSA) by Lowe et al. 2019 and Clark et al. 2019.

The population size required to support a viable population is likely variable across spatial scales and is unknown for *Phyllostegia pilosa*, but generally speaking, the larger the population, the more genetically healthy and thus the more robust to extirpation.

Table 2. Characteristics of ecosystems known to support *Phyllostegia pilosa*.

HSA Ecosystem	**Island(s)/Region**	**Elevation (m)+**	**Precipitation (cm) +**
Wet forest (montane subtype)	Maui /Haleakalā and Molokaʻi	823-2200 m	>250 cm
Mesic forest (montane-subalpine subtype)	Maui/Haleakalā *	900-2000 m	100-380 cm
Mesic forest (lowland subtype)	Molokaʻi	30 to 1600 m	100-380 cm

*Reeves and Amidon 2019; + m=meters; cm=centimeters

Habitat Descriptions

Wet Forests

Montane subtype

The montane wet forest ecosystem is found on the islands of Hawaiʻi, Maui, Molokaʻi, Oʻahu, and Kauaʻi between 2700 and 7217 ft (823 and 2,200 m) elevation and receives > 98.5 inches (in) (250 centimeter (cm)) annual precipitation (Table 2). The boundary between the lowland and montane rainforests is not generally agreed upon by all botanists and ecologists, and it may be variable on the different islands. At upper elevations, these forests may grade into mesic forests while at lower elevations they often merge with lowland wet ecosystems (Clark et al. 2019). The dominant tree species of montane rainforests is most often ʻōhiʻa. A distinct type of forest with tall *Acacia koa* (koa) and ʻōhiʻa occurs in areas with deep soil above the elevations of 900–1,200 m. Montane rainforests are multilayered, below the canopy of ʻōhiʻa (or koa and ʻōhiʻa) is a layer of diverse lower-statured trees in which no one species is dominant. Epiphytic (growing on the surface of a plant) mosses, liverworts, lichens, ferns and hapuʻu are abundant on tree trunks and fallen logs. Fallen logs serve as nurse logs for seedling germination of wet forest species. On the island of Hawaiʻi a layer composed almost entirely of hapuʻu is present, this occurs on other islands as well but to a lesser extent. As with lowland rainforest the ground cover consists of mosses, sedges and a diverse array of fern species (Clark et al. 2019; Cuddihy 1989; Gagné and Cuddihy, 1999). Native biological diversity is moderate to high in this ecosystem (TNC 2006a).

Mesic forests

Montane-subalpine subtype

The montane-subalpine mesic forest subtype occurs above the ʻōhiʻa (*Metrosideros*) lowland wet forest, below montane wet forests, and leeward of koa/ʻōhiʻa (*Acacia koa/Metrosideros*) montane wet forests on the islands of Kauaʻi, Maui, and Hawaiʻi (Lowe et al. 2019; Gagne and

Cuddihy 1999). It occurs between 2952-6561 ft (900-2000 m) elevation and receives 54.3-149.6 in (100-380 cm) annual precipitation. The understory is variable and composed of sedges, ferns, and shrubs (Gagne and Cuddihy 1999). Four subcategories are recognized under the mesic montane-subalpine subtype: ʻōhiʻa (*Metrosideros*) montane mesic forest, koa/ʻōhiʻa (*Acacia koa/Metrosideros*) montane mesic forest, koa/ʻōhiʻa/Aʻe (*Acacia koa/Metrosideros/Sapindus*) mesic forest, and olopua (*Notelaea sandwicensis*) montane mesic forest (Lowe et al. 2019; Gagne and Cuddihy 1999, Table 2). Native biological diversity is high in this system (TNC 2006b).

