U.S. Fish and Wildlife Service

Recovery Plan for 15 Species from the Island of Hawai‘i

Hawaiian picture-wing fly (*Drosophila digressa*). Photo by Dr. Karl Magnacca.

Cyrtandra nanawaleensis (ha‘iwale or kanawao ke‘oke‘o). Photo by Joshua VanDeMark.

Recovery Plan for 15 Species from the Island of Hawai‘i

U.S. Fish and Wildlife Service
Portland, Oregon

Approved: HUGH MORRISON Digitally signed by HUGH MORRISON Date: 2023.07.18 15:23:10 -07'00'

Regional Director
Pacific Region 1

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RECOVERY PLANNING PROCESS

The Service uses a three-part framework for recovery planning (click here for details). This approach is intended to reduce the time needed for recovery planning, increase the relevancy of recovery plans over a longer timeframe, and increase the flexibility of recovery planning documents by making them easier to modify as new information or circumstances arise. Under this process, a recovery plan includes the statutorily-required elements under section 4(f) of the Endangered Species Act (Act) (objective and measurable recovery criteria, site-specific management actions, and estimates of time and costs), along with a concise introduction and our strategy for how we plan to achieve species recovery. The recovery plan is supported by two supplementary documents: a species status assessment or species biological report, which describes the best available scientific information related to the biological needs of the species and assessment of threats; and the recovery implementation strategy, which details the particular near-term activities needed to implement the recovery actions identified in the recovery plan. Under this approach, new information on species biology or details of recovery implementation may be incorporated by updating these supplementary documents without concurrent revision of the entire recovery plan, unless changes to statutorily-required elements are necessary.

Thus, this recovery plan document is one piece of a three-part framework.

1. The **Species Status Assessment** (SSA) or **Species Report** (SR) inform the recovery plan. Each report describes the biology and life-history needs of a listed species (includes distinct population segments, subspecies, species groups), includes analysis of each species' historical and current conditions, and discusses threats and conservation needs of each species. The format of the SSA or SR is structured around the conservation biology principles of resiliency, redundancy, and representation (Shaffer and Stein 2000, pp. 307–310; Wolf et al. 2015, entire; Smith et al. 2018, entire). This document may be updated as needed based on new information.

   There are 15 Species Reports associated with this recovery plan (USFWS 2023b through USFWS 2023p, entire), which summarize the biology and threat status of each species addressed in the recovery plan including the geography and environmental context of their range on the island of Hawaiʻi. Species Reports include information from Habitat Status Assessments completed by the Service (Ball et al. 2020; Browning et al. 2020; Clark et al. 2020; Javar-Salas et al. 2020; Kim et al. 2020; Lowe et al. 2020; Nelson et al. 2020; Peʻa et al. 2020; Phillipson et al. 2020). Habitat Status Assessments are used to evaluate the current status, stressors, and future viability of the terrestrial habitats found in the Hawaiian Islands.

2. The **Recovery Plan** contains a concise overview of the recovery strategy for the species (indicating how its recovered state will achieve redundancy, resiliency, and representation), as well as the statutorily-required elements of recovery criteria, recovery actions, and estimates of the time and costs to achieve the plan's goals.

3. The **Recovery Implementation Strategy** (RIS) outlines how the recovery plan will be implemented. The RIS is a short-term, flexible operational document focused on how, when, and by whom the recovery actions from the recovery plan will be implemented.

This document may be updated as needed based on new information, allowing it to be adapted to changing circumstances with greater flexibility and efficiency. The RIS will be developed and maintained in cooperation with our conservation partners and will focus on the period of time and activities that work best for our partners to achieve recovery goals.

We are coordinating with conservation partners at the State of Hawaiʻi, Department of Land and Natural Resources (DLNR) Division of Forestry and Wildlife, DLNR Division of Aquatic Resources, Plant Extinction Prevention Program (PEPP), watershed partnerships, the County of Hawaiʻi, research institutions, native Hawaiian and local communicties, National Park Service, and public and private stakeholders, to identify the highest-priority actions for recovery of these species to develop a RIS.

EXECUTIVE SUMMARY

Species Status
This recovery plan addresses 15 species or subspecies (13 plants [10 species, 3 subspecies; hereafter species] and 2 invertebrates) endemic to the island of Hawaiʻi. These 15 species were listed as endangered on October 29, 2013 (USFWS 2013). Critical habitat was designated for *Bidens micrantha* spp. *ctenophylla* in 2018 (USFWS 2018). The proposed rule addressing critical habitat for the remaining 14 species was published on March 29, 2023 (USFWS 2023a).

Species included in this recovery plan

Taxon	**Common Name**	**Plant Life History and Growth Form**
Plants		
Bidens hillebrandiana ssp. *hillebrandiana*	koʻokoʻolau	Short-lived perennial herb
Bidens micrantha ssp. *ctenophylla*	koʻokoʻolau	Short-lived perennial herb
Cyanea marksii	hāhā	Short-lived perennial palm-like tree
Cyanea tritomantha	ʻakū	Short-lived perennial palm-like tree
Cyrtandra nanawaleensis	haʻiwale, kanawao keʻokeʻo	Short-lived perennial shrub
Cyrtandra wagneri	haʻiwale, kanawao keʻokeʻo	Short-lived perennial shrub
Melicope remyi (listed as *Platydesma remyi*)	no common name	Long-lived perennial shrub or shrubby tree
Phyllostegia floribunda	no common name	Short-lived perennial subshrub
Pittosporum hawaiiense	hōʻawa	Long-lived perennial tree
Pritchardia lanigera	loulu	Long-lived perennial tree
Schiedea diffusa ssp. *macraei*	no common name	Short-lived perennial vine
Schiedea hawaiiensis	no common name	Short-lived perennial herb
Stenogyne cranwelliae	no common name	Short-lived perennial vine
Invertebrates		
Drosophila digressa	picture-wing fly	Not applicable
Vetericaris chaceorum	anchialine pool shrimp	Not applicable

Recovery Vision
A recovery vision builds on the description of viability for the species and defines what recovery looks like for the species. The recovery vision for the 15 species addressed in this recovery plan is to have redundant, self-sustaining populations representing the genetic and ecological diversity of the species distributed across their ranges in habitats where threats are managed. A recovery vision for each species group or species is presented in the main body of this recovery plan.

Recovery Strategy
Achieving recovery for the 15 species will require a combination of assessments of populations and their habitat, selection of sites for long-term conservation, management of threats, development of regulatory protections, species-specific research, and conservation translocation (hereafter, translocation [i.e., deliberate movement of organisms for conservation]) to maximize resiliency, redundancy, and representation. The recovery strategy for each species group or species is presented in the main body of the recovery plan.

Many of the plant species covered by this recovery plan persist at very low numbers and are in rapid decline. To target and track recovery efforts for critically rare plants, the Hawaiʻi and Pacific Plants Recovery Coordinating Committee (HPPRCC) developed two interim recovery stages (i.e., preventing extinction and interim stabilization) with the goal of minimizing the likelihood of extinction and to stabilize populations (HPPRCC 2011). While defining these two interim recovery stages is not required under the Act, they are vital for the recovery of these species. In addition to these interim stages, we have identified the required recovery criteria that, when met, indicate downlisting or delisting a species may be warranted. Recovery will be achieved through a series of conservation stages: (1) preventing extinction, (2) interim stabilization, (3) downlisting, and (4) delisting.

The conservation measures recommended by these stages include genetic storage, managing threats in the immediate vicinity of individual plants, and translocation with the goal of protecting and/or creating multiple resilient populations of each species across its known range. The recovery of each species will follow from these initial efforts and include continued assessments of the distribution and condition of the 13 plant species and their habitat, selection of sites for their long-term conservation, management of threats, and development of regulatory protections to assure their long-term protection. These species will require protection from general or species-specific threats including vandalism, human disturbance, collection, fire, military activities, stochastic events (drought, erosion, flood, hurricanes, high surf, landslides, rockfall, treefall, volcanic eruption), rodents, logging of *Acacia koa* (koa), predation or herbivory by nonnative invertebrates (e.g., slugs, leafhoppers, beetles, scale, nonnative game birds) and vertebrates (e.g. ungulates), pollinator or disperser deficiency, introduction of disease, hybridization, lack of regeneration, and limited numbers. Recovery strategies for the individual plant species are presented in the body of the recovery plan.

The invertebrate species covered by this recovery plan presumably persist at very low numbers. Preventing extinction and stabilizing populations are immediate needs. The recovery strategy for the anchialine pool shrimp and picture-wing fly includes identification of all extant populations throughout the historical and existing suitable range of each species to assess their distribution. For both species, establishing captive-rearing programs to prevent extinction and provide future sources for conservation translocation is an immediate need. Research will inform adaptive management. Each species will need long-term protection of habitat and populations from species-specific threats which may include habitat degradation from a variety of sources, predation, loss of host plants, competition, disease, impaired water quality and flow, lack of sufficient breeding or food resources, and human-associated threats such as collection of individuals and contamination of habitat.

Recovery and long-term protection of all 15 species will require collaboration with Federal, State, County, native Hawaiian and local communities, nonprofit, and private stakeholders to develop adaptive management and monitoring plans for each species' habitats, threats, and biosecurity. Some species may require translocation to suitable historical, restored, or created habitats to achieve the resiliency necessary for the species to thrive. Recovery strategies for individual species and species groups are in the body of the recovery plan.

Interim Recovery Stages for Plant Species

Preventing Extinction

To meet the preventing extinction targets, a thorough and accurate population survey and population size estimate of the 13 listed plants must be completed throughout each species' historical range. Reproductive studies must be completed as needed to inform management. Each species requires a minimum of 3 to 6 self-sustaining populations comprised of 25 to 50 mature individuals per population with evidence of natural reproduction (i.e., viable seeds, seedlings, saplings). Threats are assessed and managed in the immediate vicinity of the populations. Genetic storage of at least 50 individuals per population, or the total number of individuals if fewer than 50 remain, are secured in a well-managed *ex situ* collection (such as a nursery or seed bank) (Guerrant et al. 2004, entire).

Interim Stablization

To meet the interim stabilization targets for the 13 listed plant species, all preventing extinction targets must be achieved as well as having 3 to 6 self-sustaining populations comprised of 100 to 300 mature individuals per population and threat management continues around each population. Monitoring is in place to assess individual plant survival, population trends, trends of major limiting factors, and the response of populations to threat management. In addition, all populations must be adequately represented in a well-managed *ex situ* collection (Guerrant et al. 2004, entire).

Recovery Criteria

The following tables summarize the downlisting and delisting criteria for the 15 species covered in this recovery plan. See the body of the recovery plan to locate detailed explanations of each criterion.

Plant Species

Downlisting and Delisting Criteria — 13 Plant Species

	Criterion 1	Criterion 2
Downlisting Criteria	At least 5 or 10 resilient populations, each with 200 or 500 individuals (number of populations and individuals depends on the species' life history characteristics).	Habitat and threats are managed; monitoring and management plans are completed and implemented for each species.
Delisting Criteria	At least 10 or 20 resilient populations, each with 200 or 500 individuals (number of populations and individuals depends on the species' life history characteristics).	Habitat and threats are managed; monitoring of population status and threats is ongoing.

Animal Species

Downlisting and Delisting Criteria — 1 Anchialine Pool Shrimp Species

	Criterion 1	Criterion 2	Criterion 3	Criterion 4
Downlisting Criteria	At least six distinct anchialine pool complexes are occupied by stable populations.	Land protections are in place for each distinct anchialine pool complex in *Downlisting Criterion 1.*	Occupied anchialine pools in *Downlisting Criterion 1* have sufficient water quality to support the species and are protected from habitat degradation.	All major threats to habitat and individuals are managed; monitoring and management plans are completed and implemented.
Delisting Criteria	At least 11 distinct anchialine pool complexes are occupied by stable populations.	Land protections are in place for each distinct anchialine pool complex in *Downlisting Criterion 1.*	Occupied anchialine pools in *Delisting Criterion 1* have sufficient water quality to support the species and are protected from habitat degradation.	All major threats to individuals and habitat are managed; monitoring of population status and threats is ongoing.

Downlisting and Delisting Criteria — 1 Picture-wing Fly Species

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5
Downlisting Criteria	At least five populations with stable population indices are distributed throughout the species' historical or in otherwise suitable habitat; all units of designated critical habitat are occupied by at least one population.	A captive-rearing program is established to support reestablishment in historical and suitable range.	Each picture-wing fly population site in *Downlisting Criterion 1* has viable populations of appropriate host-plant species.	Threats to suitable habitat supporting populations in *Downlisting Criterion 1* are managed and afforded land protections to ensure long-term persistence of the species.	All major threats to individuals and populations in *Downlisting Criterion 1* are managed; monitoring and management plans are completed and implemented; measures are in place to prevent introduction of new threats to host plants.
Delisting Criteria	Ten years of systematic surveys have documented significant increases in population indices and the species is represented by at least 10 populations distributed throughout its historical range or in otherwise suitable habitat; all units of designated critical habitat are occupied by 1 or more populations.	Each population site in *Delisting Criterion 1* has viable populations of appropriate host-plant species.	All major threats to suitable habitats supporting populations in *Delisting Criterion 1*, are managed and habitats are afforded land protections to ensure long-term persistence of the species.	All major threats to individuals and populations in *Delisting Criterion 1* are managed; monitoring of threats and population status is ongoing; measures are in place to prevent introduction of new threats.	N/A

Recovery Actions and their Costs

Recovery actions and cost estimates for all 15 species are shown in the table below. Cost estimates are preliminary. Project-level details of recovery action implementation will be developed with partners in a separate recovery implementation strategy (RIS) document, which will supplement this recovery plan. Implementation is subject to availability of funds and is at the discretion of partners.

Estimated Costs of Recovery Actions for all 15 Species (in Fiscal Year 2023 dollars) over a 20-year time horizon.

Recovery Actions	Recovery Action #	Estimated Cost
Determine the current distribution and status of the species and their habitats.	1.0	**$4,576,119**
Protect populations and manage threats to habitat.	2.0	**$149,057,791**
Manage species-specific threats.	3.0	**$47,598,925**
Expand the distribution of existing wild populations and establish new populations.	4.0	**$69,155,075**
Conduct additional research essential to recovering the 15 species and restoring their habitats.	5.0	**$31,608,955**
Implement regulations and policy to support species recovery.	6.0	**$3,925.373**
Total Estimated Cost for First 20 Years of Recovery[1]:		**$305,922,239**

[1] Over the 50–95-year projected time to recovery, cost estimation is highly uncertain. We focus here on estimated costs for the initial 20 years of recovery implementation.

Date of Recovery

If all actions are fully funded and implemented as outlined, including cooperative efforts by all partners needed to achieve recovery, we estimate that the earliest years that delisting criteria could be met would be between 2078 and 2118 for the plant species, 2073 for the picture-wing fly, and 2083 for the anchialine pool shrimp.

ACRONYMS AND ABBREVIATIONS

Act	Endangered Species Act
CRB	coconut rhinoceros beetle
DLNR	State of Hawaiʻi Department of Land and Natural Resources
DOFAW	State of Hawaiʻi Division of Forestry and Wildlife
HDOH	Hawaiʻi State Department of Health
HPPRCC	Hawaiʻi and Pacific Plants Recovery Coordinating Committee
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
NAR	Natural Area Reserve
NMFS	National Marine Fisheries Service
PEPP	Plant Extinction Prevention Program
PIFWO	Pacific Islands Fish and Wildlife Office
ppt	parts per thousand
RIS	Recovery Implementation Strategy
ROD	Rapid ʻŌhiʻa Death
RPI	Recovery Planning and Implementation
Service	U.S. Fish and Wildlife Service
SR	Species Report
SSA	Species Status Assessment
ssp	subspecies
USFWS	U.S. Fish and Wildlife Service

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I. INTRODUCTION

The Endangered Species Act of 1973, as amended (16 U.S.C. 1531 *et seq.*) (Act) protects species of wildlife and plants that are listed as endangered or threatened. Recovery is defined as "the process by which listed species and their ecosystems are restored and their future is safeguarded to the point that protections under the Act are no longer needed," according to National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service (Service) Interim Recovery Planning Guidelines, Version 1.4 (NMFS and USFWS 2018).

Recovery plans are guidance documents developed to provide recommendations to reduce or alleviate threats to the species (includes distinct population segments, subspecies, species groups) and ensure self-sustaining populations in the wild. Section 4(f)(1) of the Act requires that recovery plans include: (1) a description of site-specific management actions necessary to conserve the species; (2) objective, measurable criteria that, when met, will allow the species to be removed from the Federal Lists of Endangered and Threatened Wildlife and Plants; and (3) estimates of the time and cost required to achieve the plan's goals and intermediate steps.

This recovery plan addresses 15 species or subspecies (13 plants [10 species, 3 subspecies; hereafter species], 1 anchialine pool shrimp, and 1 picture-wing fly) that occur on the island of Hawai‘i (Figure 1). All 15 species were listed as endangered on October 29, 2013 (Table 1; USFWS 2013). The Recovery Outline for Hawai‘i Island was published on October 31, 2019 and addressed these same 15 species (USFWS 2019).

Critical habitat was designated on August 21, 2018 (USFWS 2018), for one plant species, *Bidens micrantha* ssp. *ctenophylla* (Table 1). Critical habitat is currently being determined for the anchialine pool shrimp, the picture-wing fly, and the other 12 plant species.

A. BACKGROUND

1. Basic Species Information

The species addressed in this recovery plan occur on the island of Hawai‘i (Table 1; Figure 1). Detailed species descriptions, life history, status, historical and current range, and distribution are contained in the proposed listing rule (USFWS 2012), final listing determination (USFWS 2013), and 15 Species Reports (USFWS 2023b through USFWS 2023p). The 15 listed species are known from 8 habitats: coastal, dry shrublands and grasslands, dry forest, mesic forest, mesic shrublands and grasslands, wet forest, wet shrublands and grasslands, and wetlands (Tables 2 and 3; Ball et al. 2020; Browning et al. 2020; Clark et al. 2020; Javar-Salas et al. 2020; Kim et al. 2020; Lowe et al. 2020; Nelson et al. 2020; Pe‘a et al. 2020). These species and their habitats occur on public and private lands (USFWS 2013). See Appendix A for the list of species with their associated Species Report and Habitat Status Assessment(s).

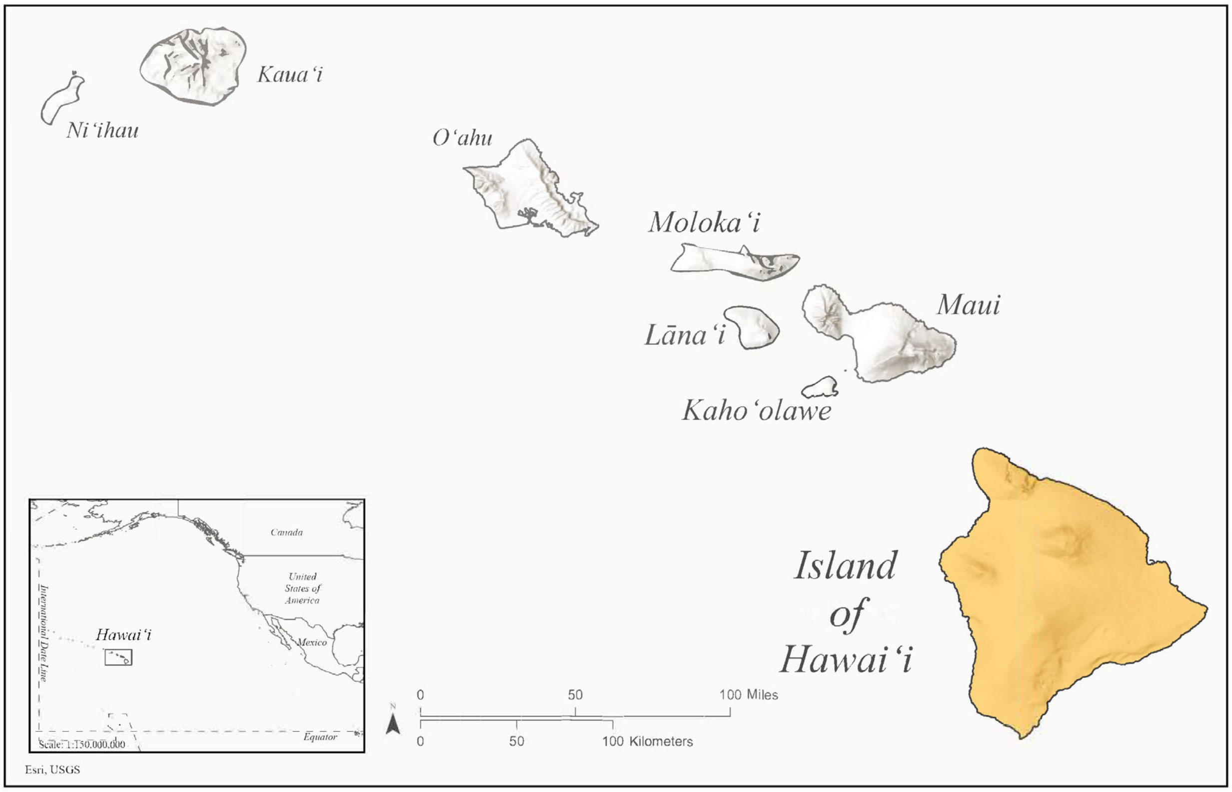

Figure 1. The main Hawaiian archipelago with the island of Hawai'i shown in yellow. Map compiled from Esri (2021) and Hawai'i Statewide Geographic Information System Program (2022) datasets.

The 13 plant species addressed in this recovery plan consist of perennial trees, palm-like trees, shrubs, subshrubs, vines, and herbs. Many of these plant species are maintained *ex situ* (off site, e.g., in a botanical garden or rare plant facility) in controlled propagation, as germplasm, or in micropropagation storage such as seedbanks, or both (Table 1). Ten of the plant species have short life spans defined here as greater than 1 year but less than 10 years, and the remaining 3 species (*Melicope remyi*, *Pittosporum hawaiiense*, and *Pritchardia lanigera*) have life spans greater than 10 years. Collectively, the 13 plant species occupy 7 terrestrial habitats: coastal habitat, dry shrublands and grasslands, dry forest, mesic forest, mesic shrublands and grasslands, wet forest, and wet shrublands and grasslands.

Vetericaris chaceorum was first discovered at Lua o Palahemo in 1986; since then, the species has been documented in five anchialine pools (Kensley and Williams 1986, pp. 417–418; Brock 2004, entire; Sakihara 2012, p. 89). Of these, one occurs at Lua o Palahemo, three occur inside the Manukā Natural Area Reserve (NAR) and another occurs outside the Manukā NAR (USFWS 2023b). Lua o Palahemo is approximately 9.3 miles (mi) (15 kilometers [km]) from the anchialine pools at Manukā and there is no known subterranean connection between the two areas (Fransen et al. 2013, p. 630), thus we consider them two distinct populations (Table 1). The last detection of the anchialine pool shrimp at Lua o Palahemo and at Manukā occurred in 1991 and 2016, respectively (Shizuma et al. 2016, p. 33). Anchialine pools are coastal land-locked bodies of water that have underground hydrological connections to the ocean and show tidal fluctuations in water level. These pools are mixohaline (brackish), with salinities typically ranging from 2 parts per thousand (ppt) to concentrations just below that of sea water (32 ppt), although some pools are recorded as having salinities as high as 41 ppt (Maciolek 1983, pp 607–612; Brock et al. 1987, p. 200; Browning et al. 2020 p. 4) and surface temperatures ranging from 62.6 to 96.8 degrees Fahrenheit (17 to 36 degrees Celsius) (Yamamoto et al. 2015, pp. 5, 7). The upper and lower salinity tolerance is not known for the life stages of *V. chaceorum*. The shrimp inhabit an extensive network of water-filled interstitial spaces (cracks and crevices) leading to and from the actual pool, a characteristic that has precluded researchers from ascertaining accurate population size estimates without draining the entire pool (Holthuis 1973, p. 36; Maciolek 1983, pp. 613–616; Iwai et al. 2009, entire). Water flow in anchialine pools is influenced by tidal fluctuations and occurs primarily underground with no consistent surface connection to the ocean (Maciolek and Brock 1974, p. 5; Browning et al. 2020, p. 4). Some pools contain surface water only during high-tide events (Maciolek and Brock 1974, p. 5). *V. chaceorum* is a blind predator of small invertebrates and captures prey in a basket formed by its pereiopods (walking limbs) as it swims (Kinzie 2010 in litt., entire). Gut content analysis by Kensley and Williams (1986, p. 426) documented a large quantity of orange-colored oil and numerous crustacean fragments, some of which proved to be from another endangered anchialine pool shrimp, *Procaris hawaiana*. While feeding habits have not been observed in the field, in the lab *V. chaceorum* actively catch and consume ʻōpaeʻula (*Halocaridina rubra*) (Sakihara 2012 in litt., entire; Yamamoto et al. 2015, p. 40). For the purposes of this recovery plan, because there is no evidence that the species has been extirpated from Lua o Palahemo, it is considered extant despite a lack of surveys (USFWS 2023b, p. 7). It is considered extant at Manukā because conditions have not changed since the 2016 surveys (USFWS 2023b, pp. 8, 18).

The picture-wing fly is endemic to the island of Hawaiʻi and historically known from five locations, ranging in elevation from approximately 2,000 to 4,500 feet (ft) (610 to 1,370 meters [m]) in mesic forest and montane wet forest habitats (Hardy and Kaneshiro 1968, p. 182; Montgomery 1975, p. 95; Magnacca 2006 in litt., entire; Magnacca 2012 in litt., entire; Kaneshiro 2013 in litt., pp. 1–2; USFWS 2013, p. 64643; Magnacca 2023 in litt, entire). Based on the most recent surveys, the species persists at three locations, including the Olopua Kīpuka fenced exclosure in mesic montane habitat of the Manukā NAR, in montane wet habitat of ʻŌlaʻa Forest within Hawaiʻi Volcanoes National Park, and in the Honomalino Forest Reserve. The number of individuals at each of these locations is unknown (Table 1). Given the limited number of surveys outside of the species known range, it is possible that small populations exist in areas not recently surveyed (Table 1) (Magnacca 2019 in litt., entire). Adult picture-wing flies are generalist microbivores (microbe eating) and feed on decomposing plant material. Females oviposit (lay their eggs) only in stems and bark of decaying *Charpentiera* spp. (pāpala), *Ceodes brunoniana* (pāpala kēpau [previously known as *Pisonia brunoniana*]), and *Rockia sandwicensis* (pāpala kēpau [previously known as *Pisonia sandwicensis*]) or host plants (Magnacca 2012 in litt., entire; Rossetto and Caraballo-Ortiz 2020, entire). Breeding generally occurs year-round, but egg laying and larval development increases following the rainy season. The larvae complete their development in the decaying tissue before dropping to the soil to pupate. Pupae develop into adults in approximately 1 month. Adults become sexually mature about 1 month later and live for 1 to 2 months (Spieth 1974 pp. 385, 389; Science Panel 2005 pp 3–5). This picture-wing fly species is not currently in a captive-rearing program.

Taxonomic Classification or Changes in Nomenclature

There has been a recent taxomonic change for one plant species covered in this recovery plan that does not affect its range or endangered status. *Platydesma remyi* was first described by Sherff (1939, pp. 557–558) as *Claoxylon remyi* and was later placed in the genus *Platydesma* by Degener et al. (1960, entire). This taxonomy was accepted by Stone in Wagner et al. (1999, p. 1210) and at the time of listing, the species was taxonomically classified as *Platydesma remyi* (USFWS 2013). In 2017, *Platydesma* was placed within the genus *Melicope*, as supported by molecular phylogenetic studies (Appelhans et al. 2017). The new scientific name for this species is *Melicope remyi* in the most recent taxonomic treatment in the checklist of Hawaiian flora (Smithsonian Institution 2020, entire). We will refer to this species as *Melicope remyi* through the remainder of this recovery plan.

Table 1. Species, number of wild populations and individuals, *ex situ* or captive-rearing status, recovery priority number, and dates of final listing rule and critical habitat designation or status.

Taxon	Number of Populations	Number of Individuals	*Ex situ* Conservation	Recovery Priority Number[1]	Listing	Critical Habitat
PLANTS						
Bidens hillebrandiana ssp. *hillebrandiana*	1	40	Propagation	6	USFWS 2013	Proposed[3]
Bidens micrantha ssp. *ctenophylla*	4	500	Seed storage, propagation	3	USFWS 2013	USFWS 2018
Cyanea marksii	4	67	Seed storage, propagation	5	USFWS 2013	Proposed[3]
Cyanea tritomantha	18	>400	Seed storage, propagation	5	USFWS 2013	Proposed[3]
Cyrtandra nanawaleensis	6	<37	Leaf cuttings, propagation	5	USFWS 2013	Proposed[3]
Cyrtandra wagneri	3	5	Seed storage, propagation	5	USFWS 2013	Proposed[3]
Melicope remyi	2	25	Propagation	5	USFWS 2013	Proposed[3]
Phyllostegia floribunda	3	9	Seed storage, propagation	5	USFWS 2013	Proposed[3]
Pittosporum hawaiiense	24	317	Propagation	2	USFWS 2013	Proposed[3]
Pritchardia lanigera	9	150–200	Seed storage, propagation	2	USFWS 2013	Designation not prudent[4]
Schiedea diffusa ssp. *macraei*	1	1	Seed storage, propagation	6	USFWS 2013	Proposed[3]

Taxon	**Number of Populations**	**Number of Individuals**	***Ex situ* Conservation**	**Recovery Priority Number**[1]	**Listing**	**Critical Habitat**
PLANTS Cont'd.						
Schiedea hawaiiensis	1	12	Seed storage, propagation	5	USFWS 2013	Proposed[3]
Stenogyne cranwelliae	2	7	Propagation	5	USFWS 2013	Proposed[3]
INVERTEBRATES						
Drosophila digressa	≥3	Unknown	None	5	USFWS 2013	Proposed[3]
Vetericaris chaceorum	2	Unknown	None	5[2]	USFWS 2013	Designation not prudent[4]

[1]Recovery Priority Number is based on degree of threat, recovery potential, taxonomic distinctiveness, and presence of an actual or imminent conflict between the species and development activities (click here for details).
[2]Recovery Priority Number revised since finalization of the Recovery Outline for Hawai‘i Island.
[3]Critical habitat proposed (USFWS 2023a).
[4]Designation of critical habitat in the proposed rule is not prudent because of the threat of overutilization and collection (USFWS 2023a, pp. 18761–18762).

2. Threats

A description of the threats to the 15 species is provided below and summarized in Table 2 (plants) and Table 3 (anchialine pool shrimp and picture-wing fly). Threats are organized by species groups and by the five listing threat factors (A through E). Although some threats are shared among species groups, impacts to individual species and the actions needed to eliminate or manage the threats may differ. In addition to known threats, the plant species may be affected by the nonnative two-spotted leaf hopper (*Sophonia rufofascia*), coconut rhinoceros beetle (*Oryctes rhinoceros*), phantasma scale (*Fiorinia phantasma*), citrus black spot fungus (*Guignardia mangiferae*), nonnative ants, pollinator deficiency, and vandalism and trash dumping; these potential threats are identified in Table 2.

<u>Plants</u>

Factor A (Present or threatened destruction, modification or curtailment of its habitat or range)

The 13 plant species addressed in this recovery plan face varying degrees of habitat loss and degradation (Table 2). Depending on the species and its habitat, nonnative ungulates including mouflon sheep (*Ovis gmelini musimon*), pigs (*Sus scrofa*), feral cattle (*Bos taurus*), goats (*Capra hircus*), and sheep (*Ovis aries*). Ungulates degrade habitats by: (a) creating trails that damage native vegetative cover; (b) destabilizing substrate causing erosion, landslides, rockfalls, and vegetation loss; (c) injuring roots, seedlings, or plants through trampling, and/or rooting; (d) creating gullies that contribute to flooding or destabilization of the substrate; and (e) promoting invasion of nonnative species through the transport of seeds, vegetative plant parts, or creation of openings (Cuddihy and Stone 1990, pp. 63–64; Duenas et al. 2018, entire; Wehr et al. 2018, entire).

Destruction and degradation of habitat by development is a threat specific to *Bidens micrantha* ssp. *ctenophylla* (Table 2). This species is currently found in an area of less than 10 square mi (26 square km) on the leeward slopes of Hualālai, an increasingly urbanized region of north Kona, where there is very little undisturbed native habitat (Pratt and Abbott 1996, p. 25). Development and urbanization results in habitat loss and fragmentation, which leads to edge effects and decreases in pollinator interactions (Harrison and Bruna 1999, pp. 227–228).

Invasive plant species threaten the 13 plant species by degrading native vegetation in occupied or suitable habitats (Table 2, USFWS 2013, entire). Invasive plant species compete with each of the 13 plant species in this recovery plan for water, space, nutrients, and light. These nonnative plant species modify the availability of light and nutrient cycling, alter soil-water regimes, modify nutrient cycling, and alter fire regime affecting native plant communities, and ultimately, convert native-dominated plant communities to nonnative 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 primary invasive plant species affecting the listed species addressed in this recovery plan vary by habitat and the specific locations of each population.

Fire is a serious and ongoing threat to four plant species addressed in this plan (Table 2). Fire damages and destroys native plant species, including dormant seeds, seedlings, and juvenile and adult plants. Because native plants of Hawaiʻi were subjected to fire during their evolution only in areas of volcanic activity and from occasional lightning strikes, they are not adapted to recurring fire regimes and do not quickly recover following a fire (Smith and Tunison 1991, pp. 395–397). Given this, many invasive plants, particularly fire-tolerant grasses, outcompete native plants and inhibit their regeneration in areas affected by fire (D’Antonio and Vitousek 1992, pp. 70, 73–74; Tunison et al. 2002, p. 122). The number and size of wildfires are increasing in the main Hawaiian Islands and successive fires burn deeper into native habitat, further reducing habitats that support the plants covered in this recovery plan. Fire alters microclimatic conditions, creating conditions favorable to nonnative plants. Human alteration of landscapes and the introduction of nonnative plants, especially grasses, has led to greater frequency, intensity, and duration of fires (Brown and Smith 2000, p. 172). Grass-fueled fire often kills most native trees and shrubs (D’Antonio and Vitousek 1992, pp. 70, 73–74).

Drought may directly affect at least five plant species addressed in this plan and their habitats (Table 2). Drought has the potential to occur at any time and causes the direct loss of individuals due to dehydration and death. In addition, drought causes the loss or degradation of habitat due to the mortality of individual native plants, increases the frequency and extent of forest and brush fires, and modifies water availability and vegetation composition (Javar-Salas et al. 2020; Lowe et al. 2020; Ball et al. 2020; Pe‘a et al. 2020; Clark et al. 2020; Nelson et al. 2020). Drought frequency and extent may be exacerbated by climate change, as noted below under *Factor E (Other natural or manmade factors affecting the species continued existence)*.

All 13 plant species are vulnerable to stochastic events (e.g., hurricanes, earthquakes, lava flows, and tsunamis) that can result in mortality of individuals or destroy and alter their habitat; habitat alteration may modify the amount of light and create disturbed areas conducive to invasion by nonnative pest species (Table 2; USFWS 2013, entire). Disturbed areas and gaps in the canopy facilitate the establishment of nonnative plants, which can outcompete native species. Depending on the location, some species are also vulnerable to erosion, landslides, rockfalls, treefalls, and flooding which cause either direct loss of the species or alter their habitat (Table 2). For plant species that persist in low numbers, stochastic events can be particularly devastating.

Factor B (Overutilization for Commercial, Recreational, Scientific or Educational Purposes)

Pritchardia species are one of the most widely cultivated ornamental palm genera in the world (Maunder et al. 2001, cited in Chapin et al. 2004, p. 278). Of the 13 plant species addressed in this plan, *Pritchardia lanigera* is particularly vulnerable to overutilization. Several websites advertise the sale of Hawaiian *Pritchardia* plants and seeds, including *P. lanigera*. Based on the number of *Pritchardia* plants and seeds collected from the wild in Hawai‘i and the demand for them, overcollection of *P. lanigera* is a serious and ongoing threat (Table 2; Chapin et al. 2004, p. 278).

Factor C (Disease and Predation)

Several plant diseases have the potential to negatively affect the 13 plant species either directly or indirectly by disrupting the native forest canopy structure. The plant disease Rapid ‘Ōhi‘a Death (ROD) is an ongoing threat to *Metrosideros polymorpha* (‘ōhi‘a), an important canopy tree in many Hawaiian forests. Rapid ‘Ōhi‘a Death is caused by two fungal pathogens, *Ceratocystis lukuohia* and *C. huliohia*, and can kill individual trees as well as groups of trees (Barnes et al. 2018, entire). Both pathogens are found on the island of Hawaiʻi and the disease is widespread (Friday et al. 2022, entire). While ʻōhiʻa is not a listed species, it is a major structural element of native forests and thus ROD has the potential to create canopy gaps, modify light and microclimate conditions in the understory, and promote establishment of nonnative plants within the habitats of all 13 species. Other disease threats include myrtle rust (*Austropuccinia psidii*), which also affects ʻōhiʻa and other plants in the Myrtaceae family, and powdery mildew (*Neoerysiphe galeopsidis*), which affects species in the genus *Phyllostegia* and thus could directly affect populations of *Phyllostegia floribunda* (Table 2; USFWS 2023j).

Introduced ungulates threaten the 13 plant species by eating seedlings, shoots, or young plants before they can become established and tolerate herbivory. In addition, ungulates trample and crush individual listed plants.

Three species of nonnative rats, including the Polynesian rat (*Rattus exulans*), the roof rat (*R. rattus*), and the Norway rat (*R. norvegicus*) are present in the Hawaiian Islands and threaten at least 11 of the plant species addressed in this plan. Rodents in general, and particularly rats, can damage or kill individual plants by eating their seeds, flowers, stems, leaves, roots, and other plant parts (Table 2; Atkinson and Atkinson 2000, p. 23), which can significantly affect regeneration. Rats have been responsible for the decline, extirpation, and extinction of plant species throughout Hawaiʻi (Cuddihy and Stone 1990, pp. 68–70).

Intentionally introduced game birds, such as ring-necked pheasant (*Phasianus colchicus*), California quail (*Callipepla californica*), Erckel's francolin (*Pternistis erckelii*), black francolin (*Francolinus francolinus*), gray francolin (*F. pondicerianus*), and the Chukar partridge (*Alectoris chukar*), threaten *Schiedea hawaiiensis* at the Pōhakuloa Training Area (Table 2; CSU 2015, pp. 55–56) by feeding on individual plants and by spreading nonnative plants by dispersing seeds via their droppings, including grasses, which contributes to fuel loads and increases the threat of fire (D'Antonio and Vitousek 1992, p. 73; Vitousek et al. 1997, p. 6). While these species may also disperse native seeds, as previously noted, invasive plants often outcompete native Hawaiian species for resources (Cole et al. 1995, p. 311; Cuddihy and Stone 1990, p. 74).

Nonnative slug species in Hawaiʻi are generalist herbivores found in mesic shrublands, mesic forests, and wet forest ecosystems that threaten populations of at least seven plant species addressed in this plan and their habitats by feeding on seedlings and low-statured herbaceous plants, destroying plant parts and killing plants (Table 2; Joe 2006, p. 10; HBMP 2010, unpublished data; USFWS 2016b, p. 67803; Clark et al. 2020, p. 9; Lowe et al. 2020, p. 14). Slugs have a two-fold effect on the ecosystems of Hawaiʻi. Not only do they reduce recruitment of rare species by consuming seedlings, but they may also facilitate the success of some invasive plant species (Joe and Daehler 2008, pp. 252–253).

The nonnative two-spotted leaf hopper has been reported to be a potential threat to *Pritchardia* species in the Hawaiian Islands and thus may be a potential threat to *Pritchardia lanigera* (Table 2; Chapin et al. 2004, p. 279). This insect damages leaves and typically causes chlorosis (yellowing due to disrupted chlorophyll production) to browning resulting in the eventual death of the foliage (Jones et al. 2000, pp. 171–180). This damage can result in death of the plant, owing to the combined action of its feeding and oviposition (egg laying). In addition to the mechanical damage, the insect may introduce pathogens that can also lead to loss of vigor and death (Alyokhin et al. 2004, p. 1).

Nonnative *Coccotrypes* beetles bore into and feed on native palm tree fruits, including *Pritchardia* species (Table 2; Swezey 1927, entire; Science Panel 2005, entire; Magnacca 2005 in litt., p. 1). *Coccotrypes* beetles prefer trees with large seeds like those of *Pritchardia*. They bore into the fruit causing it to drop before reaching maturity, thereby reducing natural regeneration (Magnacca 2005 in litt., p. 1; Science Panel 2005, entire). The effect of *Coccotrypes* beetles on Hawaiian *Pritchardia* species is expected to increase if these beetles are not controlled, potentially resulting in significant impacts to populations of *Pritchardia lanigera* (Magnacca 2005 in litt., p. 1).

Another nonnative beetle that is a potential threat to *Pritchardia lanigera* is the coconut rhinoceros beetle (CRB). The CRB, a large scarab beetle about 2 in (5 cm) long, is considered one of the most damaging insects to coconut and African oil palm trees in southern and southeast Asia, as well as to the western Pacific islands, and could devastate populations of native and nonnative palm trees in Hawaiʻi (OISC 2021, entire). Beetles bore into the crowns of palms where they feed on sap. Eggs are laid inside rotting palm logs, mulch, or compost, and larvae develop to adults within 4 months, continuing the cycle. In 2013, the CRB was discovered on Oʻahu and spread across the island within a few months (Hawaiʻi Department of Agriculture 2022, entire). While currently not present on the island of Hawaiʻi, if the CRB reaches the island, the effect on the remaining *P. lanigera* palms could be devastating.

Nonnative insects and fungi pose a potential threat to the continued existence of *Pittosporum hawaiiense* in the wild. A number of insects can infest and compromise tree health. An example is the phantasma scale, which was first reported in Hawaiʻi in 2004 (Brooks et al. 2012, p.2). These insects create blotches on leaf surfaces, cause leaves to drop early, and reduce plant vigor. This pest has been observed infesting *Pittosporum tobira* in Hawaiʻi, and the potential exists for it to infect other members of the genus, including *P. hawaiiense*. In addition, nonpathogenic isolates of the endophyte, citrus black spot fungus, were detected through genetic sampling of leaves from *Pittosporum hawaiiense* (Baayen et al. 2002, p.467). Many fungal epiphytes in this genus remain latent in the host plant for a prolonged period of time, and in some cases, symptoms are only expressed as a result of adverse environmental conditions (Rodrigues et al. 2003, p. 45). Effects of climate change may shift host/fungi interactions in multiple plant and fungi species. Changing temperature and rainfall patterns as a result of climate change may affect germination rates, growth rates, competitive ability of one species relative to the other, and facilitate expansion of fungal range (Gagne et al. 2011, p.184-85). This could leave *P. hawaiiense* vulnerable to colonization of new and pathogenic fungi.