Lowland subtype

The lowland mesic forest subtype is found on the islands of Hawaiʻi, Molokaʻi, Maui, Kauaʻi and Oʻahu between 98.4 to 5249.3 ft (30 to 1600 m) elevation. On the islands of Maui Nui, this ecosystem is typically found on the leeward slopes of Molokai, Lanai, and Maui (Gagne and Cuddihy 1999, p. 75; Lowe et al. 2019). This ecosystem occurs in the mesic zone between the dry leeward and wet windward climates that receive between 54.3-149.6 in (100-380 cm) annual precipitation (Table 2; Lowe et al. 2019). Vegetation composition is variable, ranging from open to dense tree layers with a diverse canopy, subcanopy, with tall-shrubs and lianas (Gagne and Cuddihy 1999; Lowe et al. 2019). These forests grade into lowland wet forests upslope and at their lower limits grade into either lowland mesic or dry shrublands, or lowland dry forests, depending on topography and moisture. Seven subcategories of native lowland mesic forests are recognized: ʻōhiʻa (*Metrosideros*) lowland mesic forest, koa (*Acacia koa*) lowland mesic forest, olopua (*Nestegis sandwicensis*) lowland mesic forest, lama/ʻōhiʻa (*Diospyros/Metrosideros*) lowland mesic forest, Diverse lowland mesic forest, loulu (*Pritchardia*) lowland mesic forest, and pāpala kēpau/pāpala (*Pisonia/Charpentiera*) lowland mesic forest (Gagne and Cuddihy 1999, Lowe et al. 2019). Native biological diversity is high in this system (TNC 2006c).

Synopsis of Species' Ecological Needs

Viability is the likelihood that a species will sustain populations over time. To do this, *Phyllostegia pilosa* needs a sufficient number and distribution of self-sustaining populations to withstand environmental stochasticity (resiliency), adapt to changes in its environment (representation), and withstand catastrophes (redundancy) (Table 3).

Table 3. Ecological requirements for species-level viability in *Phyllostegia pilosa*.

3Rs	Requisites of long-term viability	Description
Resiliency (able to withstand stochastic events)	Interconnected, healthy populations across a diversity of climatic conditions	Populations with: 1) large N_e, sufficient number of individuals in close proximity to ensure pollination (out-crossing) 2) connectivity between populations, and 3) spatial heterogeneity; high connectivity among populations dispersed across diverse climatic conditions (spatial heterogeneity)

3Rs	Requisites of long-term viability	Description
Representation (to maintain evolutionary capacity)	Maintain adaptive diversity of the species.	Healthy populations distributed across areas of unique adaptive diversity (i.e., ecoregions, ecosystems).
	Maintain evolutionary processes	Maintain evolutionary drivers--gene flow, natural selection, genetic drift- to mimic historical patterns.
Redundancy (to withstand catastrophic events	Sufficient distribution of healthy populations	Sufficient distribution to guard against catastrophic events wiping out portions of the species adaptive diversity, i.e., to reduce covariance among populations.
	Sufficient number of healthy populations	Adequate number of healthy populations to buffer against catastrophic losses of adaptive diversity.

FACTORS INFLUENCING VIABILITY

Threats

The immediate and potential extrinsic and intrinsic threats facing *Phyllostegia pilosa* include the destruction and adverse modification of habitat by feral ungulates (hoofed animals), competition with alien plants, loss of substrate due to landslides/flooding, herbivory and seed predation by introduced rodents, and slugs, infection by fungal pathogens (powdery mildew), limited numbers, human disturbance, and climate change. Threats are summarized in Table 4.

Table 4. Summary of threats to *Phyllostegia pilosa* (Maui PEPP 2016-2018; Oppenheimer 2022).

Feral Ungulates (Browsing/ Trampling)	Alien Plants	Loss of substrate (landslides, flooding, etc.)	Rodents/ Powdery Mildew	Slugs	Human Disturb.	Limited Numbers	Climate change
X	X	X	X	X	P	X	X

X=Threat
P= Potential Threat

Extrinsic Threats

Human Disturbance

Loss of habitat for *Phyllostegia pilosa* occurred from the conversion of habitat to pasture, and from human disturbance such as logging and forestry planting of non-native tree species (Oppenheimer 2022, pers. comm.).

Browsing and trampling by introduced ungulates

The native plants of the Hawaiian Islands evolved in the absence of mammalian predators, browsers, or grazers. Many of the native species have lost unneeded defenses against threats such as mammalian predation and competition with aggressive, weedy plant species that are typical of continental environments (Loope 1992, p. 11; Gagne and Cuddihy 1999, p. 45; Wagner et al.