Nonnative ant species can interfere with the pollination of some plant species that are suspected to be pollinated by insects and ants and are therefore considered a potential threat to the 13 plant species. Ants, particularly yellow crazy ants (*Anoplolepis gracilipes*), deprive pollinators such as yellow-faced bees (*Hylaeus* spp.) of food by consuming large quantities of nectar without pollinating the plant (Lach 2008, entire). In addition, native bees are less likely to land on flowers occupied by ants (Krushelnycky et al. 2005, p. 9; Magnacca 2015 in litt., entire).

Factor D (Inadequacy of existing regulatory mechanisms)

Existing State and Federal regulatory mechanisms are inadequate at preventing the introduction of nonnative species into Hawaiʻi or managing the spread of nonnative species between islands and watersheds (Table 2; Howarth and Medeiros 1989, entire; Staples and Cowie 2001, pp. 9–10). Many invasive plants established in Hawaiʻi have ranges that are expanding into various ecosystems. Resources available to reduce the spread of these species and counter their negative ecological effects are limited (State of Hawaiʻi 2017, p. 44). Management of established nonnative invasive plants 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 plants remains limited in scope (State of Hawaiʻi 2017, pp. 12, 42). The introduction of new invasive plant species to the State of Hawaiʻi is a significant risk to the 13 plant species.

Factor E (Other natural or manmade factors affecting the species continued existence)

Alteration of genetic composition due to hybridization is considered a threat to four plant species (Table 2; USFWS 2013, p. 64684). Hybridization can lead to the loss of genotypically distinct species and varieties and could ultimately result in the formation of new species or alternatively, lead to loss of a species' unique genetic characteristics through "introgression" of genes from another species (Orians 2000, p. 1949; Ellstrand 1992, pp. 77, 81; Levin et al. 1996, pp. 10–16; Rhymer and Simberloff 1996, p. 85). Hybridization is especially problematic for rare species in proximity to a closely related abundant species (Rhymer and Simberloff 1996, p. 83).

At least five plant species are threatened by lack of regeneration (Table 2; USFWS 2013, p. 64684). The causes for this lack of reproduction (i.e., production of flowers, fruits, seeds) and recruitment are not well understood, though inbreeding depression, fruit abortion, or seed predation may play a role. Lack of recruitment due to herbivory by rodents and slugs has been noted for other plant species addressed in this plan as discussed above under *Factor C* (*Disease and Predation*). The lack of mutualists, including pollinators, is a threat to one species, and a potential threat to at least one other species. The loss of pollinators may also contribute to the lack of regeneration seen as viable seed production can decline due to reduced pollination.

Vandalism and trash dumping are potential threats to *Bidens micrantha* ssp. *ctenophylla* at the Kaloko Makai Development area because these activities damage or destroy individuals (Table 2; USFWS 2013, p. 64645).

Acacia koa (koa) logging and habitat disturbance associated with logging on land adjacent to the Kīpāhoehoe NAR may be a threat to *Phyllostegia floribunda* due to a lack of fencing or other demarcation of land ownership (Table 2; DLNR 2002, p. 9).

Limited numbers likely exacerbate threats to more than half of the plant species (Table 2). As a result, these species may experience the following: (1) reduced reproductive vigor due to ineffective pollination or inbreeding depression; (2) reduced levels of genetic variability, leading to a diminished capacity to adapt and respond to environmental changes, thereby lessening the probability of long-term persistence; and (3) increased likelihood that a single catastrophic event may result in the extirpation of remaining populations and the extinction of the species (Barrett and Kohn 1991, pp. 3, 7; Newman and Pilson 1997, pp. 354–355).

Species with small, isolated populations 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).

All 13 plant species are susceptible, to varying degrees, to changes in environmental conditions resulting from climate change (Table 2). Changes include increasing storm frequency and intensity, increasing temperatures, and decreasing precipitation, which can result in changes to species' microclimates (IPCC 2014, pp. 6–11). Such changes may lead to the loss of listed individuals or the degradation or loss of the habitat that supports the listed species.

Table 2. Summary of habitats used by the 13 plant species addressed in this recovery plan and their threats[1] organized by the five listing factors[2].

		Factor A					Factor B	Factor C				Factor D	Factor E[4]	
Species	**Habitat[3]**	**Agriculture and Urban Development**	**Ungulates**	**Nonnative Plants**	**Fire**	**Stochastic Events**	**Overutilization**	**Disease**	**Predation or Herbivory by Ungulates**	**Predation or Herbivory by Other Nonnative Vertebrates**	**Predation or Herbivory by Nonnative Invertebrates**	**Inadequate Existing Regulatory Mechanisms**	**Other Species-specific Threats**	**Climate Change**
Bidens hillebrandiana ssp. *hillebrandiana*	CO	--	P, G	✓	--	Dr, E, H, HS, L, Rf	--	Pt	✓	R	A (Pt)	✓	LN	✓
Bidens micrantha ssp. *ctenophylla*	DSG, DF	✓	P, G	✓	✓	Dr, H	--	Pt	✓	R	A (Pt)	✓	Hy, LN, TD (Pt), V (Pt)	✓
Cyanea marksii	WF	--	P, G, C, M	✓	--	Dr, H, F, L, Rf	--	Pt	✓	R	Sl	✓	LN, PD(Pt)	✓
Cyanea tritomantha	WF, WSG	--	P, C	✓	--	F, H, L Rf, Tf	--	Pt	✓	R	Sl	✓	LN, NR, PD	✓
Cyrtandra nanawaleensis	MF, MSG, WF	--	P	✓	--	H, Vo	--	Pt	✓	R	A (Pt), Sl	✓	Hy, LN	✓
Cyrtandra wagneri	WF	--	P, C	✓	--	E, F, H	--	Pt	✓	R	A (Pt), Sl	✓	Hy, LN	✓

Species	Habitat[3]	Factor A					Factor B	Factor C				Factor D	Factor E[4]	
		Agriculture and Urban Development	Ungulates	Nonnative Plants	Fire	Stochastic Events	Overutilization	Disease	Predation or Herbivory by Ungulates	Predation or Herbivory by Other Nonnative Vertebrates	Predation or Herbivory by Nonnative Invertebrates	Inadequate Existing Regulatory Mechanisms	Other Species-specific Threats	Climate Change
Melicope remyi	WF	--	P	✓	--	H	--	Pt	✓	--	A (Pt)	✓	LN, NR	✓
Phyllostegia floribunda	MF, MSG, WF, WSG	--	P, C	✓	✓	Dr, H	--	PM	✓	--	A (Pt), Sl	✓	LN, K	✓
Pittosporum hawaiiense	DF, MF, WF	--	C, M, P	✓	✓	H	--	Pt	✓	R	A(Pt)	✓	CF(Pt), PS(Pt), NR, Hy	✓
Pritchardia lanigera	MSG, WF, WSG	--	C, G, M, P	✓	--	H	✓	Pt	✓	R	A (Pt), CRB (Pt), Lh (Pt), B	✓	NR	✓
Schiedea diffusa ssp. *macraei*	WF	--	P, C	✓	--	H	--	Pt	✓	R	A (Pt), Sl	✓	LN, NR	✓
Schiedea hawaiiensis	DF	--	P, G, M, S	✓	✓	Dr, H	--	Pt	✓	R, GB	A (Pt)	✓	LN	✓

Species	Habitat[3]	Factor A					Factor B	Factor C				Factor D	Factor E[4]	
		Agriculture and Urban Development	Ungulates	Nonnative Plants	Fire	Stochastic Events	Overutilization	Disease	Predation or Herbivory by Ungulates	Predation or Herbivory by Other Nonnative Vertebrates	Predation or Herbivory by Nonnative Invertebrates	Inadequate Existing Regulatory Mechanisms	Other Species-specific Threats	Climate Change
Stenogyne cranwelliae	WF	--	P	✓	--	H	--	Pt	✓	R	Sl	✓	LN	✓

[1]Threats: A = ants; B = beetles; C = cattle; CF = citrus black-spot fungus; CRB = coconut rhinoceros beetle; Dr = drought; E = erosion; F = flooding; G = goats; GB = Nonnative game birds; H = hurricanes; HS = high surf; Hy = hybridization; K = koa logging; L = landslide; Lh = leafhoppers; LN = limited numbers; M = mouflon; NN = nonnative; NR = no regeneration; P = pigs; PD = pollinator deficiency; PS = phantasma scale; PM = powdery mildew; Pt = potential threat to species; R = rats; Rf = rockfall; S = sheep; Sl = slugs; TD = trash dumping; Tf = treefall; Va = vandalism; Vo = volcanic eruption; ✓ = Known threat to species, not itemized

[2]Factor A = Present or threatened destruction, modification, or curtailment of its habitat or range; Factor B = Overutilization for commercial, recreational, scientific, or educational purposes; Factor C = Disease or predation; Factor D = Inadequacy of existing regulatory mechanisms; and Factor E = Other natural or manmade factors affecting its continued existence.

[3]Habitats: CO = coastal; DSG = dry shrubland and grassland; DF = dry forest; MF = mesic forest; MSG = mesic shrubland and grassland; WF = wet forest; WSG = wet shrubland and grassland.

Anchialine Pool Shrimp

Factor A (Present or threatened destruction, modification or curtailment of its habitat or range)

Anthropogenic activities are a threat to *Vetericaris chaceorum* and its habitat (Table 3). More than 90 percent of anchialine habitats across the State of Hawai‘i have been lost or degraded by anthropogenic activities like coastal development and the spread of invasive species (Brock 2004, p. i). Of the 300 pools on the island of Hawai‘i surveyed in 2002 (Acly 2003), 43 percent appeared to not support shrimp populations of any species (Wiegner et al. 2006, p. 30).

Coastal development negatively affects *Vetericaris chaceorum* through direct destruction of their habitat, increases in nutrients, and reduction in water quality (Table 3). On the island of Hawai‘i, development between Kawaihae and Kailua-Kona, with a high density of anchialine pools, has resulted in the filling of many pools with rock and other debris (Mitchell et al. 2005, pp. 40, 44, 465; DLNR 2015, p. 7–410). In pools that have been infilled, anchialine pool shrimp may still be able to survive below the water table in cracks and crevices, but the species is likely to occur at a lower population density than in intact pools (Brock and Kam 1997, p. 12). Although regulations limit coastal development, habitat degradation remains a threat due to polluted runoff from rainfall and flooding, and from storm surge overflow events (Brock and Kam 1997, p. 12). Reduced water salinity from runoff negatively affects anchialine pool shrimp, as they are thought to be intolerant of salinities below 10 ppt (Maciolek 1983 pp. 611–612).

Habitat degradation and/or destruction by ungulates is a threat to the anchialine pool shrimp (Table 3; Richardson 2012 in litt., pp. 1–2). Feral goats and cattle trample and forage on both native and nonnative plants around and near anchialine pools, which causes erosion and increases sediment entering the pool. Further, cattle carcasses have been observed in the pool at Lua o Palahemo, thus reducing water quality (Kinzie 2010 in litt., entire).

Aside from the direct destruction of anchialine pools via flooding and ungulates, indirect, persistent impacts can occur from nutrient loading and other activities and/or perturbations that reduce water quality (Table 3). Fertilizers, pesticides, and polluted runoff from resort, urban, and commercial development may leach into the groundwater and introduce these effluents into anchialine pools. This can cause direct harm to the anchialine pool shrimp or alter the chemical properties of the anchialine pool, thereby affecting productivity of all species that depend on anchialine pools. In addition to pesticides and nutrients, freshwater runoff from landscaping is also potentially harmful, because the anchialine shrimp is thought to be intolerant of low salinity (Maciolek 1983, pp. 611–612; Lau 2012 in litt., entire).

Water extraction (i.e., withdrawal of subsurface fresh water human use) from underground fresh water sources increases salinity levels of anchialine pools and may negatively affect the anchialine pool shrimp that rely on the delicate balance of mixohaline (brackish water) habitats. Although upper and lower salinity tolerances are unknown for all stages of *Vetericaris chaceorum*, alteration of pool salinity may affect reproductive success and survival (Maciolek 1983, pp.607–612; Brock et al. 1987, p. 200; Conry 2012 in litt., entire; USFWS 2016, p. 67834).

Anchialine pools can be degraded by changes to nearby native plant communities. Many native plants have been replaced by invasive plants, including *Prosopis pallida* (kiawe), mainly as the result of years of pressure from historical cattle grazing (D'Antonio and Vitousek 1992, p. 65; Wagner et al. 1999, pp. 45, 55, 58–62; Dudley et al. 2014, p. 4). While the impact of invasive plants is not as direct as invasive fish and invertebrates (see below), some plants such as kiawe may threaten the health of anchialine pools through the introduction of leaf litter. Kiawe has been identified as a potential cause of nutrient loading (Table 3; Brock et al. 1987, p. 205; Street et al. 2008, p. 370). As a nitrogen-fixing plant, kiawe can add large quantities of nitrogen to soils, which alters nutrient availability and productivity in anchialine pools through direct additions of nitrogen-rich litter (Dudley et al. 2014, p. 5). Furthermore, leaf litter that is deposited and trapped in the anchialine pool can lead to filling and accelerate the natural senescence of the anchialine pool habitat (Brock 2004, p. 34).

Stochastic disturbance and catastrophic events such as hurricanes, earthquakes, and tsunamis can degrade or destroy habitat and result in the direct loss of *Vetericaris chaceorum* (Table 3). The coastal area where anchialine pools are found can be directly exposed to storm surge and flooding associated with severe storm events. Indirect effects may include flooding of anchialine pools with fresh water resulting in altered salinity. Altered salinity may effect reproductive success as well as survival of anchialine pool shrimp and/or their prey (Maciolek 1983, pp 607–612; Brock et al. 1987, p. 200; Conry 2012 in litt., entire; USFWS 2016, p. 67834). Anchialine pools can be degraded or destroyed by the transport and deposition of sand and coral rubble by storm surge (Brock 2004, p. 12). In addition, storm surge can result in the introduction of predators such as fish into anchialine pools. Because so few pools are occupied by the anchialine pool shrimp, introduction of fish into a single pool may have catastrophic population-level effects. Natural events such as earthquakes or lava flows can directly alter or destroy habitat. Since the anchialine pool shrimp depends on the hypogeal (i.e., subterranean) environment for connectivity, any alteration to this environment could have devastating consequences for reproductive success and the maintenance of genetic diversity. Small populations are demographically vulnerable to extinction caused by random fluctuations in population size and sex ratio. Thus, both catastrophic events and stochastic disturbance may lead to species extinction (Lande 1988, p. 1455).

Factor B (Overutilization for commercial, recreational, scientific, or educational purposes)

Collection for the pet trade threatens *Vetericaris chaceorum* (Table 3). In the past several years, one species of anchialine shrimp, *Halocaridina rubra*, has been increasingly prized by aquarists and companies in the pet trade industry worldwide because of its ability to live in hermetically (airtight) sealed containers and its utility as live feed for seahorses (Weese and Santos 2009, entire; Yamamoto et al. 2015, p. 83). Although *H. rubra* is not listed as threatened or endangered, there is an increasing chance that *V. chaceorum* may either intentionally or accidentally be harvested as the popularity of pet trade in *H. rubra* grows. *Halocaridina rubra* most likely serves as prey for *V. chaceorum* when the species occur together in pools. Because *V. chaceorum* are so rare, one person with a hand-net could do irreparable damage to a population (Yamamoto et al. 2015, entire). Existing legal restrictions are insufficient to deter or prevent collection. Additionally, because *V. chaceorum* appears to be blind (Kensley and Williams 1986, p. 426; Lau 2012 in litt., entire), a marked reduction in the density of its prey (*H. rubra*) could impact foraging success (Kinzie 2010 in litt., entire).

Factor C (Disease and Predation)

In general, predation caused by the accidental or intentional introduction and spread of nonnative fish (e.g., bait and aquarium fish) is considered the greatest threat to anchialine pool fauna in Hawaiʻi (Table 3; Brock 2004, p. 16). More than 95 percent of anchialine pools along the Kona coast on the island of Hawaiʻi have been contaminated by invasive, nonnative fish over the past 20 to 30 years (Yamamoto and Tagawa 2000, p. 37; Havird et al. 2013, pp. 189–190), including members of the family Poeciliidae (e.g., mosquito fish [*Gambusia affinis*], shortfin or Atlantic molly [*Poecilia mexicana*], guppy [*Poecilia reticulata*]) as well as tilapia (*Tilapia mossambica*), in the family Cichlidae (Table 3; Dudley et al. 2017, p. 2). These nonnative species can complete their entire life cyle in the pools and therefore are more of a threat than are native fish (see below). In addition to likely preying on *Vetericaris chaceorum,* nonnative fish are especially problematic for the anchialine pool habitat because their waste products block water flow, resulting in destruction of pool habitat (Wada 2018 in litt., entire; Wada 2021 in litt., entire).

Based on observations of other species of anchialine pool shrimp, invasive fish can potentially impact *Vetericaris chaceorum* through competition, predation, and the introduction and the potential transmission of parasites and disease (Table 3; Maciolek 1984, pp. 131–161; Chai 1993, p. 59). The presence of invasive fish has been directly linked to the decline in anchialine pool shrimp (*Halocaridina rubra* and *Metabetaeus lohena*) at Kaloko-Honokōhau on the west coast of the island of Hawaiʻi (Brock and Kam 1997, p. 56). In areas where they are the dominant fauna, invasive fish prey on and displace anchialine pool shrimp from suitable habitat (Brock 1985, pp. 3–31; Bailey-Brock and Brock 1993, p. 354). In addition, in pools where invasive fish have been introduced, *H. rubra* exhibited strong diel (24 hour) activity patterns not seen in fishless pools (Capps et al. 2009, p. 16; see below). While invasive fish have not been documented to affect *V. chaceorum*, given their impacts to other anchialine pool shrimp species such as *Halocaridina rubra*, similar effects to *V. chaceorum* are likely.

Marine fish have also been detected in at least one anchialine pool within the Manukā pool complex; these fish are suspected to have been intentionally introduced by anglers (Table 3; Sakihara 2012, entire). Recreationalists use anchialine pools as “holding pools” for bait fish (e.g., nonnative freshwater fish like tilapia, mosquito fish, and native marine fish like āholehole [*Kuhlia* spp.] and kūpīpī [blackspot sergeant; *Abudefduf sordidus*]) (Wada 2013 in litt., entire). While invasive fish remain the main threat, native fishes commonly found offshore such as āholehole or ulua/pāpio (*Caranx* sp.) can extirpate shrimp from anchialine pools if introduced naturally (e.g., hurricane, tsunami) or intentionally by humans (e.g., anglers) (Kinzie 2010 in litt., entire; Wada 2013 in litt., entire). The impact of native marine fish on *Vetericaris chaceorum* is undocumented but is likely similar to that of freshwater fish on other species of anchialine pool shrimp.

Invasive fish can alter the ecological succession of pools due to predation on detrital feeders (amphipods and isopods) and primary consumers such as *Halocaridina rubra* (Table 3; Brock 2004, p. i). Predation reduces and displaces hypogeal shrimp from the lighted sections of anchialine pools (Brock 2004, p. 16). As a result, a gradual succession of macroalgae establish and grow epiphytically on the benthic cyanobacterial crust (Brock 2004, p. 16). With herbivorous hypogeal shrimp present (*H. rubra*), these epiphytes never overpopulate the benthos (Brock 2004, p. 16). Without *H. rubra*, overgrowth by macrophytes leads to the loss of the cyanobacterial crust (Brock 2004, p. 16). With this change in anchialine pool flora comes a significant change in the appearance of the anchialine pool system from one that has anchialine characteristics (i.e., clear well-flushed basins, cyanobacterial crusts, and a fauna dominated by hypogeal shrimp) to a system characterized by a mud substratum, poor water exchange, floating chlorophyte mats, and exotic fishes (Brock 2004, p. 16). These changes potentially increase the infilling and senescence of anchialine pools (Brock 2004, p. 16).

The Tahitian prawn (*Macrobrachium lar*) is another invasive predator of anchialine pool shrimp (Table 3). Tahitian prawns are known to prey on *Halocaridina rubra* (Chai et al. 1989, p. 6). Furthermore, as a primarily nocturnal species, the Tahitian prawn influences the activity and presence of *H. rubra* at night, causing reverse diel patterns compared to the effects of invasive fish (Carey et al. 2011, pp. 38–40). Although Sakihara (2017, p. 13) found that the effects of Tahitian prawn on anchialine pool shrimp diel activity was habitat dependent—*H. rubra* was not affected in pools that were dark and deep—the presence of Tahitian prawn in conjunction with invasive fish could severely restrict the overall activity of anchialine pool shrimp by making shrimp susceptible to both diurnal and nocturnal predation. While no studies have been done on the impact of Tahitian prawn on *Vetericaris chaceorum*, the Tahitian prawn has been documented in at least one pool adjacent to pools occupied by *V. chaceorum* and it is likely to affect the endangered anchialine pool shrimp in at least two ways (Sakihara 2012, p. 91). First, Tahitian prawn may prey on *V. chaceorum*. Second, as *V. chaceorum* preys on *H. rubra*, the Tahitian prawn may compete with *V. chaceorum for* food.

Factor D (Inadequacy of existing regulatory mechanisms)

Existing State and Federal regulatory mechanisms are not preventing the introduction of nonnative speces into Hawaiʻi or controlling the spread of nonnative species between watersheds or maintaining instream flow standards (Howarth and Medeiros 1989, entire; Staples and Cowie 2001, pp. 9–10). Existing mechanisms do not prevent the introduction of invasive freshwater or marine fish into anchialine pools, the intentional dumping of trash into anchialine pools, nor the intentional or accidental collection of the anchialine pool shrimp for the aquarium trade.

In addition to Federal regulations, all terrestrial and aquatic invertebrates (including *Vetericaris chaceorum*) are protected under (1) the State of Hawaiʻi Revised Statues (1993) chapter 195D-4-f license; and (2) DLNR chapter 124: Indigenous Wildlife, Endangered and Threatened Wildlife, and Introduced Wild Birds. State NARs were created to preserve and protect examples of Hawaiʻiʻs ecosystems and geological formations. Designation as a State NAR prohibits the removal of any native organism and the disturbance of pools (Hawaiʻi Administrative Rules 13-209-4), however, enforcement at remote locations is difficult. Despite protections, the National Park Service faces similar challenges in enforcing prohibition of anchialine pool shrimp collection and pool disturbance at Kaloko-Honokōhau National Historical Park. In addition, no State regulatory protection of *V. chaceorum* exists at Lua O Palahemo and the five anchialine pools adjacent to the Manukā NAR which means that they are not subject to the same protections from potentially harmful activity as the pools that are located within the NAR (Table 3; Conry 2012, in litt).

Hawaiʻi Revised Statutes, Title 19. Health 342E, established a nonpoint source pollution management and control program. In 2021, the Hawaiʻi State Department of Health (HDOH) finalized the Hawaiʻi Nonpoint Source Management Plan 2021–2025 to guide the Stateʻs nonpoint source pollution management efforts over a 5-year period (HDOH 2021, entire). The plan proposes to establish a Department of Health Surface Water Protection Branch that will administer the Nonpoint Source Pollution Control Rules proposed under Hawaiʻi Administrative Rules Chapter 11-56 (HDOH 2021, p. 92–95). However, HDOH has not yet established a comprehensive nonpoint source pollution branch for control and enforcement against nonpoint source pollution. Until the Water Protection Branch is established and the nonpoint source pollution control and management Administrative Rules are finalized (HDOH 2022), nonpoint source pollution is a State-unregulated threat to anchialine pool shrimp.

Factor E (Other natural or manmade factors affecting the species continued existence)

Anchialine pools have been used by humans as baths, latrines, and dumps because of their depressional features, proximity to the beach, and their freshwater content (Table 3). Plastics, fishing line, bottles, cans, marine, and other debris increase the accumulation of sediment in pools by plugging cracks and trapping sediments, which affects water flushing rate and accelerates pool senescence (Kensley and Williams 1986, pp. 417–418; Bozanic 2004, p. 1; Brock 2004, pp. 13–17; Wada 2010 in litt., entire). Chemical contamination (including oil and grease) of anchialine pools has been documented on the island of Hawaiʻi (Brock 2004, pp. 15–16), which affects water quality and can result in the local extirpation of hypogeal shrimp species. Fecal coliform bacteria can introduce disease and other pathogens (Chan 1995, p. 14; Brock 2004 p. 15). Human trampling, swimming, and bathing in and adjacent to anchialine pools can degrade anchialine pool habitat characteristics (Brock 2004, pp. 13–17, 26).

Use of off-road vehicles adjacent to anchialine pools can result in an increase of erosion and accumulation of sediment (Table 3). The negative impacts from sedimentation are discussed under <u>*Anchialine Pool Shrimp*</u> *Factor A* above (Richardson 2012 in litt., entire).

The persistence of *Vetericaris chaceorum* is tenuous as the species only occurs in five pools at two sites on the island of Hawaiʻi (Table 3). The limited distribution of anchialine pool shrimp as well as the apparent small number of individuals increases the species' vulnerability to extirpation or extinction from demographic and environmental stochasticity as well as catastrophic events; inbreeding depression also could affect the species' reproductive success. In addition, small populations may suffer a loss of genetic diversity over time due to random genetic drift, resulting in a decreased evolutionary potential and lessened ability to cope with environmental change (Lande 1988, p. 1455). However, because the interconnectedness of pools supporting shrimp is currently unknown, the magnitude of this threat is difficult to quantify. The fact that *V. chaceorum* is currently not part of a captive breeding program also increases their vulnerability to stochastic events (Table 3).

Anchialine pool habitats are subject to gradual disappearance due to accumulation of wind-blown materials through a process known as senescence (Table 3; Maciolek and Brock 1974, entire; Brock 2004, p. 11). According to Brock (2004, p. 11), anchialine pools are ephemeral and senescence can occur in as little as 100 years after an anchialine pool is created. Conditions promoting rapid senescence include an increased amount of sediment deposition, exposure to light, shallowness, and a weak connection with the water table, resulting in sediment and detritus accumulating within the pool instead of being flushed away with tidal exchanges and ground water flow (Maciolek and Brock 1974, entire; Brock 2004, pp. 16, 34).

The proximity of existing anchialine pool complexes to the coast puts them at risk from coastal inundation associated with climate change (Table 3; Marrack et al. 2021, entire). With sea levels projected to rise over the next century (Parris et al. 2012, entire), coastal ecosystem distribution and community structure are expected to change significantly due to flooding, erosion, salt-water intrusion, or a combination of these factors (Nicholls and Cazenave 2010, pp. 1517–1519; Church et al. 2013, pp. 1137–1138; Williams 2013, pp. 184–196). The anchialine pools at Manukā are in the expected coastal inundation zones. Impacts from sea-level rise and coastal inundation may include: (1) complete inundation of pools and therefore elimination of entire anchialine pool habitats, particularly at Manukā NAR, where low-lying areas for expansion of new pools does not occur (Marrack et al. 2021, entire); (2) an increase in the likelihood of exposure to predatory native marine fish not normally found in the anchialine pool ecosystem; (3) overtopping and movement of invasive fish from existing anchialine ponds and pools; and (4) increase in the deposition of coral rubble and other debris into anchialine pools due to increased storm intensity resulting in blockages of subterranean interconnections within pool complexes, blockage of pools from the ocean, and in-filling of the pools.

Table 3. Summary of habitats used by the two invertebrate species addressed in this recovery plan and their threats[1] organized by the five listing factors[2].

		Factor A							Factor B	Factor C			Factor D	Factor E	
Species	**Habitat[3]**	**Agriculture and Urban Development**	**Water Extraction**	**Ungulates**	**Nonnative Animals**	**Nonnative Plants**	**Fire**	**Stochastic Events**	**Overutilization**	**Disease**	**Predation by Nonnative Vertebrates**	**Predation by Nonnative Invertebrates**	**Inadequate Existing Regulatory Mechanisms**	**Other Species-specific Threats**	**Climate Change**
Drosophila digressa	MF, WF	✓	--	C, G, M, P	--	✓	✓	Dr, F, H, LHP, Vo	--	--	CF (Pt)	A, PW, W	✓	B, CBS, LCF, LF, LHP, LN, LP, NC, ROD, We	✓
Vetericaris chaceorum	AP, CO	✓	✓	C, G	✓	✓		E, F, H, Ts, Vo	Aq, Co	Pt	Fi	TP	✓	HD, LN, LP, NC, NL, NS, RU, RV, SD, SLR, Tr, WQ, Va	✓

[1]Threats: A = ants; Aq = aquarium trade; B = beetles (damage to host plants); C = cattle; CBS = competition for breeding substrates; CF = coqui frog; Co = collection; Dr = drought; E = earthquakes; F = Flooding; Fi = fish; G = goats; H = hurricane/high winds; HD = human disturbance (contamination, illegal dumping, fisheries, marine debris, and trash); LCF = limoniid crane flies; LF = lack of sufficient larval food resources; LHP = loss or lack of host-plant substrate; LN = limited numbers of individuals; LP = low population number; M = mouflon; NC = not in captive-rearing program; NL = nutrient loading; NS = natural senescence of pools; P = pigs; Pt = potential threat; PW = parasitoid wasps; ROD = Rapid ʻŌhiʻa Death; RU = recreational use; RV = recreational vehicles; SD = sedimentation; SLR = sea level rise; TP = Tahitian prawn; Tr = trampling; Ts = tsunami; Va = Vandalism; Vo = volcanic eruption; W = western yellowjacket wasps; We = weevils (damage to host plants); WQ = water quality reduction; ✓ = Known threat to species, not itemized.

[2]Factor A = Present or threatened destruction, modification, or curtailment of its habitat or range; Factor B = Overutilization for commercial, recreational, scientific, or educational purposes; Factor C = Disease or predation; Factor D = Inadequacy of existing regulatory mechanisms; Factor E = Other natural or manmade factors affecting its continued existence.

[3]Habitats: AP = anchialine pools; CO = coastal; MF = mesic forest; WF = wet forest.

Picture-wing Fly

Factor A (Present or threatened destruction, modification or curtailment of its habitat or range)

The picture-wing fly depends on specific plant species (hereafter host plants) to complete its life history, and those species can be negatively affected by nonnative ungulates. *Drosophila digressa* requires decaying stems or bark of *Charpentiera* spp., *Ceodes brunoniana*, and *Rockia sandwicensis* for oviposition and larval development (hereafter host-plant substrate) (Montgomery 1975, p. 95; Magnacca 2012 in litt., entire). *Charpentiera* spp., *Ceodes brunoniana*, and *Rockia sandwicensis* are highly susceptible to damage from feral pigs, feral and domestic cattle, mouflon sheep, and goats (Table 3; Stone 1985, p. 271; Cuddihy and Stone 1990, pp. 63, 66; Foote and Carson 1995, pp. 369–371; Kaneshiro and Kaneshiro 1995, pp. 8, 39; Magnacca et al. 2008, p. 32; Magnacca 2012 in litt., entire; Science Panel 2005, pp. 1–23; Hess 2008, p. 3). Magnacca (2012 in litt., entire) observed the lack of regeneration of picture-wing fly host plants due to destruction of seedlings by pig rooting. Cattle browse *Charpentiera* spp., *Ceodes brunoniana*, and *Rockia sandwicensis* (Magnacca et al. 2008, p. 32; Magnacca 2012 in litt., entire). *Charpentiera* spp. appears to continue to decrease throughout its range due to browsing from mouflon sheep (Table 3; Science Panel 2005, pp. 1–23). Goats also occupy the habitats of the picture-wing fly where they access and forage in extremely rugged terrain and, like mouflon sheep, they have a high reproductive capacity (Table 3; Clarke and Cuddihy 1980, pp. C–19, C–20; van Riper and van Riper 1982, pp. 34–35; Culliney 1988, p. 336; Cuddihy and Stone 1990, p. 64; Hess 2008, p. 3; Kessler 2011 in litt., entire). *Charpentiera* spp. are shrubby trees and are very susceptible to browsing. As a result, the host plants of this picture-wing fly species have decreased throughout their range in areas that are not fenced and ungulate-free. Browsing also alters the essential microclimate in picture-wing fly habitat by opening the understory. This can lead to increased desiccation of soil and host plants and disruption of the host-plants' life cycle and decay processes. This subsequently disrupts the picture-wing fly's life cycle, particularly oviposition and the availability of host-plant substrates required for the larval development (Magnacca et al. 2008, pp. 1, 32).

Ungulates also disperse nonnative seeds and create open, disturbed areas which facilitate the establishment of nonnative plants (Table 3). Nonnative plants adversely affect microhabitat by modifying the availability of light, shifting soil-water regimes, changing nutrient cycling processes, altering fire characteristics of native plant habitat, outcompeting natives, and inhibiting the growth of native plant species (Vitousek et al. 1987, p. 224). The picture-wing fly's host plants are susceptible to competition from nonnative plants (Table 3; Foote and Carson 1995, pp. 370–37; Starr et al. 2003, p. 3; Science Panel 2005, entire; USFWS 2023i, entire). As described above in the *Plants* section *Factor A*, invasive plant species compete with native plants for water, space, nutrients, and light. This results in the conversion of native habitat to one dominated by nonnative vegetation which does not support *Drosophila digressa* (Cuddihy and Stone 1990, p. 74; Vitousek 1992, pp. 33–35).

Severe to extreme drought over the past 20 to 30 years has impacted the mesic forest habitat of the picture-wing fly at Manukā NAR. This has resulted in overall habitat degradation and appears to alter decay processes of the picture-wing fly host plants. Drought also alters the entire plant community on which the fly depends. Virtually all of the ʻōhiʻa canopy at the Manukā

NAR died over the past 20 to 30 years, due to prolonged drought; this area previously received most of its water from fog intercepted by tall ʻōhiʻa trees (Magnacca 2012 in litt., p. 1). Although the dominant host plant of the picture-wing fly at this site, *Rockia sandwicensis*, has benefited from the increase in sunlight due to the ʻōhiʻa dieback, the increase in *R. sandwicensis* seedlings and juveniles is unlikely to be sustained over time (Magnacca 2012 in litt., entire). Even if these host plants survive to maturity, it is unlikely that the much drier habitat conditions will support the picture-wing fly (Magnacca 2012 in litt., entire). The wet montane habitat of ʻŌlaʻa Forest within Hawaiʻi Volcanoes National Park is also experiencing drought (NIDIS 2020, entire).

Fire, as described in the *Plants* section *Factor A*, is a threat to the picture-wing fly. Extreme drought conditions are also contributing to the number and intensity of the wildfires on the island of Hawaiʻi (USFWS 2013, pp. 64663–64664; McDaniel 2023 in litt., entire). Long-term drought has resulted in an increasing accumulation of dead trees in the Manukā NAR, which increases the fuel load and threat of wildfires in one of the three known occurrence locations of the picture-wing fly (USFWS 2013, p. 64664). The extraordinary amount of dead wood accumulation in this mesic habitat means any fire that occurs there likely would be extremely damaging (Table 3). Fires result in a reduction of native plant cover and habitat, an increase in nonnative plant and animal species, and a reduction in availability of host plants for the picture-wing fly (Giambelluca et al. 1991, p. v; D'Antonio and Vitousek 1992, pp. 77–79).

Drought and the proximity of picture-wing fly habitat to areas with volcanic activity as well as to habitats dominated by nonnative grasses also increases the threat of fire to the persistence of *Drosophila digressa* (Table 3). The introduction of nonnative plants, especially grasses, has led to greater frequency, intensity, and duration of fires (Brown and Smith 2000, p. 172). Grass-fueled fire often kills most native trees and shrubs (D'Antonio and Vitousek 1992, pp. 70, 73–74). Fire is a threat particularly in the mesic portion of the picture-wing fly's range at Hualālai due to the presence of nonnative plant species (Science Panel 2005).

Stochastic events such as hurricanes, high winds from severe storms, and volcanic eruptions can result in the direct loss of picture-wing fly individuals and/or extirpate a population (Table 3; Carson 1986, p. 7; Foote and Carson 1995, pp. 369–370). High winds can destroy host plants and dislodge fly larvae from their hosts exposing the fly larvae to predation by nonnative yellowjacket wasps (Carson 1986, p. 7; Foote and Carson 1995, p. 371).

Factor B (Overutilization for commercial, recreational, scientific, or educational purposes)

Overutilization is not known to be a threat.

Factor C (Disease and Predation)

Picture-wing flies evolved in the absence of predation and competition from ants, which can be particularly destructive predators because of their high densities, recruitment behavior, aggressiveness, and broad range of diet (Reimer 1993, pp. 13–17). Ants prey directly on the eggs and larvae of the picture-wing flies or exclude flies from breeding resources or shelter sites (Krushelnycky et al. 2005, p. 6). The threat of ant predation on the picture-wing fly is amplified by the fact that most ant species have winged reproductive adults (Borror et al. 1989, p. 738) and can quickly establish new colonies in new locations (Staples and Cowie 2001, p. 55). These attributes allow some ants to extirpate geographically isolated populations of native arthropods (Nafus 1993, pp. 19, 22–23).

All ant species occurring in Hawaiʻi are nonnative (Perkins 1913, p. xxxix) and at least five particularly aggressive species threaten the picture-wing fly. Big-headed ants (*Pheidole megacephala*), long-legged or yellow crazy ants, Papuan thief ants (*Solenopsis papuana*), tropical fire ants (*Solenopsis geminata*), and Argentine ants (*Linepithema humile*) are aggressive, generalist predators that have severely impacted the native insect fauna (Reimer 1993, pp. 13–17; Krushelnycky and Gillespie 2010, pp. 643–655; Krushelnycky et al. 2017, entire). As a group, ants occupy most of the habitat types of Hawaiʻi; however, many ant species are still invading the mid-elevation montane mesic forests where the picture-wing fly occurs. Few ant species have been able to colonize undisturbed montane wet ecosystems; rather, they are more likely to occur in mesic habitats (Reimer 1993, pp. 13–17). Of the five aggressive ant species, the Papuan thief ant is the only species that has invaded intact mesic to wet forest and occurs in high densities. This species occurs on all the main Hawaiian Islands, and is still expanding its range (Reimer 1993, p. 14; Krushelnycky et al. 2017, entire). Thus, this ant is a major threat to the picture-wing fly throughout its range.

Coqui frogs, *Eleutherodactylus coqui*, were introduced to the State of Hawaiʻi in the late 1980s (Woolbright et al. 2006, p. 122) and are widespread on the island of Hawaiʻi (DLNR 2023). Based on the spatial patterns of the coqui frog foraging behavior and spread to higher elevations, the frogs pose a potential predation threat to the picture-wing flies (Table 3). The frogs can consume large numbers of insects each night and may prey on adult *Drosophila* species (Bernard and Mautz 2016, pp. 3413–3414). Dipterans, the soft bodied insect order that includes the picture-wing flies, represent 1.21 percent of the frog stomach content at lower elevations (Bernard and Mautz 2016, pp. 3413–3416). Though this proportion is low, the exposure and lengthy lekking (male territorial defensive displays with other males) and mating behaviors of the picture-wing flies leave them vulnerable to predation.

The western yellowjacket (*Vespula pensylvanica*) is an aggressive, generalist wasp that threatens the picture-wing fly (Table 3; Gambino et al. 1987, p. 170). This species is now particularly abundant between 1,969 and 5,000 ft (600 and 1,524 m) in elevation throughout the State (Gambino et al. 1990, pp. 1088–1095; Foote and Carson 1995, p. 371). The wasp is widespread in mesic and montane wet habitats on Hawaiʻi where the picture-wing fly species occur. In temperate climates, the yellowjacket has an annual life cycle; however, in Hawaiʻi colonies often persist through a second year. This facilitates larger populations and thus a greater impact on prey populations (Gambino et al. 1987, pp. 169–170). The wasps have been observed carrying and feeding on adult Hawaiian picture-wing flies (Kaneshiro and Kaneshiro 1995, pp. 40–45). Native picture-wing flies may be particularly vulnerable to predation by wasps due to their conspicuous lekking behavior and courtship displays that can last for several minutes (Kaneshiro 2006, pp. 4–5; Kaneshiro 2006 in litt., entire). These wasps are also believed to feed on picture-wing fly larvae in their host-plant substrate (Carson 1986, pp. 3–9). The concurrent arrival of the western yellowjacket and decline of picture-wing fly observations in some areas suggest the wasp may have played a significant role in the decline of some picture-wing fly populations

(Carson 1986, pp. 3–9; Foote and Carson 1995, p. 371; Kaneshiro and Kaneshiro 1995, pp. 40–45; Science Panel 2005, pp. 1–23).

The number of native parasitic wasps in Hawaiʻi is limited, and only species in the family Eucoilidae are known to use Hawaiian picture-wing flies as hosts (Table 3; Montgomery 1975, pp. 74–75; Kaneshiro and Kaneshiro 1995, pp. 44–45). Several species of nonnative, small parasitic wasps (Braconidae) were introduced to Hawaiʻi to control nonnative fruit flies in the family Tephritidae (Funasaki et al. 1988, pp. 105–160). These parasitic wasps are also known to attack other fly species, including native Tephritidae flies. While these parasitic wasps have not been recorded parasitizing Hawaiian picture-wing flies and, in fact, may not successfully develop in Drosophilidae, females will indiscriminately sting any fly larvae in their attempts to oviposit, resulting in mortality of the larvae (USFWS 2013, p. 64676). Because of this indiscriminate behavior, nonnative parasitoid wasps represent a threat to *Drosophila digressa*.

Factor D (Inadequacy of existing regulatory mechanisms)

As previously described in the *Plants* section *Factor D*, the loss of habitat and introduction of harmful nonnative species due to inadequate regulation and biosecurity is also a threat to *Drosophila digressa* (Table 3). Recovery of the species will require active management of protected areas, which will include exclusion and removal of feral ungulates, management and removal of invasive plants and insects, and the restoration and translocation of host-plant species.