1999, pp. 3-6). For example, Carlquist (in Carson 1974, p. 29) notes "Hawaiian plants are notably free from many characteristics thought to be deterrents to herbivores (toxins, oils, resins, stinging hairs, coarse texture)." Native Hawaiian plants are therefore highly vulnerable to the impacts of introduced mammals and alien plants. In addition, species restricted and adapted to highly specialized locations are particularly vulnerable to changes (from nonnative species, hurricanes, fire, and climate change) in their habitat (Carson 1974, pp. 28-29; Loope 1992, pp. 3-6; Stone 1989, pp. 88-95; Lowe et al. 2019; Clark et al. 2019). Non-native ungulates (feral pigs, goats, cattle, and axis deer) are a threat to the ecosystems known to support *Phyllostegia pilosa* (Lowe et al. 2019; Clark et al. 2019; PEPP 2010-2019). There are direct observations of feral pig (*Sus scrofa*) herbivory on reintroduced *P. pilosa* reducing its resiliency (PEPP 2009, p. 93). While rooting in the ground in search of the invertebrates and plant material they eat, feral pigs disturb and destroy vegetative cover, trample plants and seedlings, and threaten forest regeneration by damaging seeds and seedlings (Stone and Anderson 1988, p. 137). They disturb soil and cause erosion, especially on steep slopes. Alien plant seeds are dispersed on their hooves and coats as well as through their digestive tracts, and the disturbed soil is fertilized by their feces, helping these plants to establish (Cuddihy and Stone 1990; Wagner et al. 1999a).

Competition with Invasive plants
Nonnative plants are a threat to mesic and wet forest ecosystems that support *Phyllostegia pilosa* (Lowe et al. 2019; Clark et al. 2019). Invasive plants observed to threaten habitat and reintroduced individuals of *P. pilosa* include: *Hedychium gardnerianum* (Kahili ginger) and *Miconia crenata* (Koster's curse), *Rubus argutus* (blackberry), and *Fraxinus uhdei* (tropical ash) (PEPP 2016-2018). Alien plant species modify the availability of light, alter soil-water regimes, modify nutrient cycling, and alter fire regimes which affects native plant communities (Smith 1985, pp. 180–181; Cuddihy and Stone 1990, p. 74; D'Antonio and Vitousek 1992, p. 73; Vitousek et al. 1997, p. 6). The most-often cited effects of nonnative plants on native plant species are displacement through competition. Competition may be for water or nutrients, or it may involve allelopathy (chemical inhibition of other plants) (Smith 1985 *in* Cuddihy and Stone 1990, p. 74). Nonnative plants may also displace native species by preventing their reproduction, usually by shading and taking up available sites for seedling establishment (Vitousek et al. 1987 *in* Cuddihy and Stone 1990, p. 74).

Landslides/flooding
Storms, flooding and landslides can destroy wet and mesic forests, altering succession in areas with poor drainage or on steep ridges and valleys (Lowe et al. 2019; Clark et al. 2019; Restrepo and Vitousek 2001; Walker 1999). Due to the steep topography in some areas on Maui where outplantings of *Phyllostegia pilosa* occur, erosion, treefall, and disturbance caused by heavy rain and flooding has the potential to negatively affect this species reducing its redundancy and resiliency.

Climate change (drought/storms)
Changing climate is considered a primary threat to the wet and mesic forest ecosystems that supports *Phyllostegia pilosa* (Lowe et al. 2019; Clark et al. 2019). The species has limited environmental tolerances, limited ranges, restricted habitat requirements, small population sizes, and low numbers of individuals. Therefore, we would expect this species to be vulnerable to projected environmental impacts that may result from changes in climate, and subsequent

impacts to their habitats. These impacts include long periods of decline in annual precipitation resulting in a reduction in moisture availability, an increase in drought frequency and intensity, and a self-perpetuating cycle of nonnative plants (such as nonnative grasses adapted to fire and dry conditions) intruding and displacing native plant communities.

In a climate change vulnerability study, a similar rare Maui endemic mint, *Phyllostegia haliakalae,* was found to have a medium level of vulnerability to predicted climate change (Fortini et al. 2013, p. 84). Findings of the study showed an increase in vulnerability from wet to dry ecosystems, with wet systems being at least risk to climate change (Fortini et al. 2013, p. 37). This species overlaps with the known range of *Phyllostegia pilosa,* and also occurs in the wet and mesic forest ecosystems of Haleakalā. Because this species is currently only being reintroduced into mesic and wet forest habitats, it is likely to have a similar climate change vulnerability risk as *P. haliakalae.*

Rodents

Invasive rodents (*Rattus rattus* and *Mus musculus*) are a prominent stressor for vegetation in the ecosystems that support *Phyllostegia pilosa* (Lowe et al. 2019). All three species of rat (black, Norway, and Polynesian) have been reported to adversely impact many endangered and threatened Hawaiian plants (Stone 1985, p. 264; Cuddihy and Stone 1990, pp. 67–69). Rodents damage plant propagules, seedlings, and native trees, which changes forest composition and structure (Cuddihy and Stone 1990, p. 67) reducing redundancy and resiliency in ecosystems that support *P. pilosa*.

Predation by non-native slugs

The health and distribution of mesic forests are affected by introduced herbivores, including slugs (Clark et al. 2019; Lowe et al. 2019). Non-native slugs are found in wet and mesic forests where *Phyllostegia pilosa* occurs and they are considered to be a threat to seedling recruitment by the PEPP program (PEPP 2010-2019). Predation by non-native slugs adversely impacts native plant species through mechanical damage, destruction of plant parts, and mortality (Joe 2006, p. 10; HBMP 2008). Joe and Daehler (2008, p. 252) found that native Hawaiian plants are more vulnerable to slug damage than nonnative plants. In addition, larvae of native *Lepidoptera* sp. also predate *Phyllostegia* species (Oppenheimer 2022, pers. comm.) To date there has been no natural recruitment observed at any location where *P. pilosa* has been reintroduced.

Infection by fungal pathogens

Fungal pathogens, such as powdery mildew, are considered a potential threat to *Phyllostegia pilosa*, as this leaf disease commonly affects other species in the genus *Phyllostegia* (Zahn and Amend 2017, entire; Schierman 2014, p. 1). Powdery mildew is a common disease involving several different species of fungi (Davis et al. 2008, p. 1). Most powdery mildew fungi grow as thin layers of mycelium (fungal tissue) on the surface of the affected plant part. Powdery mildew first appears as white, powdery spots that may form on both surfaces of leaves, on shoots, and sometimes on flowers and fruit. These spots spread over the leaves and stems, which may turn chlorotic, necrotic, and fall off (Davis et al. 2008, p. 2). Spores, which are the primary means of dispersal, make up the bulk of the white, powdery growth visible on the plant's surface (Davis et al. 2008, p. 2). If plants of *P. pilosa* become overwhelmed with powdery mildew, then they could slowly begin to die as leaves and stems become chlorotic and fall off. Additionally, reproduction may be reduced as flowers and fruits are infected by powdery mildew. Therefore, fewer individuals of *P. pilosa* are able to reach reproductive maturity, produce seeds, and contribute to the structure of a population. Recently, researchers have experimented with inoculation of native species with probiotic fungal cultures and have found them to protect other native *Phyllostegia* species at some reintroduction sites (Zahn and Amend 2017, entire).

Intrinsic Threats

Small population dynamics

There are current and ongoing threats to this species due to factors associated with small numbers of populations and individuals. Currently, there are no known wild populations of *Phyllostegia pilosa* (Oppenheimer pers comm. 2019).

These threats are exacerbated by this species inherent vulnerability to extinction from stochastic events (low resiliency and redundancy) at any time because of their endemism, small numbers of individuals and populations, and restricted habitats. With only 7 reintroduced locations of 81 or fewer individuals, reduced reproductive vigor and extinction due to stochastic events, such as hurricanes or landslides, are also threats to *Phyllostegia pilosa.* Additionally, continual outplantings are required for species survival in the absence of natural recruitment, due to its short-lived life history (Oppenheimer 2022, pers. comm.)