Factor E (Other natural or manmade factors affecting the species continued existence)

Competition for larval host-plant substrate from several species of nonnative limoniid crane flies can adversely impact picture-wing flies (Table 3). The larvae of these crane flies feed in the decomposing bark of the host plants used by the picture-wing fly species (Science Panel 2005, pp. 1–23; Magnacca 2005 in litt., entire; Montgomery 2005 in litt., entire). This results in a reduction of available plant material for the picture-wing fly larvae. Competition between *Drosophila* spp. larvae and other fly larvae can exhaust food resources, which affects both the probability of picture-wing fly larvae survival and the body size of adults, resulting in reduced adult fitness, fecundity, and lifespan (Grimaldi and Jaenike 1984, pp. 1113–1120). Several species of soldier flies and flies in the family Neriidae may also pose similar threats to Hawaiian picture-wing flies (Science Panel 2005, pp. 1–23).

Stem- and bark-breeding picture-wing fly species, due to their dependence on older, senescent, or dying plants, are sensitive to declines in host-plant populations (Table 3; Magnacca et al. 2008, p. 32). The loss or decrease in host-plant substrates and the degradation or loss of habitat providing the humidity requirements of the picture-wing fly and decay cycle of the host plants contribute to the decline in picture-wing fly populations. This subsequently disrupts the picture-wing fly's life cycle, particularly oviposition and larval development, which are dependent on the availability of suitable decaying substrate (Magnacca et al. 2008, pp. 1, 32).

In addition to threats from ungulates, *Charpentiera* spp., one of two known host plants of *Drosophila digressa*, are threatened by the nonnative branch and twig borer beetle (*Amphicerus* *cornutus*), long-horned beetle (*Sybra alternans*), the black twig borer (*Xylosandrus compactus*), and a weevil (*Oxydema fusiforme*) (Table 3; Medeiros et al. 1986, p. 29; Giffin 2003, p. 81). These insects directly damage *Charpentiera* spp. through their feeding and boring, and indirectly by increasing the susceptibility of the host plants to other insects and/or diseases.

Rapid ʻŌhiʻa Death as described in the *Plants* section *Factor C* is also an ongoing threat to *Drosophila digressa*. The disease is present throughout the range and current habitat of the picture-wing fly (Friday et al. 2022, entire). Like drought, the loss of canopy allows more sunlight to reach the forest floor, increasing the temperature and lowering the humidity and subsequently adversely affecting the picture-wing fly and its habitat (Table 3).

The limited number of individuals and populations make the species vulnerable to catastrophic events (e.g., hurricane, drought, volcanic eruption). Species with few populations are less resilient to threats that would likely have a relatively minor impact on widely distributed species (Table 3; USFWS 2013, pp. 64683–64684). For example, the reducavailability of host-plant substrate or an increase in predation or parasitization would likely be inconsequential to a widely distributed species but could result in a significant decrease in survival or reproduction of a species with a limited distribution. *Drosophila digressa* is currently not in captive breeding program, which also increases their vulnerability to stochastic events (Table 3).

Changes in environmental conditions that may result from climate change include increasing temperatures, decreasing precipitation, and increasing storm intensities. The habitats of *Drosophila digressa* are likely to be negatively affected by changes in temperature, humidity, precipitation, and the frequency and severity of storms (Table 3; Clark et al. 2020, entire; Lowe et al. 2020, entire). These stressors may change the habitats on the island of Hawaiʻi and exacerbate other threats making the habitats unsuitable for the picture-wing fly, its host plants, or both. Additionally, changes in temperature and humidity may alter the decay cycle of the host-plant substrate the picture-wing flies require for breeding.

II. RECOVERY

A. RECOVERY VISION AND STRATEGY

A recovery vision is an explicit expression of recovery in terms of resiliency (the ability of a population to recover from periodic disturbance), redundancy (the number of populations of a species distributed across the landscape), and representation (the range of variation found within a species). It builds on the description of viability for the species and defines what recovery looks like for the species. The recovery strategy provides a recommended approach for achieving the recovery vision, and ultimately, the down- and delisting criteria.

1. Recovery Vision

Recovery of the 13 plant species entails each species having redundant populations distributed throughout their respective habitats. These populations should be self-sustaining, resilient, and represent the existing genetic diversity in the species. Habitats should be protected from ungulates, fire, agriculture and urban development, and other forms of degradation. Where possible, habitats should be connected to facilitate genetic exchange. Nonnative plants, nonnative insects, and disease should be sufficiently managed, so that each species maintains stable, secure, and naturally reproducing populations.

Recovery of *Vetericaris chaceorum* entails the species having redundant populations distributed throughout coastal habitats in anchialine pool complexes on the island of Hawaiʻi. Populations should be resilient, self-sustaining, and represent the existing genetic diversity in the species. Their anchialine pool habitats should be protected from ungulates, coastal development, human disturbance, sedimentation, and other forms of degradation. Water quality and quantity should be managed and protected to support the species. Predators, overcollection, and other threats should be managed such that the *V. chaceorum* maintains their presence at currently occupied anchialine pool complexes as well as expanding their range into unoccupied anchialine pool complexes.

Recovery of *Drosophila digressa* entails having redundant populations distributed throughout the mesic and montane wet habitats of the island of Hawaiʻi. Populations should be self-sustaining, resilient, and represent the existing genetic diversity in the species. Habitats of each species should support connectivity between populations for genetic exchange, when possible. Their mesic and montane wet forest habitats should be protected from ungulates, fire, and other forms of degradation and provide sufficient host plants in the appropriate stage of decay to support picture-wing fly populations. All threats to the picture-wing fly and its host plants should be managed such that both maintain stable to growing populations.

2. Recovery Strategy

For the purposes of this recovery plan, conservation translocation (hereafter translocation) is the human-mediated deliberate movement of organisms from one site for release in another for a conservation benefit, and includes population restoration (reinforcement and reintroduction) and conservation introductions (assisted colonization and ecological replacement) as defined in

IUCN (2013, entire). Translocations will follow guidelines of the International Union for Conservation of Nature/Species Survival Commission (IUCN/SSC) (IUCN 2013, entire).

General Cross-Species Recovery Strategy

The 15 plant and invertebrate species addressed in this recovery plan use 8 natural habitat types. Large portions of these habitats have been destroyed, reduced in size, degraded such that the habitat no longer supports stable or growing populations, are in need of management and protection, or a combination of these conditions (Ball et al. 2020; Browning et al. 2020; Clark et al. 2020; Javar-Salas et al. 2020; Kim et al. 2020; Lowe et al. 2020; Nelson et al. 2020; Pe‘a et al. 2020). Collectively, restoration and protection of the 8 habitat types are beneficial to all 15 species and provide for the species-specific habitats necessary for the recovery of each species. Restoration, management, and protection of these habitats should be informed by science-based management plans. On private lands, such efforts may require conservation agreements with landowners.

Nonnative species, particularly invasive plants, disease, herbivores, and predators affect all 15 species either by altering their habitats or by directly impacting the species. Recovery of the 15 species will require monitoring and management of nonnative invasive plants, ungulates, other vertebrates, and invertebrates; fencing and nonleathal or lethal control of herbivores or predators, and minimizing development in natural habitats required for recovery. The microclimate needs of each species should be documented and modeled to determine how suitable microclimates will shift due to climate change. Hurricanes, tsunamis, volcanic eruptions, and floods will intermittently affect habitats to varying degrees. Mitigating the effects of these events requires conserving sufficient habitats to support redundant viable populations of the listed species throughout their respective ranges. Having species representation in genetic storage will provide a source for propagation of some species. *Ex situ* collections and captive propagation may be necessary as sources for translocation and to ensure preservation of genetic representation if a species becomes extirpated from the wild.

Recovery will also require development and enforcement of water regulations to manage threats to groundwater quality and quantity. This would include regulating and managing subsurface water extraction, flow, and non-point source pollution that can impact terrestrial and aquatic species. Recovery will require long-term protection from dewatering and water diversion.

Recovery will require working with State, Federal, County, native Hawaiian and local communities, nonprofit, and private statkeholders (collectively, conservation partners) to reestablish the viability of each species across its range. Recovery will require collaboration and partnerships with conservation partners to prevent the introduction and establishment of new invasive species that negatively affect the 15 species, their habitats, or both, and impede recovery. These partnerships should work to expand and improve border inspections and implement the Hawai‘i interagency biosecurity plan (State of Hawai‘i 2017, entire). Biosecurity measures are essential to avoid introduction of new invasive species to the island of Hawai‘i, prevent reintroduction of invasive species if eradication programs are successful, and intercept or control invasive species that may be brought in from outside the State. New invasive species include invasive plants; invertebrates and vertebrates; and diseases of plants, anchialine pool shrimp, and/or picture-wing flies. Implementation of the biosecurity plan requires continued outreach to travelers to Hawai‘i and between islands, enforcement, and adaptation to address new introductions.

Monitoring and evaluation of the effects of actions implemented to achieve recovery are critical to inform and adapt future management. In addition, all populations will require monitoring to identify new threats, track demographic variables, water quality parameters, and resiliency, where feasible. Post-delisting monitoring will be needed to confirm delisted species continue to meet recovery criteria.

General Recovery Strategy

The recovery strategy for the 15 species in this recovery plan entails 5 principal steps. For some species, the first three steps may be accomplished concurrently; for other species, the steps may need to be accomplished sequentially. Monitoring and evaluation throughout the five steps are important components associated with each action and its consequences within each of the five steps. The results of monitoring and evaluation form a feedback loop for adaptively adjusting management strategies for each species in each step.

The first step to achieving recovery is identifying and prioritizing all populations, curtailing their decline, and stabilizing each species. Prioritization and population management should conserve the existing representation and diversity of each species. To stabilize populations, threats identified in recent Species Reports (USFWS 2023b through USFWS 2023p) need to be managed. Regulation development, codification, and enforcement will be required to manage resource- and species-based threats and provide long-term protection of habitats and resources for terrestrial and aquatic ecosystems. Continuous monitoring will be necessary to identify any new or previously unrecognized threats. These threats must then be ameliorated. This will require working with conservation partners to protect and manage populations of the species across their ranges.

After halting population declines, the second step is to determine the status of each species' population(s) and their respective habitats and then prioritize, protect, and manage the habitats supporting these populations such that threats are ameliorated and the populations are stabilized or increasing.

Once populations are protected and managed and are stable or increasing, the third step is to increase redundancy and population resiliency throughout each species' range. For many species, this will require establishing new populations, using genetically appropriate individuals in occupied or unoccupied habitat to increase redundancy within each species' historical and/or current range, and/or reinforcing small populations to increase their resiliency. Populations of some species may be established outside their historical range via conservation introductions in response to changing environmental conditions.

The fourth step is downlisting. Once a species has met all its downlisting criteria, the species can be considered for downlisting. The fifth step is delisting. Once a species has met all its delisting criteria, the species can be considered for delisting. An assessment of a species' status in relation to the five listing factors found in section 4(a)(1) and the definitions of "endangered" and "threatened" in section 3 of the Act, respectively, will be used to determine whether downlisting or delisting is appropriate. This subsequent review may be initiated without all the recovery criteria in this plan having been fully met. A decision to downlist or delist a species is informed by the recovery criteria but is ultimately based on an analysis of threats using the best scientific and commercial data available. However, recovery criteria are mileposts that measure progress toward recovery. Because we cannot envision the exact course that recovery may take, and our understanding of the vulnerability of a species to threats is likely to change as more is learned, it is possible that a status review may indicate that delisting is warranted although not all recovery criteria are met. Conversely, it is possible that recovery criteria could be met, but a status review indicates that delisting is not warranted. For example, a new threat not addressed by the current recovery criteria could result in the species continuing to be threatened or endangered.

Many aspects of the 15 species' life history, genetics, demographics and ecology, propagation and captive rearing, population viability, priority threats, and management needs are poorly understood. In addition, the effects of climate change on each species will need to be evaluated to plan for possible conservation introductions to new suitable habitats outside their historical range. Research on these topics will occur concurrently with each of the above five steps, and the results will inform management actions and recovery actions.

The general recovery actions for each of the identified threats of the three species groups (plants, anchialine pool shrimp, and picture-wing fly) are described below.

Recovery Strategy for Plants

For the 13 plant species, recovery will require protection from nonnative ungulates (Table 2). Construction and maintenance of ungulate-proof fencing around each population or habitats supporting multi-species should be considered in conjunction with lethal removal of ungulates. Ungulates must be removed from all fenced areas that are needed for the recovery of the plant species.

For the 13 plant species, recovery will require some degree of management and protection from invasive plants throughout their geographic range and new areas will be needed for recovery of each species (Table 2). Management or eradication of habitat-modifying invasive plants is necessary to enhance the habitat and improve the survival of the 13 plants. Research and development of new control tools should be considered. Measures are needed to prevent the spread of incipient invasive species into sites occupied by populations needed to achieve recovery. Support for the Hawaiʻi interagency biosecurity plan (State of Hawaiʻi 2017, entire) is necessary to prevent the arrival and spread of invasive species to the State of Hawaiʻi and interisland movement of invasive species already established in the archipelago.

For at least four plant species, recovery will require fire management and prevention strategies (Table 2). Fire management plans and infrastructure should be developed for sites needed for recovery, including suitable but unoccupied sites. Plans should consider the likely increased risk of wildfire due to climate change. Management actions that reduce the likelihood of fire should be implemented to protect the occupied and suitable habitats of these plant species.
To minimize the effects of drought and stochastic events such as hurricanes, volcanic eruptions, floods, and landslides, these species will need resilient populations that are redundant and

represented throughout, and possibly outside of, their historical range (Table 2). Redundant populations will incorporate each species existing genetic representation where possible within each population, as appropriate. Translocation supported by genetic information and *ex situ* propagation will be considered and implemented when needed. The feasibility and conservation benefit of translocating species outside of their known historical range to mitigate for drought and stochastic events will be considered.

Recovery of plant species threatened by overutilization (*Prichardia lanigera*) by humans will require public outreach and education to promote and support native species awareness (Table 2). Protection is needed for plants affected by other anthropogenic threats such as koa logging (*Phyllostegia floridunda*) and nonnative game birds introduced for public hunting (*Schiedea hawaiiensis*). Development and implementation of specific actions to reduce these threats are needed.

Research will be conducted as needed to better understand threats such as plant diseases that may affect species' viability or their habitat as well as to develop tools to detect, manage, and eradicate diseases (Table 2). Plant diseases such as ROD, with the potential to degrade the habitats of all 13 plant species, need to be successfully managed. Populations of the 13 species will need to be monitored to detect diseases, assess their impacts, and control outbreaks as soon as possible.

Recovery of most of the plant species will require long-term management to control rodents, slugs, and insect herbivores (Table 2). A rodent control or eradication program will need to be developed and implemented to support reproduction, natural recruitment, and survival of each plant species. In addition to rodent control, protection of vulnerable plant species will require a slug control program to be developed and implemented. One plant species (*Pritchardia lanigera*) will require long-term management and protection against introduced beetles and leafhoppers (Table 2). Management or eradication will require new tools be developed and implemented to effectively control these nonnative insects. Recovery of some plant species may also require long-term management and protection against introduced ants. In cases where native pollinators avoid plants occupied by ants or other nonnative invertebrates, development and implementation of a long-term control program for the ants and/or other invertebrate species will be necessary.

Recovery of plant species with the potential to hybridize or that are experiencing a lack of regeneration will require research to inform management (Table 2). Propagation of genetically appropriate individuals for genetic storage and translocation to augment populations that are not regenerating should be considered. Methods to monitor population growth and status, including the genetic composition of progeny for species threatened by hybridization, will need to be developed. Research on population genetics to identify hybrid individuals and adapt management actions to vulnerable plant populations will likely be needed. Removal of hybrid plants will need to be considered. Research on demographics, pollination, and propagule dispersal as well as the evaluation of genetic threats to species' viability, which may be necessary to inform management needed to increase population resiliency, may be required. Tools to control and manage limiting factors and enhance survival and reproduction will need be developed and implemented.
Threats to over half of the plant species are exacerbated by limited number of individuals of each species (Table 2). Translocation will be a crucial action to achieve recovery and will require

species-specific plans. Plans will need to consider the genetic composition and number of founders, suitable source population(s), as well as the species' reproductive capacity and the suitability and availability of habitat. Plants propagated for translocation should be genetically representative of the source populations, and translocated individuals should represent the appropriate genetic composition for the habitat to which they are translocated. The selection of translocation sites will be prioritized based on a suite of factors including their conservation value to multiple species and the likelihood of successful threat management. If necessary, sites will be prepared for translocation. If necessary, the feasibility and conservation benefit of translocating species outside of their known historical range (i.e., assisted colonization) will be considered to provide sufficient redundancy and representation.

Recovery of plant species susceptible to environmental changes related to climate change (Table 2) will require microclimate modelling and the identification of suitable habitat based on historical and existing species' distributions and potential future climate conditions. This information will be essential to expanding species' ranges using translocation to include new suitable habitat. Prior to establishing any populations outside of a species' known range, habitat suitability and existing and new threats need to be assessed and managed. Translocations should be informed by each species' life history, demographic viability, pollinators, natural recruitment, and other factors that could influence the likelihood of successful population establishment.

Recovery Strategy for Anchialine Pool Shrimp

The extent of the distribution of *Vetericaris chaceorum* is currently unknown. Systematic surveys throughout the species' known range will be necessary to identify populations (redundancy) and quantify genetic and environmental variation (representation) of occupied pools. The rarity and cryptic nature of the species may require development and implementation of new technologies (Breininger et al. 2019, entire).

For recovery, occupied anchialine pool complexes will need to be identified, actively managed, and protected from all threats. Research to determine what the species needs to achieve a stable or increasing condition, and to identify anchialine pool restoration methods, will be necessary to prevent extinction and ultimately support resilient populations. Measures to enhance *Vetericaris chaceorum* survival and population growth should be developed and implemented. Unfortunately, little is known about the biology and life history of the species and research is needed on the range of suitable anchialine pool habitats and species-specific conditions required by the species such as water quality, pH, dissolved oxygen, light, temperature, salinity ranges, colonization, and population dynamics to inform management actions for each anchialine pool complex. Population viability analysis tools or other means of measuring population health and growth should be developed. Identification of methods to enhance the anchialine pool shrimp survival and reproduction will be necessary. A captive-rearing program may be necessary to prevent extinction of the species and provide a future source for translocations. Populations must show evidence of growth before they can be used as source populations to initiate a captive-rearing program or support translocation efforts.

Recovery of *Vetericaris chaceorum* will require protection from coastal development throughout its range to prevent the filling of pools, protect water quantity and quality, and minimize dewatering. Long-term protection from freshwater fluctuations caused by sub-surface water extraction, dewatering, and water diversion, which alter the freshwater availability and salinity of the anchialine pool complexes and directly impact the species will be required. Protection of habitat around anchialine pools to prevent degradation should be implemented. Monitoring and management of water quality factors, such as for nutrient concentrations, contaminants, pH, dissolved oxygen, salinity levels, temperature, and cyanobacteria, will also be needed.

Recovery of *Vetericaris chaceorum* will require protection from ungulates in the vicinity of anchialine pool habitats throughout the species' range. Construction and maintenance of ungulate-proof fencing around habitats surrounding anchialine pools will need to be considered followed by lethal removal of ungulates from fenced areas if ungulates cannot be controlled by other means.

Recovery of *Vetericaris chaceorum* will require some degree of protection and management from invasive plants, especially kiawe, Christmas berry, pickleweed, introduced milo, and others, in and around anchialine pool habitats to decrease nutrient loading in, and senescence rates of, anchialine pools.

Recovery of *Vetericaris chaceorum* will require that anchialine pools are protected from invasive fish and invertebrates or eradication of these species if present. Once the distribution of the anchialine pool shrimp is known, determining the status of predators is critical to planning the next steps for recovery. Removal of invasive fish and invasive invertebrates will be needed at each occupied pool complex and at sites selected for reintroduction. Because existing invasive invertebrate eradication techniques could adversely impact *V. chaceorum*, novel and safe techniques to eradicate invasive invertebrates will need to be developed and tested. Removal of invasive fish and invertebrates using carbon dioxide, baited traps, hand nets, *Tephrosia purpurea* ('ahuhu), and/or rotenone should be considered at occupied and unoccupied sites.

To minimize the effect of a catastrophic event such as a hurricane or volcanic eruption, the distribution of anchialine pool shrimp will need to be expanded via translocations to suitable existing anchialine pools or to anchialine pool complexes that have been restored or created outside of the species' historical range. Expanding the number and distribution of anchialine pool complexes occupied by the anchialine pool shrimp would increase species' overall redundancy and limit its vulnerability to catastrophic events. Created and/or restored anchialine pool complexes should be distributed to minimize the risk that a catastrophic event could result in the extirpation of a population. In addition, populations created or augmented via translocation should be representative of the species' existing genetic variation.

Although none has been identified to date, disease is a potential threat to *Vetericaris chaceorum*. Diseases from invasive fish and fecal coliform are potential threats to the viability of the anchialine pool shrimp. The development of tools to avoid, detect, or cure diseases and control or eradicate pathogens that could adversely affect both wild and captive anchialine pool shrimp should be considered.

Recovery of *Vetericaris chaceorum* will require the enforcement of Federal and State laws to protect the anchialine pool shrimp from illegal activities such as dumping, harassment, and collection. This will also require public outreach to promote awareness of, and support for, native species; signage and education; and enforcement of penalties to prevent unpermitted activities in anchialine pools and illegal harassment and collection. Establishing a Hawaiʻi State Department of Health Water Protection Branch and finalizing the nonpoint source pollution control and management Administrative Rules are needed to regulate nonpoint source pollution affecting anchialine pool shrimp and their habitat.