Limited Number of Individuals and Populations

Species that are endemic to single islands are inherently more vulnerable to extinction than are widespread species, because of the increased risk of genetic bottlenecks, random demographic fluctuations, climate change effects, and localized catastrophes such as hurricanes, landslides, rockfalls, drought, and disease outbreaks (Pimm et al. 1988, p. 757; Mangel and Tier 1994, p. 607). These problems are further magnified when populations are few and restricted to a very small geographic area (low redundancy), and when the number of individuals in each population is very small (low resiliency). Populations with these characteristics face an increased likelihood of stochastic extinction due to changes in demography, the environment, genetics, or other factors (Gilpin and Soulé 1986, pp. 24–34). A single, stochastic event can result in the extinction of an entire species, if all the representatives of that species are concentrated in a single area (low redundancy). In addition, small, isolated populations often exhibit reduced levels of genetic variability (low representation), which diminishes the species' capacity to adapt and respond to environmental changes, thereby lessening the probability of long-term persistence and lowering its resiliency (e.g., Barrett and Kohn 1991, p. 4; Newman and Pilson 1997, p. 361). Very small, isolated populations of plants also are more susceptible to reduced reproductive vigor due to ineffective pollination, inbreeding depression, and hybridization due to low representation. The problems associated with small population size and vulnerability to random demographic fluctuations or natural catastrophes are further magnified by synergistic interactions with other threats, such as those discussed above.

We consider the limited numbers of populations and few individuals (81 reintroduced plants) to be a serious and ongoing threat to *Phyllostegia pilosa*. In addition, the last known wild occurrence of *P. pilosa* was in 2015 and all reintroduced individuals are represented by only two founders (none of which are naturally recruiting). The species is planted only on Haleakalā on Maui, making it susceptible to threats from habitat degradation or loss by flooding, landslides, or tree falls, or a combination of these, because of their limited distribution in wet and mesic forest ecosystems and in locations with steep terrain (USFWS 2013; PEPP 2009, pp. 23–24, 49–58). Rare species may experience: (1) reduced reproductive vigor due to ineffective pollination or inbreeding depression; (2) reduced levels of genetic variability, leading to diminished capacity to adapt and respond to environmental changes, thereby lessening the probability of long-term persistence; and (3) a single catastrophic event may result in extirpation of remaining populations and extinction of the species.

Pollinator deficiency
Phyllostegia spp. and other Lamiaceae are believed to have evolved with an insect pollinator (Lindqvist and Albert 2002, p. 3). We currently do not have information on the role this may have played in the potential for outcrossing and if in-breeding depression may be a threat due to pollinator deficiency. It is likely that this species is be able to produce viable seeds without out-crossing, as individual plants have been observed to produce viable seed (Oppenheimer 2022, pers. comm.).

Other threats
Inadequate Regulatory Mechanisms
Current biosecurity regulations and existing funding is not sufficient to prevent the ongoing threats from introduced species which pose a threat to the wet and mesic forest ecosystems required by *Phyllostegia pilosa* (Clark et al. 2019; Lowe et al. 2019). With no change in current conservation management parameters, threats from established pests (e.g., nonnative ungulates, weeds, and invertebrates) are expected to continue into the future (Lowe et al. 2019). Existing State and Federal regulatory mechanisms are not preventing the introduction into Hawaii of nonnative species or the spread of nonnative species between islands and watersheds (USFWS 2016*)*.

Conservation Efforts
Watershed Partnerships
The East Maui Watershed Partnership (EMWP) manages lands where reintroduced individuals of *Phyllostegia pilosa* occur (Figure 5). Most of the ongoing conservation management actions undertaken by the EMWP addresses threats to upland habitat from nonnative species (e.g., feral ungulates, nonnative plants) and may include fencing, ungulate removal, nonnative plant control, and outplanting of native, as well as rare native, species on lands within the partnership (HAWP 2018; Lowe et al. 2019). These efforts help to increase resiliency and redundancy of *P. pilosa* individuals being reintroduced in the managed watershed partnership area.

The Nature Conservancy
The Nature Conservancy's Waikamoi Preserve encompasses 5,141 ac (2,080 hectares (ha)) along the northern boundary of Haleakalā National Park on Maui. The preserve was established in 1983, through a perpetual conservation easement with Haleakalā Ranch Company, to protect one of the largest intact native rain forests in Hawaiʻi (TNCH 2006, p. 3). The Nature Conservancy is a member of the East Maui Watershed Partnership and manages wet and mesic forest habitat where *Phyllostegia pilosa* is being reintroduced by the Plant Extinction Prevention Program (Figure 5). Additional conservation actions on the TNC preserve include fencing, weed and ungulate control, outplanting, and the protection and restoration of rare species. Efforts by The

Nature Conservancy to reduce threats to habitat where *P. pilosa* is being reintroduced, helps to increase the likelihood that outplanted populations will naturally recruit and therefore increase the resiliency, representation and redundancy of the species.