The limited number of *Vetericaris chaceorum* populations restricted to a limited geographic area exacerbates threats to this species' persistence. Management to support breeding and population growth needs to be developed and implemented. Translocation from wild and captive populations to augment existing and establish new populations will likely be necessary to increase the number of individuals and populations. Establishing new populations via translocation should include the species' remaining genetic diversity where possible.

Climate change has the potential to adversely affect the anchialine pool shrimp. Recovery of *Vetericaris chaceorum* will require development of microclimate models and identification of suitable habitat based on the species' historical and current distributions and potential future climate conditions. Use of appropriate scale in the analysis will be necessary to identify microclimates that will be appropriate for sustaining the anchialine pool shrimp populations long-term. Expanding the range of the anchialine pool shrimp through translocation to include new or unoccupied anchialine pools that could support the species should be considered. Such considereration should be informed by research to assess habitat suitability, threats, and species viability.

Recovery Strategy for the Picture-wing Fly

The biology and population status of the picture-wing fly species are poorly known. Research on population needs and the restoration techniques necessary to prevent extinction and facilitate population growth should be a priority. Thorough, systematic surveys will be needed to identify populations and better understand the species' representation, redundancy, and host plants. All populations identified should be immediately protected and actively managed to control threats. The habitat of the picture-wing fly and its host plants (*Charpentiera* spp., *Ceodes brunoniana*, and *Rockia sandwicensis*) will require some degree of immediate protection and/or restoration, depending on the species of host plant. A captive-rearing program will be necessary to provide an insurance population in case of extirpation from the wild and to provide a future source of individuals for translocation (population restoration and/or conservation introduction).

Picture-wing flies are sensitive to declines in their host plants, which serve as substrates for their eggs and larvae. Altered decay cycles in host plants caused by decreasing availability of host plants due to browsing and trampling by ungulates, competition with nonnative plants, drought, or other phenomena can subsequently alter the life cycle of the picture-wing fly by disrupting their early stages of development. Mesic and wet forest habitats that support host-plant populations as well as other resources needed to support *Drosophila digressa* populations, or that can be restored to provide these needs, should be identified, prioritized, and protected/restored throughout the species' range. Restoration and management plans will focus on actions that support stable to growing populations of the picture-wing fly and its host plants. This will entail identifying and managing existing populations of host plants that provide egg-laying and larval substrates and may require supplementing these breeding resources through augmentation, recruitment support, and protection, such that host-plant substrate is available to support stable to growing populations of picture-wing flies in the long term. These management actions will require working collaboratively with conservation partners. Conservation agreements and other modes of habitat conservation should provide for long-term persistence of *D. digressa* and its habitat.

Drosophila digressa and its host plants will require long-term protection from introduced ungulates throughout the species' range. Construction and maintenance of ungulate-proof fencing around picture-wing fly populations and their hosts will be needed if ungulates cannot be controlled by other means. Ungulates will need to be removed from fenced areas that enclose habitats supporting picture-wing flies and their host plants.

The recovery strategy for *Drosophila digressa* and its habitat will require development of long-term fire management plans. This should include identifying specific fire management actions, developing infrastructure for protecting each picture-wing fly population, and initiating actions to reduce the likelihood of fire. Fire management plans will be adaptive to accommodate climate change and other stochastic changes that increase fire risk and fuel load.

Measures to enhance picture-wing fly population growth and size should be developed and implemented. Little is known about the biology and habitat requirements of *Drosophila digressa* other than the need to protect its egg laying and larval substrates as well as protecting all life stages from threats. Thus, research into the range of host plants and host-plant substrates used by this species; basic breeding needs including light, temperature, and humidity; dispersal and colonization; and population dynamics will be needed to inform management. Defining the specific microclimate needs of *D. digressa* will be necessary to effectively create and manage populations. Methods to enhance the species' habitat, including the survival of host plants, as well as the reproduction and survival of *D. digressa* should be developed and implemented. Population viability analysis or other means of measuring population health and growth will be needed.

Management or eradication of habitat-modifying invasive plants throughout the species' range will be necessary. *Drosophia digressa* prefers shaded habitats with high humidity, although specific microhabitat needs are unknown, and its host plants are highly susceptible to competition from invasive plants. Maintaining or restoring native forests at each picture-wing fly population will facilitate genetic exchange among populations.

Once existing populations are protected, management should focus on establishing additional populations throughout the species' known range, including in critical habitat, as a buffer against stochastic (e.g., drought) and catastrophic events (e.g., hurricanes, high wind events, volcanic eruptions). Such events may cause the loss of picture-wing flies, their host plants, and/or modify the microclimate necessary for their breeding and survival. Expanding the number and distribution of picture-wing fly populations throughout its range will improve redundancy and limit their vulnerability to stochastic and catastrophic events. Populations created to increase redundancy will incorporate the species' remaining genetic diversity where possible, to minimize the loss of diversity. This could entail creating large contiguous populations throughout its range or a series of smaller, discrete populations. Research to identify dispersal distance and current and future range of the species will be needed.

At least five species of non-native ants threaten *Drosophila digressa* via predation or competition for resources. Recovery of the picture-wing fly will require identifying appropriate ant control or eradication methods, applying these methods, and monitoring the results. The management or eradication of ants at or near sites occupied by *D. digressa* will consider (a) the species of ant present, (b) the methods available and the need to develop new control and/or eradication technologies, and (c) the risk that controlling one ant species will benefit another ant species. Research may be needed to identify appropriate ant control and/or eradication methods.

Predation by nonnative western yellowjacket is a threat to *Drosophila digressa* due to their conspicuous lekking and courtship displays. Considerations for management and control of western yellowjacket will be analogous to those described above for ant control. Programs to control predatory wasps will need to be developed and implemented if research indicates western yellowjacket or other nonnative predatory wasps are adversely affecting picture-wing fly populations.

Parasitization by nonnative parasitoid wasps is a threat to *Drosophila digressa*. Research to evaluate parasitization of each life stage of the species will identify effects on populations and develop measures to manage impacts to *D. digressa*.

Competition for larval substrates of picture-wing fly from nonnative invertebrates poses a threat to the species. Research to quantify competition from nonnative Limoniiid crane flies and other, yet unidentified, invertebrates will be needed. Techniques to control invertebrate competition for larval substrate resources will need to be developed and implemented. Competition for larval substrate resources should be considered during the development of management plans for the picture-wing fly and its host plants. Plans should address the effects of increases in nonnative limoniid crane fly populations as host-plant availability is increased.

Management of picture-wing fly host-plant substrates will require control of nonnative vertebrate and invertebrates that damage or kill the host plants. Several species of nonnative borer beetles and a weevil are known to damage *Charpentiera* spp. Research to identify control strategies to manage these invertebrate threats will be needed.

Management of picture-wing fly habitat will include maintaining, restoring, and protecting the understory microclimate conditions that support *Drosophila digressa* and its host plants. This will include managing ROD, which is an ongoing threat to ‘ōhi‘a, an important canopy tree in the mesic and wet habitats of the picture-wing flies. ‘Ōhi‘a is a major structural element of native forests and ROD results in canopy gaps. Those gaps modify light and microclimate conditions in the understory and promote establishment of nonnative plants in otherwise intact native forest. Research into ROD control, prevention measures, and replacement of overstory canopy will be necessary to create and maintain the microclimate required by the picture-wing flies and their host plants in mesic and wet forests.

The demography and breeding requirements of *Drosophila digressa* should be researched. The persistence of the species is threatened by the limited number of populations. The dependence of the picture-wing flies on their host plants results in this species highly vulnerable to reproductive failure, and cyclical population variation related to fluctuations in breeding resources. This research will inform the management of existing populations, captive-rearing programs, and future translocations.

Natural recolonization into suitable but unoccupied or restored habitats is likely to be slow or nonexistent, given the current condition of the species. Thus, translocations will likely be necessary to establish additional populations. Design of a successful translocation program will require documenting the species' current distribution and genetic structure as well as their breeding (e.g., mate selection) and dispersal behavior. A captive-rearing program will be needed to provide the individuals necessary for reintroduction, reinforcement, and conservation introductions. Research will be conducted as needed to support these efforts.

Changes in environmental conditions resulting from climate change include increasing temperatures, decreasing precipitation, and increasing storm intensities. The habitats of all picture-wing fly species, including *Drosophila digressa*, are likely to be affected by changes in temperature, humidity, precipitation, and storm frequency and severity. These stressors may change the species' habitats and exacerbate other threats making the habitats unsuitable for the picture-wing fly, its host plants, or both. Additionally, changes in temperature and humidity may alter the decay cycle of the host-plant substrate the picture-wing flies requires for breeding. The development of microclimate models and identification of suitable habitat based on the historical and current distribution of *D. digressa* and potential future climate conditions will be necessary. Expansion of the species' range to new areas due to climate change may be necessary.

Management plans will need to be adaptive and include monitoring to allow for feedback to the plan and accompanying actions. Tools to effectively monitor and measure population growth and status should be developed and used to inform any management plans for the picture-wing fly, its host plants, and habitat. New threats to each population will need to be identified and managed. This will include supporting implementation of the State of Hawaiʻi 2017 interagency biosecurity plan to prevent the introduction of new invasive species to the island of Hawaiʻi and into the habitat of the picture-wing fly.

B. RECOVERY CRITERIA

Section 4(f)(1)(B)(ii) of the Act states that each recovery plan shall incorporate, to the maximum extent practicable, "objective, measurable criteria which, when met, would result in a determination... that the species be removed from the List." Legal challenges to recovery plans (see Fund for Animals v. Babbitt, 903 F. Supp. 96 [D.D.C. 1995]) and a Government Accountability Audit (GAO 2006, entire) also have affirmed the need to frame recovery criteria in terms of threats assessed under the five listing factors.

Recovery criteria serve as objective, measurable guidelines to assist in determining when an endangered species has recovered to the point that it may be downlisted to threatened, or that the protections afforded by the Act are no longer necessary and the species may be delisted. Delisting is the removal of a species from the Federal Lists of Endangered and Threatened Wildlife and Plants (Lists). Downlisting is the reclassification of a species from endangered to threatened. The term "endangered species" means any species (species, subspecies, or distinct population segment) that is in danger of extinction throughout all or a significant portion of its range. The term “threatened species” means any species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.

Recovery criteria represent our best assessment, at the time the recovery plan is completed, of the conditions that would likely result in a determination that listing under the Act as threatened or endangered is no longer required. However, revisions to the Lists, including delisting or downlisting a species, must reflect determinations made in accordance with sections 4(a)(1) and 4(b) of the Act. Section 4(a)(1) requires that the Secretary determine whether a species is an endangered species or threatened species because of threats to the species, based on an analysis of the five listing factors in section 4(a)(1). Section 4(b) requires that the determination be made “solely on the basis of the best scientific and commercial data available.” Thus, while recovery plans provide important guidance to the Service, States, Territories, and other partners on methods of minimizing threats to listed species and measurable criteria against which to measure progress towards recovery, they are guidance and not regulatory documents.

Thus, a decision to delist or downlist a species is informed by the recovery criteria but is ultimately based on an analysis of threats using the best scientific and commercial data available. All classification decisions consider an analysis of the following five factors: (1) is there present or threatened destruction, modification, or curtailment of the species’ habitat or range; (2) is the species subject to overutilization for commercial, recreational scientific or educational purposes; (3) is disease or predation a limiting factor; (4) are there inadequate existing regulatory mechanisms in place outside the Act (taking into account the efforts by States and other organizations to protect the species or habitat); and (5) are other natural or manmade factors affecting its continued existence. When delisting or downlisting a species, we first propose the action in the *Federal Register* and seek public comment and peer review of our analysis. Our final decision is announced in the *Federal Register*.

The species addressed in this recovery plan should be considered for downlisting and delisting when the following objective(s) and criteria have been met. Downlisting and delisting criteria are subject to change as additional information becomes available about species’ biology and threats. Monitoring and evaluation of each population is an essential part of assessing the viability of the 15 species addressed by this recovery plan. It will be necessary to (a) monitor the number of individuals and population distribution to determine population growth status and redundancy, (b) identify and evaluate new or existing threats and their management in each species’ habitat, (c) evaluate habitat management actions, and (d) use the evaluations to adapt the management actions. Evaluations will require the establishment of baselines against which each recovery criterion can be compared. As such, long-term monitoring is expected, continuing throughout the species’ status as listed, and past the time of delisting.

1. Recovery Criteria — Plants

Objective — Manage threats and habitats to establish resilient and self-sustaining populations of each listed plant species on the island of Hawai‘i.

The Hawai‘i and Pacific Plants Recovery Coordinating Committee (HPPRCC), comprised of biologists from Federal and State agencies, private conservation organizations, botanical gardens, and universities, was established to advise the Service on the biology and management needs for recovery of listed plants. The HPPRCC has outlined general actions and targets for the stages leading towards recovery of listed Hawaiian plants (HPPRCC 2011, entire). Current information is lacking for many Hawaiian plant species with respect to the status of the species and their habitats, breeding systems, genetics, and propagule storage options. We have, therefore, adopted downlisting and delisting criteria for Hawaiian plants based on the revised general recovery objective guidelines developed by the HPPRCC (2011, entire). Many of the Hawaiian plant species persist at very low numbers so we developed criteria for avoiding imminenet extinction and an interim stabilization stage before downlisting, to assist in tracking progress toward the goal of recovery, based on the recommendations of the HPPRCC. While these two “interim recovery stages” are not required under the ESA, they are critical to the recovery of these species. These criteria are assessed on a species-by-species basis, as additional information becomes available before considering downlisting and delisting.

For the purposes of recovery criteria in this recovery plan, a plant population is considered a group of conspecific individuals that are in close spatial proximity to each other (i.e., less than 3,280 ft [1,000 m] apart) and are presumed to be genetically similar and capable of sexual reproduction (HPPRCC 2011, p. 1). The number of mature individuals per population required to meet the interim stabilization target addresses the fact that numbers between 100 to 500 individuals are likely needed to avoid inbreeding, while numbers required to satisfy downlisting and delisting criteria addresses the fact that around 5,000 mature individuals are needed to maintain evolutionary potential, so that a species can adapt to changing environments (Reed et al. 2002, pp. 12–13; Traill et al. 2010, pp. 30, 32; HPPRCC 2011, pp. 7–10).

General distinctions made by the HPPRCC that are relevant to the 13 plants in this plan include the following:

- *Life span*: Long-lived perennials are those taxa either known or believed to have life spans greater than 10 years; short-lived perennials are those with life spans greater than 1 year but less than 10 years; and annuals are those with life spans less than or equal to 1 year (Tables 4–7; referred to as ‘long’ and ‘short’, respectively). None of the 13 listed species are currently believed to be annuals. When it is unknown whether a species is long or short-lived, we have erred on the side of caution and considered the species short-lived. We currently do not have the data to determine the life span of most of these species. As more data is collected, we will update species’ life span categorizations.
- *Reproduction strategies*: Obligate outcrossers are species that either have male and female flowers on separate plants or otherwise require cross-pollination to fertilize seeds, and therefore require equal numbers of male and female individuals contributing to reproduction, doubling the number of individuals needed per recovery stage (HPPRCC 2011, pp. 5, 6, 8, 10). The majority of genetic variation in a species that predominantly reproduces vegetatively or asexually (i.e., without the use of seeds) is typically found among populations versus within populations (HPPRCC 2011, p. 4). Therefore, species dependent on vegetative reproduction require additional populations. Whether *Stenogyne cranwelliae* reproduces vegetatively is unknown; however, other members of this genus reproduce vegetatively and thus we categorized it as such. This characteristic will be assessed as additional information becomes available.
- *Population size trends*: Species characterized by large fluctuations in the number of mature individuals or a known history of severe declines in the number of mature

individuals in the population require a larger number of mature individuals (approximately 50 percent higher) than species without such fluctuations, for the population to persist during, for example, drought years and to recover during typical years (HPPRCC 2011, pp. 5–10). While our current understanding is that none of the 13 listed plants have populations that greatly fluctuate in size, should a species be identified as having this characteristic the minimum number of mature individuals needed in each of the stages would be increased by 50 percent.

- *Immediate vicinity*: Immediate vicinity of a population is defined as a 163 ft (50 m) buffer around the existing population, but depends on the threats specific to the population and on the response of the population to control of those threats, so will require adaptive management to ensure improving populations (HPPRCC 2011, p. 4).

The following targets for the preventing extinction and interim stabilization stages and the downlisting and delisting criteria were determined based on known biology of the 13 plants in this recovery plan considering the above general guidelines.

Interim Recovery Stages:

Preventing Extinction

To meet the preventing extinction targets, several conditions should be satsified. The minimum number of populations and reproducing individuals per population identified in Table 4 should be realized. All major threats must be managed in the immediate vicinity of the populations. Each population must show evidence of natural reproduction (i.e., viable seeds, seedlings, saplings). And lastly, 50 mature individuals from each population, or the total number of individuals if fewer than 50 remain, must be represented in an *ex situ* collection that is secure and well managed as defined in the Center for Plant Conservation's guidelines (Guerrant et al. 2004, entire).

Table 4. Number of populations and individuals needed for each plant species to meet the preventing extinction stage based on population and life history characteristics.

Life Span	Population and Life History Characteristics	Number of Populations	Reproducing Individuals Per Population	Species
Long	No specific characteristics known	3	25	*Melicope remyi*
		3	25	*Pritchardia lanigera*
Long	Obligate outcrosser	3	50	*Pittosporum hawaiiense*
Short	No specific characteristics known	3	50	*Bidens hillebrandiana* ssp. *hillebrandiana*
		3	50	*Bidens micrantha* ssp. *ctenophylla*
		3	50	*Cyanea marksii*
		3	50	*Cyanea tritomantha*
		3	50	*Cyrtandra nanawaleensis*
		3	50	*Cyrtandra wagneri*
		3	50	*Phyllostegia floribunda*
		3	50	*Schiedea diffusa* ssp. *macraei*
		3	50	*Schiedea hawaiiensis*
Short	Vegetatively reproducing	6	50	*Stenogyne cranwelliae*

Interim Stabilization

In addition to achieving the minimum number of populations and reproducing individuals per population identified in Table 5, to meet the Interim Stabilization targets, populations should be successfully reproducing, including evidence of seedlings transitioning to mature individuals and/or have age-class distribution indicative of a stable population. All major threats must be managed around the target populations. The populations must be adequately represented in an *ex situ* collection that is secured and well maintained as defined in the Center for Plant Conservation's guidelines (Guerrant et al. 2004, entire). Reintroduced populations can be counted toward the minimum number of populations when they are producing viable seed or vegetatively regenerating. Genetic analysis must be conducted for all wild and any reintroduced populations to determine the genetic variation within and among populations, incorporating any stock in controlled propagation that has been lost in the wild. The results of the genetic analyses will be used to develop translocation strategies to correct any genetic deficiencies and determine if translocated individuals should be sourced from one or multiple wild populations. Adequate monitoring is in place to assess individual plant survival, population trends, trends of major limiting factors, and the response of populations to threat management.

Table 5. Number of populations and individuals needed for each plant species to meet the interim stabilization stage based on population and life history characteristics.

Life Span	Population and Life History Characteristics	Number of Populations	Reproducing Individuals per population	Species
Long	No specific characteristics known	3	100	*Melicope remyi*
		3	100	*Pritchardia lanigera*
Long	Obligate outcrosser	3	200	*Pittosporum hawaiiense*
Short	No specific characteristics known	3	300	*Bidens hillebrandiana* ssp. *hillebrandiana*
		3	300	*Bidens micrantha* ssp. *ctenophylla*
		3	300	*Cyanea marksii*
		3	300	*Cyanea tritomantha*
		3	300	*Cyrtandra nanawaleensis*
		3	300	*Cyrtandra wagneri*
		3	300	*Phyllostegia floribunda*
		3	300	*Schiedea diffusa* ssp. *macraei*
		3	300	*Schiedea hawaiiensis*
Short	Vegetatively reproducing	6	300	*Stenogyne cranwelliae*

Recovery Criteria:

Downlisting

To consider downlisting the 13 plant species from endangered to threatened, the following criteria should be met.

Downlisting Criteria

Criterion 1: In addition to achieving the minimum number of reproducing individuals per population identified in Table 6, at least 5 or 10 of these populations (depending on the species' life history characteristics) designated for dowlisting must be stable, secure, and naturally reproducing for a minimum of 10 years. Downlisting should not be considered until an adequate population viability analysis has been conducted to confirm the number of individuals needed to achieve a viable population. This analysis should be based on current management and monitoring data collected at regular intervals determined by the life history, threats, and management parameters of the species (i.e., major limiting factors, breeding system, population structure and density, and proven management methods of major threats). However, a viability analysis should only be one of the factors used in making a decision to downlist a species.

Criterion 2: Habitat around each population must be managed for threats to ensure that it will support the long-term persistence of the species. To achieve this, each of the populations identified for downlisting will have an adaptive management and monitoring plan. The former will identify actions and procedures necessary to ensure that all habitat threats (e.g., ungulates, invasive plants) are controlled and the latter will identify the tools, procedures, and schedules needed to track and assess the response of species to management. Species-specific management actions may continue to be necessary after downlisting to ensure the populations of each species are stable or increasing.

Table 6. Number of populations and individuals needed for each plant species to meet Downlisting Criterion 1 based on population and life history characteristics.

Life Span	Population and Life History Characteristics	Number of Populations	Reproducing Individuals per population	Species
Long	No specific characteristics known	5	200	*Melicope remyi*
		5	200	*Pritchardia lanigera*
Long	Obligate outcrosser	5	400	*Pittosporum hawaiiense*
Short	No specific characteristics known	5	500	*Bidens hillebrandiana* ssp. *hillebrandiana*
		5	500	*Bidens micrantha* ssp. *ctenophylla*
		5	500	*Cyanea marksii*
		5	500	*Cyanea tritomantha*
		5	500	*Cyrtandra nanawaleensis*
		5	500	*Cyrtandra wagneri*
		5	500	*Phyllostegia floribunda*
		5	500	*Schiedea diffusa* ssp. *macraei*
		5	500	*Schiedea hawaiiensis*
Short	Vegetatively reproducing	10	500	*Stenogyne cranwelliae*

Delisting

To consider delisting the 13 listed plant species, the above downlisting criteria should be met for a 10-year period, as well as the following criteria.

Delisting Criteria

Criterion 1: In addition to meeting the downlisting criteria and achieving the minimum number of reproducing individuals per population identified in Table 7, at least 10 or 20 populations (depending on the species' life history characteristics) needed for delisting must be stable, secure, and naturally reproducing for a minimum of 20 years within secure and viable habitats.

Criterion 2: Threats to the species' habitat and to populations are managed. Threats to the habitat of each population needed to meet *Delisting Criterion 1* are managed to ensure that the habitat will support the long-term persistence of the species. For example, where ungulates are present, all of the populations needed for delisting will be within fenced areas free of ungulates, with agreements from conservation partners to maintain protections for the long-term persistence of the species. Monitoring the status and threats of each population is ongoing. Population censuses and updates to the status of threats to these populations are completed annually during the 20-year period preceding delisting. Species-specific management actions (e.g., hand-pollination, propagation, and translocation) are no longer necessary, but an ongoing need for habitat-scale management actions may remain if long-term agreements are in place.

Table 7. Number of populations and individuals needed for each plant species to meet Delisting Criterion 1 based on population and life history characteristics.

Life Span	Population and Life History Characteristics	Number of Populations	Reproducing Individuals per population	Species
Long	No specific characteristics known	10	200	*Melicope remyi*
		10	200	*Pritchardia lanigera*
Long	Obligate outcrosser	10	400	*Pittosporum hawaiiense*
Short	No specific characteristics known	10	500	*Bidens hillebrandiana* ssp. *hillebrandiana*
		10	500	*Bidens micrantha* ssp. *ctenophylla*
		10	500	*Cyanea marksii*
		10	500	*Cyanea tritomantha*
		10	500	*Cyrtandra nanawaleensis*
		10	500	*Cyrtandra wagneri*
		10	500	*Phyllostegia floribunda*
		10	500	*Schiedea diffusa* ssp. *macraei*
		10	500	*Schiedea hawaiiensis*
Short	Vegetatively reproducing	20	500	*Stenogyne cranwelliae*

Rationale for Plant Recovery Criteria

The recovery criteria for the 13 plants are based on the currently known biology of the species from the latest respective Species Reports, the Hawai‘i and Pacific Plants Recovery Coordinating Committee’s Revised Recovery Objective Guidelines, and expert opinion (HPPRCC 2011, entire; Table 1). Rationale for the need to control threats to the listed plants and their habitats are detailed in the Recovery Strategy section of this document.

Several life history traits explained above were identified as important to maintaining stable effective population size and were therefore incorporated into the numbers of populations or mature individuals needed for downlisting or delisting, depending on the impact of each life history trait (Pavlik 1996, entire). Translocations will be a crucial action to achieving recovery for many of these Hawaiian plants, especially to increase resiliency and redundancy in the face of increasing catastrophic events. Each translocation effort should consider the genetic composition of the founders, number of founders used, number of individuals from each founder, and the species’ reproductive capacity and habitat availability. For all species, maintaining suitable habitat will be required to maintain viable populations, and in some cases habitat restoration will be necessary. Maintaining robust ex situ storage collections for propagation will be key to maximizing diversity and representation for each species.

The minimum number of populations and the number of reproducing individuals in each population needed to prevent extinction (and to meet the preventing extinction targets) are based on models that demonstrate loss of genetic variation in populations of various sizes. For example, a population of 25 individuals will lose approximately 25 percent of its genetic variation over 10 generations. Vegetatively-reproducing and dioecious species are believed to possess less genetic variation compared to monoecious and hermaphroditic species, hence the number of populations or individuals per population of the former species (vegetatively-reproducing and dioecious, respectively) need to be higher than the latter species to minimize the loss of genetic variation (HPPRCC 2011, pp. 5–10; Hartl and Clark 1989, entire).

2. Recovery Criteria — Anchialine Pool Shrimp

Objective – Manage threats and habitats to establish resilient and self-sustaining populations of *Vetericaris chaceorum* in anchialine pool complexes within the species' geographic range on the island of Hawai'i.

The term anchialine pool complex describes a group of pools that are hydrologically connected. Because hydrological connection is difficult to confirm, for the purposes of this recovery plan anchialine pool complexes will be determined by indicators of hydrology such as geographic region, distance between occupied pools, and other geographic, geological, and marine barriers. Because adult anchialine pool shrimp are not known to disperse outside of their anchialine pool complex, each distinct complex is considered a separate population.

The definition of a population used herein is primarily based on presence/absence observations of *Vetericaris chaceorum* in the epigeal (above-ground) portion of their habitat. Like other anchialine pool shrimp species, *V. chaceorum* inhabit an extensive network of water-filled interstitial spaces leading to and from the actual pool, which has precluded accurate population size estimates (Holthuis 1973, p. 36; Maciolek 1983, pp. 613–616; Iwai et al. 2009, p. 1). Often surveys for rare species of anchialine pool shrimp, including *V. chaceorum*, involve a presence/absence survey approach with the aid of baiting in their respective habitat (Iwai et al. 2009, p. 6; Wada 2016 in litt., entire). Prolonged absence, and presumably extirpation, of individuals from suitable habitat is likely the best or only measure of a species' decline, as the size of anchialine pool shrimp populations are not easily determined (Holthuis 1973, pp. 7–12; Maciolek 1983, pp. 613–616; Iwai et al. 2009, entire).

Downlisting Criteria

To consider downlisting *Vetericaris chaceorum* from endangered to threatened, the following criteria must be met.

Downlisting Criteria

Criterion 1. Occupied anchialine pool complexes are identified and protected. At least six distinct anchialine pool complexes occupied by stable *Vetericaris chaceorum* populations are distributed within suitable coastal anchialine pool habitat. Distinct anchialine pool complexes are delineated based on indicators of hydrological separation and assessed for occupation wherever possible. For a population in a complex to be considered persistent, presence/absence surveys must indicate a complex has been occupied in at least 15 of the past 20 years. Distinct occupied anchialine pool complexes should be broadly distributed to reduce vulnerability to catastrophic events.

Criterion 2. Each anchialine pool complex in *Downlisting Criterion 1* must be afforded land protections to ensure areas are available to support the long-term persistence of *Vetericaris chaceorum*. A majority of the anchialine pool complexes that support populations in *Downlisting Criterion 1* must have subterranean hydrological connectivity to the Pacific Ocean to allow for natural dispersal and range expansion of the shrimp.

Criterion 3. Coastal habitat surrounding occupied anchialine pool complexes provides water of sufficient quantity and quality to maintain the water chemistry needed to support the species at all life stages and is protected from (1) anthropogenic habitat degradation and destruction and (2) habitat degradation by fish and nonnative plants, ungulates, and invertebrates.

Criterion 4. All major threats to individual shrimp are managed at each distinct anchialine pool complex in *Downlisting Criterion 1*. Nonnative predators are absent from occupied anchialine pool complexes and other direct threats to shrimp are managed such that they are unlikely to have significant long-term impacts. Pools are managed and protected to prevent introduction of nonnative predators, competitors, or disease to the populations in *Downlisting Criterion 1*. Monitoring and management plans are completed and implemented.

Delisting Criteria

To consider delisting *Vetericaris chaceorum*, the above downlisting criteria should be met, as well as the following criteria.

Criterion 1. At least 11 distinct anchialine pool complexes occupied by stable *Vetericaris chaceorum* populations are distributed within suitable coastal anchialine pool habitat with priority given to the species' known historical range of the species. Hydrologic separation distance between anchialine pool complexes is assessed and used to delineate distinct occupied pool complexes whenever possible. For a population in a complex to be considered stable, presence/absence monitoring results must indicate that the complex has been occupied in at least 20 of the past 30 consecutive years. Distinct occupied anchialine pool complexes should be broadly distributed to reduce vulnerability to catastrophic events.

Criterion 2. Each distinct anchialine pool complex identified in *Delisting Criterion 1* must be afforded land protections to to ensure that it will support the long-term persistence of *Vetericaris chaceorum*. Functioning anchialine pool complexes in *Delisting Criterion 1* must have subterranean hydrological connectivity to the Pacific Ocean to allow for natural dispersal and range expansion of *V. chaceorum*.

Criterion 3. Coastal anchialine pool habitat occupied by the anchialine pool shrimp provides water of sufficient quantity and quality to maintain the water chemistry needed to support all life stages of *Vetericaris chaceorum* and is protected from (1) habitat degradation and destruction due to urban development, and other associated anthropogenic activities; and (2) habitat degradation by fish and nonnative plants, ungulates, and invertebrates.

Criterion 4. All major threats to individual anchialine pool shrimp are managed at each distinct anchialine pool complex in *Delisting Criterion 1*. Nonnative predators are absent from occupied anchialine pool complexes and other direct threats are managed such that they are unlikely to have significant long-term impacts. Pools are managed and protected to prevent introduction of nonnative predators, competitors, or disease to the populations in *Delisting Criterion 1*. Monitoring of population status and threats is ongoing.

Rationale for Anchialine Pool Shrimp Recovery Criteria

To prevent extinction of *Vetericaris chaceorum*, the current distribution of the species needs to be identified, stablilized, and protected from threats to the species' immediate survival. The feasibility of captive breeding to support translocations needs to be determined. Systematic surveys of anchialine pool complexes should be conducted to ensure that any unknown populations are identified and subsequently protected. All threats in the immediate vicinity of each occupied anchialine pool complex must be managed. This will require developing and implementing surveys, monitoring, and management plans to identify all populations, their distribution, and threats. Unlike the other species covered in this plan, recovery of *Vetericaris chaceorum* will be based on the species' presence within anchialine pool complexes; presence will be a surrogate for resilient and self-sustaining populations. Anchialine pool complexes must show evidence of sustained species presence as a measure of success.

The downlisting and delisting criteria for *Vetericaris chaceorum* are based on the most up-to-date information on the species biology, ecology, distribution, and threats (USFWS 2023b). The recovery criteria for *Vetericaris chaceorum* address the species' redundancy by requiring multiple anchialine pool complexes distributed throughout the species' current range. *Vetericaris chaceorum* must occur in at least 6 (downlisting) or 11 (delisting) anchialine pool complexes for a minimum of 15 and 20 years to qualify for downlisting or delisting consideration, respectively. Occupied anchialine pool complexes need to be distributed over a broad geographic range such that stochastic events would not lead to extinction of the species.

Anchialine pool complexes supporting *Vetericaris chaceorum* will require protection from ungulates, invasive fish and invertebrates, invasive plants, sedimentation, anthropogenic effects including land development, dumping, dewatering and water diversion, groundwater extraction, and water quality reduction. Protecting habitat adjacent to anchialine pool complexes, sedimentation removal, and securing land protections from occupied anchialine pools, are needed to sustain the species.

Vetericaris chaceorum requires specific hydrologic conditions for survival. Identification and management of threats that alter or modify anchialine pool quality, salinity, food resources, or other factors needed by the species will be necessary.

Downlisting and delisting will require a clear understanding of invasive fish and invertebrate distribution, abundance, and predator-prey dynamics within each anchialine pool complex.

Given the extreme rarity of *Vetericaris chaceorum*, establishing procedures and control measures to manage invasive fish and prawns and maintaining functional pool habitat will be necessary for the recovery.

The criteria address species' representation by requiring that anchialine pool habitat and the ecological needs of the species are conserved across its range, and the criteria address population resiliency by requiring threat reduction to ensure that occupied pools continue to support the species. The recovery criteria are objective and measurable and will require species presence monitoring or other appropriate analyses to consider downlisting or delisting.

3. Recovery Criteria — Picture-wing Fly

Objective – Manage threats and habitats to establish resilient and self-sustaining populations of *Drosophila digressa* throughout the species' range on the island of Hawai'i.

Downlisting

Critical habitat is being determined for *Drosophila digressa* (USFWS 2023a). Recovery criteria are based on the species' historical range and otherwise suitable habitat and requires each critical habitat management unit be occupied by the species to achieve resilient populations that provide redundancy and representation (Table 1).

To consider downlisting *Drosophila digressa* from endangered to threatened, the following criteria must be met:

Downlisting Criteria

Criterion 1. Existing population(s) of the *Drosophila digressa* are identified and stabilized. The species should be represented by at least five stable to increasing populations distributed throughout the species' historical range or in otherwise suitable habitat, as determined by surveys and research. For each population, a population index based on repeated surveys with consistent methodology must indicate stable to increasing indices over at least 5 consecutive years immediately prior to consideration of downlisting. All units of designated critical habitat unit must be occupied by at least one population.

Criterion 2. The species is in a captive-rearing program, existing genetic diversity of the species is represented, and the captive population(s) exhibit a positive growth rate that can support translocation.

Criterion 3. Research, surveys and evaluation over at least 10 years indicate each population site in *Downlisting Criterion 1* includes viable populations of host-plant species (*Charpentiera* spp., *Ceodes brunoniana*, *Rockia sandwicensis*, or other confirmed hosts) within the dispersal distance of *Drosophila digressa*.

Criterion 4. Within each of the population sites identified in *Downlisting Criterion 1*, habitats are managed and afforded land protections to ensure long-term persistence of the species; threats to host plants and the environment from invasive plants, plant diseases, ungulates, and fire have been eliminated or managed such that the microclimate (e.g., humidy, temperature, canopy cover) and the breeding resources of *Drosophila digressa* are not adversely affected and can support the life cycle of the species.

Criterion 5. All major threats to individuals and populations in *Downlisting Criterion 1* are managed such that nonnative predators and competitors are absent, or predation and competition are unlikely to have significant long-term adverse impacts on picture-wing fly population indices. Monitoring and management plans are completed and implemented and measures are in place to prevent the introduction of new nonnative predators, competitors, disease, or other threats to the plant hosts and picture-wing fly populations in *Downlisting Criterion 1*.

Delisting Criteria

To consider delisting *Drosophila digressa*, the above downlisting criteria should be met, as well as the following criteria.

Criterion 1. An additional 10 years of systematic surveys have documented significant increases in the abundance and distribution of *Drosophila digressa* populations throughout the species' range. The species is represented by at least 10 populations distributed throughout its historical range or in otherwise suitable habitat, as determined by surveys and research. All units of designated critical habitat must be occupied by one or more populations. Populations should exist within habitat that is capable of supporting natural dispersal, breeding opportunities, and expansion of occupied range. For each population, a population index based on repeated surveys with consistent methodology must indicate stable to increasing indices in at least 7 of 10 consecutive years immediately before consideration of delisting.

Criterion 2. Systematic research, surveys, and evaluation over at least 10 years since downlisting indicate each picture-wing fly population site in *Delisting Criterion 1* includes viable populations of the appropriate host-plant species within dispersal distance of *Drosophila digressa*.

Criterion 3. Within each of the population sites identified in *Delisting Criterion 1*, habitats are managed, protected, and afforded land protections to ensure long-term persistence of the species. All major threats to host plants and the environment from invasive plants, plant diseases, ungulates, and fire have been eliminated or managed such that the microclimate (e.g., humidity, temperature, canopy cover) and the breeding resources of the picture-wing fly species are not adversely affected and can support the life cycle of the species.

Criterion 4. All major threats to individuals and populations in *Delisting Criterion 1* are managed and measures are in place to prevent introduction of new threats. For each population site identified in *Delisting Criterion 1*, monitoring of threats and population status is ongoing. Results based on at least 4 years of the most recent monitoring data indicate that (a) nonnative predators are absent, or (b) predation and competition are occurring at a level is unlikely to have significant, adverse long-term impacts on the picture wing fly species' population indices.

Rationale for Picture-wing Fly Recovery Criteria

To prevent extinction of *Drosophila digressa*, all extant populations need to be identified, stabilized, and protected from threats that are suppressing and/or threatening the populations' immediate survival. Systematic surveys of existing and for unknown picture-wing fly populations should be conducted to ensure the broadest genetic representation of the species is protected and conserved in the wild and subsequently represented in captive populations. A captive-rearing program should be established to prevent extinction and to support translocations. All threats in the immediate vicinity of each wild population need immediate management. This will require developing and implementing survey, monitoring, and management plans based on the identified needs of each population. Populations must show evidence of reproduction and replacement as a measurement of success.

The downlisting and delisting criteria for the picture-wing fly are based on the most recent and best available science about the species' biology, ecology, distribution, and threats (USFWS 2023i). Although, beyond *Drosophila digressa* being dependent on the decaying stems and bark of several host plants as a larval substrate, little is known about the biology and life needs of the species. The recovery criteria require that substantive biological and ecological information about the species and its host plants be determined to inform management.

Drosophila digressa should have at least 5 (for downlisting) or 10 (for delisting) populations that sustain stable to positive trends in population indices for a minimum number of consecutive years to be considered for downlisting or delisting. These populations need to be distributed throughout the species' range to ensure genetic redundancy such that a catastrophic event would not likely lead to extinction of the species or a reduction in existing genetic diversity. Changes in listing status should be supported by population viability analyses or other analyses that are approved by the Service and considered the best science at the time downlisting and delisting are considered.

Recovery criteria include the requirement of establishing and protecting the necessary host plants, on which *Drosophila digressa* is dependent. The decaying stems and bark of *Charpentiera* spp., *Ceodes brunoniana*, and/or *Rockia sandwicensis*, are required for egg laying and larval development. A picture-wing fly may travel about 320 ft (~100 m) in search of an appropriate breeding substrate (Science Panel 2005, p. 5). Host-plant populations within this distance should be sufficient to support egg laying and larval development of each picture-wing fly population for the long-term (20 to 40 years). Host-plant substrates must be abundant enough to minimize competition from other invertebrates or managed so that competition for resources is absent. This will require that these species are managed to esure appropriate substratres are available over the long-term. To manage these host plants, methods will need to be developed to determine the amount and composition of plant hosts and larval substrate necessary to support a stable to growing populations of *D. digressa* given environmental fluctuations. Adequacy of host-plant substrates will be assessed based on composition, percentage, and number of suitable plant hosts within the habitat of each breeding population.

Host plants and larval substrates of *Drosophila digressa* will require protection from threats such as ungulates, and fire, and other plant damaging threats. In addition to threat management, translocations will ensure viable host-plant populations. This may require managing the habitat to maintain or provide suitable humidity, temperature, and other necessary conditions required by the picture-wing fly species and its hosts. Management plans will need to be in place and implemented to ensure that sufficient larval substrate is available in at least 10 populations.

Drosophila digressa requires specific environmental conditions for breeding (Magnacca et al. 2008, pp. 11, 13; Montgomery 1975, pp. 80, 84, and 95; Magnacca 2012 in litt., entire). Threats to host plants and host-plant substrate or to general habitat suitability such as drought, changes in canopy coverage, or other factors that would render the habitat unsuitable for *D. digressa* will require identification and management at each population.

Downlisting and delisting will require a clear understanding of nonnative predator distribution, abundance, and predator-prey dynamics within each population. The conspicuous lekking and breeding displays of adult *Drosophila digressa* and their undefended eggs, larvae, and pupae leave the species vulnerable to predators and parasitoids including nonnative ants, coqui frogs, western yellowjackets, parasitoid wasps, limoniid crane flies, and other insects. Populations of *D. digressa* will contribute to meeting downlisting and delisting criteria if they are successfully coexisting with predators, confirmed to be sustaining population viability, and showing stable to positive trends in population indices, with or without management. Given the rarity of *D. digressa*, managing predators and parasitoids and reinforcing and translocating populations using captive-reared picture-wing flies will be necessary to recover the species.

The recovery criteria of *Drosophila digressa* addresses redundancy by recommending multiple populations distributed throught the species' historical or suitable range. The criteria address representation by ensuring the ecological, behavioral, and genetic deiversity of the species is conserved across its range. The criteria address the resiliency of populations by managing threats. The recovery criteria are objective and measurable and will require population viability evaluations or other appropriate analyses to consider downlisting or delisting. Species-specific threat management may continue to be necessary after the species are delisted. Measures must be in place to prevent introduction of new nonnative predators, competitors, disease, or other threats to the plant hosts and picture-wing fly populations in perpetuity.

III. RECOVERY ACTIONS

This recovery plan identifies recovery actions needed to implement the recovery strategy and achieve the recovery criteria for each species. Implementation of a recovery action will depend on its priority, availability of funds and resources, coordination with partners, and complexity and logistical constraints. A broad action may have multiple components developed as needed to best accomplish recovery implementation. Specific project-level implementation of these actions will be accomplished through shorter-term activities, collectively referred to as the RIS, in coordination with recovery partners interested and willing to work on implementing the activities. Activities are intended to be adaptable and guide recovery partners to coordinate recovery implementation and further describe those responsible for each action described in the plan. Because the RIS is a short-term working document, activities described there can be modified as needed without requiring future revision of the recovery plan, so long as they remain consistent with the recovery plan.