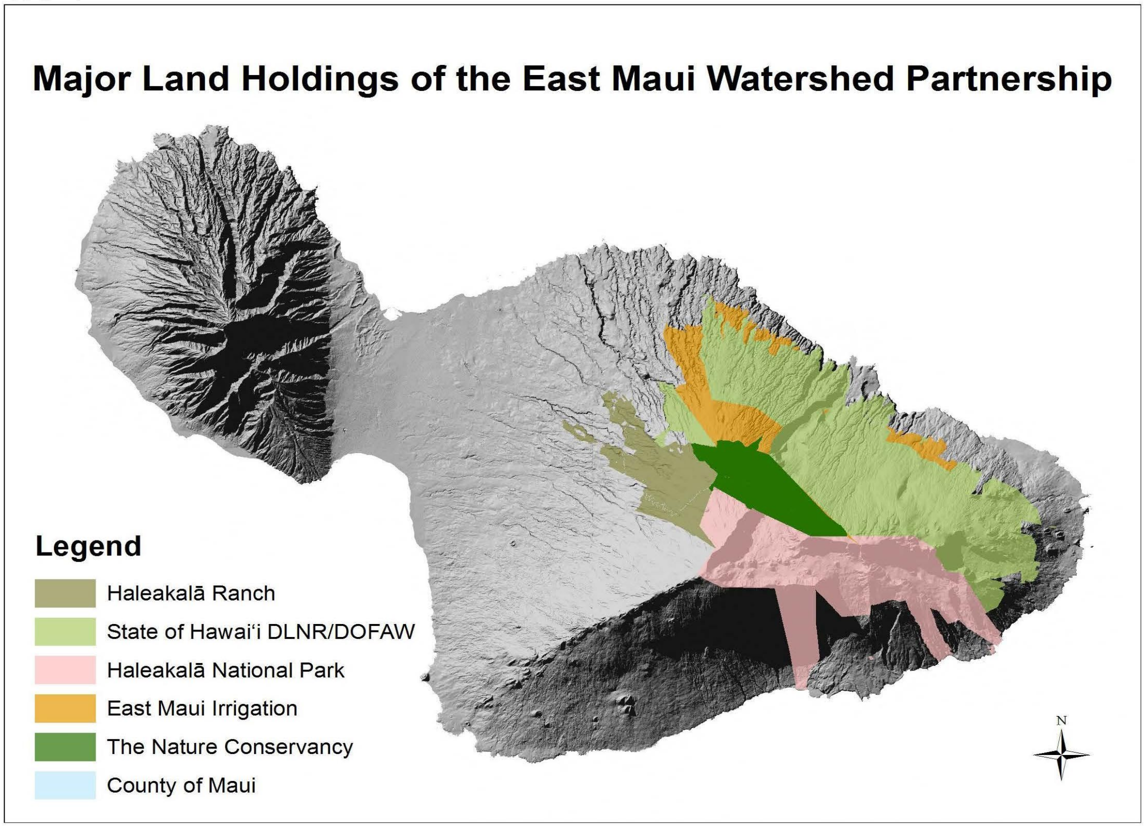

Figure 5. East Maui Watershed Partnership Landowners (HAWP 2018).

Plant Extinction Prevention Program (PEPP)
The State of Hawaii's Plant Extinction Prevention (PEPP) Program collects, propagates, and outplants species with fewer than 50 plants remaining in the wild (Lowe et al. 2019). *Phyllostegia pilosa* is a species managed by the PEPP program although it is now believed to be extinct in the wild (PEPP 2019; Wood et al. 2019, p. 2). In addition to evaluating the viability of PEPP populations, program staff also conduct fencing, weed control, and predator control (slugs, rodents) at sites where *P. pilosa* and other PEPP species have been reintroduced (Table 5). The PEPP program has reintroduced *P. pilosa* into four separate geographic areas in 14-17 locations (87 individuals) on Haleakalā (Honomanū, Haipuaʻena, Makawao and Waikamoi). Seven of these outplanting locations totaling 81 or fewer individuals remain (PEPP 2019). Natural recruitment has not been observed at reintroduction sites (Table 6). Botanists with the program also conduct extensive surveys for rare plant species in areas where populations were known to exist historically (Maui PEPP 2018, pp. 37-47; Table 1). Staff of the PEPP program adhere to strict biosanitation protocols developed by the program which includes removal of invasive plants, animals, or pathogens through the decontamination of vehicles, helicopters, tools, equipment, supplies, clothes, hands, etc. to prevent introduction or infestations of contaminants to protected plant populations and sites (PEPP 2017, p.1). Efforts by the PEPP program helps to increase the resiliency, representation and redundancy of this species.

Table 5. Management actions at reintroduction sites by PEPP.

Population	Location (Haleakalā)	Last census	Fenced	Ungulates present	Other Threats	Habitat Management
A	Honomanū/ Haipuaʻena	2015	X	N	Rats, slugs	Weed control
B	Makawao	2006 - 2018	X	N	Rats, slugs	Weed control
C	Waikamoi	2014	X	N	Rats, slugs	Weed control

Table 6. Reintroduced populations of *Phyllostegia pilosa*.

Population	Location (Haleakalā)	HSA Ecosystem	Last observed	Total Number individuals
A	Honomanū/ Haipuaʻena	Wet forest	2015	28
B	Makawao	Mesic forest	2006 -2018	46
C	Waikamoi	Mesic forest	2014	7

Olinda Rare Plant Facility (ORPF) and Lyon Arboretum
Phyllostegia pilosa has been successfully propagated at the Olinda Rare Plant Facility where an *ex situ* collection of seven plants from two distinct founder lines (TNC Waikamoi Preserve in Makawao Forest Reserve source populations) are maintained for the purpose of controlled propagation. The Lyon Arboretum also maintains one *ex situ* collection (Makawao founder) in seed storage (>17,000 seeds) and micropropagation (Table 7).

Table 7. *Phyllostegia pilosa* reference populations in controlled propagation, seed storage, and micropropagation.

Population	Reference Location	Seed Storage (Lyon Arboretum)	Micropropagation (Lyon Arboretum)	Propagation (Olinda Rare Plant Facility)
B	Makawao FR	X	X	X
C	Waikamoi	-	-	X

Source: ORPF 2018, Lyon Arboretum 2018

CURRENT CONDITION

Current Status

The last two occurrences of wild *Phyllostegia pilosa* were documented in 2014 and 2015, but both individuals have since died (Table 8; Figure 3), and the species is now possibly extinct in the wild, but persists in *ex situ* collections and *in situ* reintroductions (PEPP 2014- 2015;

Oppenheimer pers. comm. 2019; Wood et al. 2019, p. 3). Botanists continue to search for potential suitable habitat near the last known occurrences of the species (PEPP 2019; Wood et al. 2019, p. 1-3).

Phyllostegia pilosa is currently known from reintroductions at 7 locations, composed of two founder lines and totaling approximately 81 or fewer individuals on Haleakalā (Tables 6-7; PEPP 2019). No natural recruitment has been confirmed in any of the outplanted populations (PEPP 2014-2019). Reintroduced individuals occur in two ecosystems (wet and mesic forests). The species is represented in micropropagation and in genetic storage (Lyon Arboretum) with >17,000 seeds banked from one founder line (Makawao). There are two founder lines (TNC Waikamoi Preserve in Makawao Forest Reserve source populations) represented in controlled propagation (7 plants) at the Olinda Rare Plant Facility (ORPF) (Table 7).

Definitions

Redundancy is having a sufficient number of populations distributed geographically that a species can withstand catastrophic events. A catastrophic event is defined here as a rare destructive event or episode involving one or more populations and occurring suddenly. Redundancy is about spreading risk and is measured through the duplication and broad distribution of populations across the range of the species. For *Phyllostegia pilosa*, we measure redundancy based on the number of populations across the species range.

Representation is having the breadth of genetic makeup for *Phyllostegia pilosa* to adapt to changing environmental conditions. Representation can be measured through the genetic diversity within and among populations and the ecological diversity (also called environmental variation or diversity) of populations across the species' range. The more representation, or diversity, the species has, the more it is capable of adapting to changes (natural or human caused) in its environment. For genetic diversity we have not identified specific genetic differences among wild populations, but consider populations > 3280.8 ft (1,000 m) apart to be genetically distinct. We evaluate ecological representation based on the number of the ecosystem types (wet forest and mesic forest) where this species occurs.

Resiliency is having sufficiently large populations for the species to withstand stochastic events. Stochastic events are those arising from random factors such as weather, flooding, or fire. We can measure resiliency based on metrics of population size and freedom from threats including herbivory and introduced invasive plants. Larger populations protected from ungulates and invasive plants are better able to withstand disturbances such as random fluctuations, for example fluctuations in seed set (demographic stochasticity), variations in rainfall (environmental stochasticity), drought and other factors.

Table 8. Location of wild *Phyllostegia pilosa*.

Name	HSA Ecosystem	Population Type	# of Populations	Region	Number Individuals	Date of last census/obs.
B	Mesic forest	Wild	2	Haleakalā Makawao	0	6/2018

PEPP Report 2016-2019

Current Condition Viability
There are no extant wild populations of *Phyllostegia pilosa* remaining (Wood et al., 2019, p. 3). All populations are reintroduced (7 locations), totaling approximately 81 or fewer plants and none are naturally reproducing. All of the reintroduced individuals occur on Haleakalā in the wet forests of Honomanū and Haipuaʻena, and the mesic forests of TNC Waikamoi Preserve in Makawao Forest Reserve (PEPP 2016-2019). The number of plants in each population ranges from 1-38 per site (Table 6). The species has >17,000 seeds banked at Lyon Arboretum, and five founder lines, composed of seven plants, exist in *ex situ* collections at the Olinda Rare Plant Facility (ORPF).

Resiliency: We consider resiliency to be extremely low because there are no known remaining wild, naturally reproducing populations or individuals. The remaining resiliency for the species is limited to the reintroduced individuals and *ex situ* populations. The number of reintroduced individuals total 81 plants or fewer. Outplanted *Phyllostegia pilosa* are vulnerable to predation by rats and slugs and damage by flooding because they occur along streams and gulches. These ongoing threats make it more difficult for the species to recover from other stochastic environmental and demographic events. There are a large number of seeds (>17,000) from five founder lines in genetic storage and two founder lines (2 plants) in *ex situ* propagation at the ORPF that may be used to increase propagation and to recover outplants affected by stochastic events. Threats from slugs and rats are ongoing and may impact success of outplantings.

Representation: We consider representation for *Phyllostegia pilosa* to be extremely low because there are no known remaining wild, naturally reproducing populations or individuals. The remaining representation for the species is limited to the reintroduced individuals and *ex situ* locations. Plants at reintroduced locations are not naturally reproducing and they all occur in only one narrow geographic region (Haleakalā). The species is restricted to only two ecosystem types (wet and mesic forests). Only two founder lines (TNC Waikamoi Preserve in Makawao Forest Reserve source populations) are represented in *ex situ* populations.

Redundancy: We consider redundancy for *Phyllostegia pilosa* to be extremely low because there are no known remaining wild, naturally reproducing populations or individuals on east or west Maui. The remaining redundancy for the species is limited to the reintroduced individuals. The reintroduced individuals are not naturally reproducing and all 7 remaining reintroduced locations potentially could be seriously damaged if a hurricane were to strike east Maui or other extreme weather event.

Summary Species Viability
The current condition for *Phyllostegia pilosa* in terms of redundancy, representation, and resiliency is extremely low. There are no known wild, naturally reproducing populations or individuals on either Haleakalā on Maui or on Moloka'i. *Phyllostegia pilosa* exists in low numbers of approximately 81 reintroduced individuals 7 locations, none of which are naturally recruiting. *P. pilosa* is distributed in two ecosystems: wet forest and mesic forest, in four geographic areas on Haleakalā, a substantial restriction from the species' known range historically. The remaining geographic distribution provides some level of protection against catastrophic events such as hurricane, flood, and fire. *P. pilosa* has thousands of seeds in genetic storage, but only five founder lines, both from mesic forest habitat, are represented in *ex situ*

collections for controlled propagation. Because the remaining founder lines only represent a small portion of the species previous diversity, outplants resulting from *ex situ* propagation may have reduced success in reintroductions planted in wet forest habitat. Table 9 provides a summary of the current status for *P. pilosa*.

Table 9. *Phyllostegia pilosa* current status: resiliency, representation, and redundancy.

Resiliency	Representation	Redundancy	Overall Viability
Extremely Low	Extremely Low	Extremely Low	Extremely Low

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Personal Communication

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