As discussed in the Introduction, this recovery plan is a guidance document rather than being regulatory in nature. As such, implementation of recovery actions is voluntary and depends on the cooperation and commitment of numerous partners in this conservation effort. Note that all Federal agencies have an obligation under section 7(a)(1) of the Act to carry out programs for conservation of federally-listed species.

The actions needed to alleviate threats to all species and achieve recovery criteria are organized below into six categories: (1) Determine the current distribution and status of the species and their habitats, (2) Protect populations and manage threats to habitat, (3) Manage species-specific threats, (4) Expand the distribution of existing wild populations and establish new populations, (5) Conduct additional research essential to recovering the 15 species and restoring their habitats, and (6) Implement regulations and policy to support species recovery. Not all recovery actions may apply to all populations and all species. Development and implementation of a detailed monitoring plan for recovery actions is necessary to assess the effects of an action on each species, inform adaptive management responses, and evaluate progress towards recovery criteria. The applicability of actions to each group of species (plants, anchialine pool shrimp, and picture-wing fly) is summarized in Tables 8, 9, and 10, respectively.

1. Determine the current distribution and status of the species and their habitats.

- 1.1. Develop a survey methodology for each species' population(s) based on their known and historical range if not already established.
- 1.2. Conduct range-wide surveys for listed plants and invertebrates to determine or confirm their current distribution and status.
  - 1.2.1. Identify and document current ranges.
  - 1.2.2. Determine demographic structure of populations.
  - 1.2.3. Assess genetic diversity.

2. **Protect populations and manage threats to habitat.**

   The habitats that support the species, throughout their range, must be identified and protected from threats. Each species-specific site required for the species' recovery must have sufficient protected habitat to sustain the populations used to meet recovery criteria.

   2.1. Identify sites to support populations of each species.

   2.2. Prioritize and select sites based on factors including conservation value to multiple species and likelihood of success of threat control efforts.

   2.3. Develop microclimate models to identify suitable habitat based on historical and current species' distributions and habitat that would be suitable under potential future climate conditions.

   2.4. Ensure long-term protection of sites from threats. Protect sites via land acquisitions, conservation easements, landowner agreements, and/or regulatory mechanisms.

   2.4.1. Identify threats to sites occupied by populations used to meet recovery criteria for each species (hereafter recovery sites).

   2.4.2. Construct and maintain ungulate-proof fences around all recovery sites.

   2.4.3. Remove ungulates from fenced areas protecting all recovery sites and keep these sites ungulate-free.

   2.4.4. Control or eradicate habitat-modifying invasive plants at all recovery sites.

   2.4.5. Develop and implement rodent control or eradication programs within all recovery sites.

   2.4.6. Provide wildfire protection as necessary.

   2.4.6.1. Develop and implement fire management plans to assure occupied recovery sites are protected and likelihood of fire is reduced, especially in dry and mesic habitats.

   2.4.6.2. Assess the effects of climate change on wildfire risk and need for fire management plans.

   2.4.7. Protect recovery sites from human disturbance and development.

   2.4.8. Prevent other habitat modifying threats, including incipient invasive species, from invading recovery sites.

   2.4.9. Control other existing threats to recovery sites.

   2.4.10. Prevent sedimentation of anchialine pool complexes.

   2.5. Monitor management and use results to adapt management actions.

3. **Control or manage species-specific threats.**

   Each species must be protected from various species-specific threats that affect their recovery habitat and population viability.

   3.1. Develop and implement control programs for nonnative slugs.

3.2. Develop and implement control programs for nonnative rodents.

3.3. Develop and implement control programs for nonnative ants (e.g., Argentine ant, big-headed ant, yellow crazy ant, Papuan thief ant, and tropical fire ant).

3.4. Develop and implement control programs for the nonnative western yellowjacket.

3.5. Develop and implement control programs for nonnative limoniid crane flies, and other invertebrates that compete for host resources.

3.6. Develop and implement control programs for parasitoid wasps.

3.7. Develop and implement control programs for nonnative beetles and weevils.

3.8. Develop and implement control programs for nonnative leafhoppers.

3.9. Develop and implement control programs for invasive fishes.

3.10. Develop and implement control programs for Tahitian prawns.

3.11. Develop and implement control programs for nonnative game birds.

3.12. Mitigate sedimentation affecting anchialine pool complexes.

3.13. Monitor populations to detect disease, assess impacts, and control outbreaks.

3.14. Control other threats to specific species as appropriate.

3.15. Monitor the response to management and use these results to adapt management actions.

3.16. Develop and implement control programs for plant and invertebrate diseases.

4. Expand the distribution of existing wild populations and establish new populations.

Translocation efforts, including reinforcement or augmentation, reintroduction, and assisted colonization as well as social attraction will be used as needed to improve population resiliency and species redundancy and representation. Individuals bred in captivity or from wild donor populations determined to be stable or increasing will be used to augment existing or to establish new populations. Captive and *ex situ* populations will also serve to safeguard the species if wild populations are extirpated.

4.1. Identify species suitable for translocation and develop and implement translocation plans for each according to IUCN Reintroduction Guidelines (2013).

4.2. Identify areas appropriate for translocating individuals to increase the number of occupied recovery sites.

4.3. Select populations for translocation.

4.4. Prepare translocation sites within protected sites.

4.5. Establish and maintain *ex situ* captive propagation and/or rearing programs with genetically representative founders. For plants, propagate genetically appropriate individuals for genetic storage and translocation; for invertebrates, develop captive-rearing programs and establish populations from appropriate genetic sources for translocation.

4.6. Translocate genetically appropriate individuals into managed sites.

4.7. Translocate individuals outside of their known range as needed to achieve recovery.

4.8. Monitor populations and use the results to adapt management actions.

5. Conduct additional research essential to recovering the 15 species and restoring their habitats.

Research and development of tools that assess species biology and ecology, ameliorate threats, establish, or improve propagation, captive rearing, or genetic storage, and inform improvements to species growth rate and viability, are necessary for species recovery.

5.1. Develop tools to enhance habitat and species survival and reproduction.

5.2. Develop tools to inform actions that will improve species *in situ* and *ex situ*.

5.3. Maintain long-term studies on range, demographics, and dispersal.

5.4. Conduct research on threats to the viability of all life stages of the species.

5.5. Develop tools for monitoring population growth and status.

5.6. Conduct population viability analyses for each species.

5.7. Conduct studies on optimizing conservation translocation survival and success.

5.8. Conduct long-term genetic studies on captive and wild populations of each species.

5.9. Monitor range-wide population, status, population trends, and distribution at time intervals appropriate for each species.

5.10. Monitor and maintain water quality factors for the entire lifecycle of the species.

5.11. Determine biological limitations for species'resproduction and survival (e.g., salinity, temperature, water quality, water quantity, and others).

6. Implement regulations and policy to support species recovery.

Recovery will require partnerships with State, Federal, County, and private stakeholders to prevent the introduction and establishment of new invasive species or other factors that affect the species, their habitats, or both, and impede recovery.

6.1. Provide support to implement the Hawaiʻi interagency biosecurity plan to prevent the arrival and spread of new invasive species into the Hawaiian Archipelago and interisland movement of invasive species already established.

6.2. Implement public outreach and education and enforce policies that prohibit species collection and harassment.

6.3. Resolve state restrictions for using piscicides and other invasive species removal techniques.

6.4. Provide land protections to anchialine pool complexes and aquifers.

6.5. Provide protections for anchialine pool complexes from dewatering and water diversion practices, groundwater extraction, and nonpoint source pollution.

Table 8. Crosswalk relating threats, recovery criteria, and recovery actions for the 13 plant species.

Listing Factor	Specific Threat Under the Listing Factor	Recovery Criteria Numbers	Recovery Action Numbers
A Present or Threatened Destruction, Modification or Curtailment of its Habitat or Range	Agriculture and urban development	Downlisting 1 and 2; Delisting 1 and 2	1.1, 1.2, 2.1, 2.3, 2.4, 2.5, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.3, 5.4, 5.5, 5.6, 5.9, 6.1, 6.2
	Ungulates	Downlisting 1 and 2; Delisting 1 and 2	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.6, 5.9, 6.1, 6.3
	Nonnative plants	Downlisting 1 and 2; Delisting 1 and 2	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.6, 5.9, 6.1, 6.3
	Fire	Downlisting 1 and 2; Delisting 1 and 2	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.6, 5.9, 6.1
	Stochastic events	Downlisting 1 and 2; Delisting 1 and 2	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.6, 5.9, 6.1
B Overutilization	Overcollection	Downlisting 1 and 2; Delisting 1 and 2	1.2, 2.2, 2.4, 2.5, 3.14, 3.15, 5.1, 5.2, 5.4, 5.8, 6.2

Listing Factor	Specific Threat Under the Listing Factor	Recovery Criteria Numbers	Recovery Action Numbers
C Disease or Predation	Disease	Downlisting 1 and 2; Delisting 1 and 2	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.13, 3.15, 3.16, 4.1, 4.2, 4.3, 4.4, 4.6, 4.7, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.8, 5.9, 6.1, 6.2
	Predation/Herbivory by nonnative ungulates	Downlisting 1 and 2; Delisting 1 and 2	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 4.1, 4.2, 4.3, 4.4, 4.6, 4.7, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.8, 5.9, 6.1, 6.2, 6.3
	Predation/Herbivory by other nonnative vertebrates	Downlisting 1 and 2; Delisting 1 and 2	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.2, 3.11, 3.14, 3.15, 4.1, 4.2, 4.3, 4.4, 4.6, 4.7, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.8, 5.9, 6.1, 6.2, 6.3
	Predation / Herbivory by nonnative invertebrates	Downlisting 1 and 2; Delisting 1 and 2	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.1, 3.7, 3.8, 3.14, 3.15, 4.1, 4.2, 4.3, 4.4, 4.6, 4.7, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.8, 5.9, 6.1, 6.2, 6.3
D Inadequacy of Existing Regulatory Mechanisms	Inadequate existing regulatory mechanisms	Delisting 1 and 2	3.14, 6.1, 6.2, 6.3
E Other Natural or Manmade Factors	Other species-specific threats	Downlisting 1 and 2; Delisting 1 and 2	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.14, 3.16 4.1, 4.2, 4.3, 4.4, 4.6, 4.7, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.8, 5.9, 6.1, 6.2, 6.3
	Hybridization	Downlisting 1 and 2; Delisting 1 and 2	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.14, 4.1, 4.2, 4.3, 4.4, 4.6, 4.7, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.8, 5.9, 6.1, 6.2

Listing Factor	Specific Threat Under the Listing Factor	Recovery Criteria Numbers	Recovery Action Numbers
	No regeneration	Downlisting 1 and 2; Delisting 1 and 2	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.14, 4.1, 4.2, 4.3, 4.4, 4.6, 4.7, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.8, 5.9, 6.1, 6.2
	Limited number of individuals	Downlisting 1 and 2; Delisting 1 and 2	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.14, 4.1, 4.2, 4.3, 4.4, 4.6, 4.7, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.8, 5.9, 6.1, 6.2
	Limited number of populations	Downlisting 1 and 2; Delisting 1 and 2	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.14, 4.1, 4.2, 4.3, 4.4, 4.6, 4.7, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.8, 5.9, 6.1, 6.2
	Human (dumping of trash)	Downlisting 1 and 2; Delisting 1 and 2	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.14, 4.1, 4.2, 4.3, 4.4, 4.6, 4.7, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.8, 5.9, 6.1, 6.2
	Koa logging	Downlisting 1 and 2; Delisting 1 and 2	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.14, 4.1, 4.2, 4.3, 4.4, 4.6, 4.7, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.8, 5.9, 6.1, 6.2
	Climate change	Downlisting 1 and 2; Delisting 1 and 2	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.14, 4.1, 4.2, 4.3, 4.4, 4.6, 4.7, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.8, 5.9, 6.1, 6.2

Table 9. Crosswalk relating threats, recovery criteria, and recovery actions for the anchialine pool shrimp.

Listing Factor	Specific Threat Under the Listing Factor	Recovery Criteria Numbers	Recovery Action Numbers
A Present or Threatened Destruction, Modification or Curtailment of its Habitat or Range	Agriculture and urban development	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.9, 3.10, 3.12, 4.1, 4.2, 4.3,4.4, 4.6, 4.7,4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.7, 5.9, 5.10, 5.11, 6.1, 6.2, 6.4, 6.5
	Ungulates	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	2.1, 2.2, 2.4, 2.5, 3.9, 3.10, 3.12, 3.13, 3.14, 3.15, 4.1, 4.4, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.7, 5.9, 5.10, 6.1, 6.4
	Invasive animals	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.9, 3.10, 3.12, 3.13, 3.14, 3.15, 4.1, 4.3, 4.4, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.7, 5.9, 6.1, 6.2, 6.3, 6.4, 6.5
	Nonnative plants	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.14, 3.15, 4.1, 4.3, 4.4, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.7, 5.9, 6.1, 6.4, 6.5
	Stochastic events	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2,2.1, 2.2, 2.3, 2.4, 2.5, 3.9, 3.10, 3.12, 3.13, 3.14, 3.15, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 5.10, 6.1, 6.2, 6.3, 6.4, 6.5
B Overutilization	Aquarium trade and collection	Downlisting 4; Delisting 4	2.4, 6.2
C Disease or Predation	Disease	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 3.12, 3.13, 3.14, 3.15, 3.16, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8,

Listing Factor	Specific Threat Under the Listing Factor	Recovery Criteria Numbers	Recovery Action Numbers
			5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 5.10, 6.1, 6.2, 6.3, 6.4, 6.5
	Predation by invasive vertebrates	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.9, 3.12, 3.14, 3.15, 4.1, 4.4, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.9, 5.10, 6.1, 6.2, 6.3, 6.4, 6.5
	Predation by nonnative invertebrates	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.10, 3.12, 3.14, 3.15, 4.1, 4.4, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.9, 5.10, 6.1, 6.2, 6.3, 6.4, 6.5
D Inadequacy of Existing Regulatory Mechanisms	Inadequate existing regulatory mechanisms	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.9, 3.10, 3.12, 3.14, 3.15, 4.1, 4.2, 4.4, 4.6, 4.7, 4.8, 5.4, 5.5, 5.10, 6.1, 6.2, 6.3, 6.4, 6.5
E Other Natural or Manmade Factors	Human (contamination, dumping, fisheries, marine debris, and trash)	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.12, 3.14, 3.15, 4.1, 4.4, 5.4, 5.10, 6.2, 6.4, 6.5
	Limited number of individuals	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.9, 3.10, 3.12, 3.13, 3.14, 3.15, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 6.1, 6.2, 6.3, 6.4, 6.5
	Limited number of populations	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.9, 3.10, 3.12, 3.13, 3.14, 3.15, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8,

Listing Factor	Specific Threat Under the Listing Factor	Recovery Criteria Numbers	Recovery Action Numbers
			5.9, 6.1, 6.2, 6.3, 6.4, 6.5
	Not in captive-rearing program	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 4.5, 4.6, 5.1, 5.2, 5.8
	Nutrient loading	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.9, 3.10, 3.12, 3.14, 3.15, 4.1, 4.4, 4.6, 4.7, 4.8, 5.1, 5.2, 5.4, 5.5, 5.7, 5.8, 5.10, 5.11, 6.2, 6.4, 6.5
	Natural senescence of pools	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.9, 3.10, 3.12, 3.14, 3.15, 4.1, 4.4, 4.6, 4.7, 4.8, 5.1, 5.2, 5.4, 5.5, 5.7, 5.8, 5.10, 5.11, 6.2, 6.4, 6.5
	Recreational use	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.9, 3.10, 3.12, 3.14, 3.15, 4.1, 4.4, 4.7, 4.8, 5.9, 5.10, 6.1, 6.2, 6.4, 6.5
	Recreational vehicles	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.9, 3.10, 3.12, 3.14, 3.15, 4.1, 4.4, 4.7, 4.8, 5.9, 5.10, 6.1, 6.2, 6.4, 6.5
	Sedimentation	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.9, 3.10, 3.12, 3.14, 3.15, 4.1, 4.4, 4.6, 4.7, 4.8, 5.1, 5.2, 5.4, 5.5, 5.7, 5.8, 5.10, 5.11, 6.2, 6.4, 6.5
	Sea level rise	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.13, 3.14, 3.15, 4.1, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8,

Listing Factor	Specific Threat Under the Listing Factor	Recovery Criteria Numbers	Recovery Action Numbers
			5.9, 5.10, 6.1, 6.2, 6.3, 6.4, 6.5
	Trampling	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.9, 3.10, 3.12, 3.14, 3.15, 4.1, 4.4, 4.7, 4.8, 5.9, 5.10, 6.1, 6.2, 6.4, 6.5
	Water quality reduction	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.9, 3.10, 3.12, 3.14, 3.15, 4.1, 4.4, 4.6, 4.7, 4.8, 5.1, 5.2, 5.4, 5.5, 5.7, 5.8, 5.10, 5.11, 6.2, 6.4, 6.5
	Climate change	Downlisting 1, 2, 3 and 4; Delisting 1, 2, 3 and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.9, 3.10, 3.12, 3.13, 3.14, 3.15, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 5.10, 5.11, 6.1, 6.2, 6.3, 6.4, 6.5

Table 10. Crosswalk relating threats, recovery criteria, and recovery actions for the picture-wing fly.

Listing Factor	Specific Threat Under the Listing Factor	Recovery Criteria Numbers	Recovery Action Numbers
A Present or Threatened Destruction, Modification or Curtailment of its Habitat or Range	Agriculture and urban development	Downlisting 1, 2, 3, 4, and 5; Delisting 1, 2, 3, and 4	1.1, 1.2, 2.1, 2.2, 2.4, 2.5, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.4, 6.1
	Ungulates	Downlisting 1, 2, 3, 4, and 5; Delisting 1, 2, 3, and 4	2.1, 2.2, 2.4, 2.5, 3.13, 3.14, 3.15, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.4, 5.7, 6.1, 6.2, 6.3
	Nonnative plants	Downlisting 1, 2, 3, 4, and 5; Delisting 1, 2, 3, and 4	1.1, 1.2, 2.1, 2.2, 2.4, 2.5, 3.13, 3.14, 3.15, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.4, 5.7, 6.1, 6.2, 6.3
	Fire	Downlisting 1, 2, 3, 4, and 5; Delisting 1, 2, 3, and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.14, 3.15, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.4, 5.7, 6.1, 6.2
	Stochastic events	Downlisting 1, 2, 3, 4, and 5; Delisting 1, 2, 3, and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.14, 3.15, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.4, 5.7, 6.1
B Overutilization	Not applicable		
C Disease or Predation	Predation by nonnative invertebrates	Downlisting 1, 2, 3, 4, and 5; Delisting 1, 2, 3, and 4	2.1, 2.2, 2.4, 2.5, 3.3, 3.4, 3.6 3.13, 3.14, 3.15, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.4, 5.7, 6.1, 6.2, 6.3
D Inadequacy of Existing Regulatory Mechanisms	Inadequate existing regulatory mechanisms	Downlisting 1, 2, 3, 4, and 5; Delisting 1, 2, 3, and 4	3.14, 4.7, 6.1, 6.2, 6.3

Listing Factor	Specific Threat Under the Listing Factor	Recovery Criteria Numbers	Recovery Action Numbers
E Other Natural or Manmade Factors	Competition	Downlisting 1, 2, 3, 4, and 5; Delisting 1, 2, 3, and 4	1.1, 1.2, 2.1, 2.2, 2.4, 2.5, 3.5, 3.14, 3.15, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 6.1, 6.2, 6.3
	Lack of sufficient egg laying and larval resources	Downlisting 1, 2, 3, 4, and 5; Delisting 1, 2, 3, and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.5, 3.7, 3.14, 3.15, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 6.1, 6.2, 6.3
	Beetles and weevils (damage to host plants)	Downlisting 1, 2, 3, 4, and 5; Delisting 1, 2, 3, and 4	1.1, 1.2, 2.1, 2.2, 2.4, 2.5, 3.7, 3.14, 3.15, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.9, 6.1, 6.2, 6.3
	Diseases of host plants or important canopy plants	Downlisting 1, 2, 3, 4, and 5; Delisting 1, 2, 3, and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.13, 3.14, 3.15, 3.16, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.9, 6.1, 6.2, 6.3
	Limited number of individuals	Downlisting 1, 2, 3, 4, and 5; Delisting 1, 2, 3, and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.3, 3.4, 3.5, 3.6, 3.7, 3.13, 3.14, 3.15, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 6.1, 6.2, 6.3
	Limited number of populations	Downlisting 1, 2, 3, 4, and 5; Delisting 1, 2, 3, and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 3.3, 3.4, 3.5, 3.6, 3.7, 3.13, 3.14, 3.15, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 6.1, 6.2, 6.3
	Not in captive-rearing	Downlisting 1, 2, 3, 4, and 5; Delisting 1, 2, 3, and 4	1.1, 1.2, 4.5, 4.6, 5.1, 5.2, 5.8

Listing Factor	Specific Threat Under the Listing Factor	Recovery Criteria Numbers	Recovery Action Numbers
	Climate change	Downlisting 1, 2, 3, 4, and 5; Delisting 1, 2, 3, and 4	1.1, 1.2, 2.1, 2.2, 2.3, 2.4, 2.5, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 5.10

IV. TIME AND COST ESTIMATES

Recovering species can be time-consuming and expensive, as it often entails undoing centuries of impacts that have led to their current imperiled state. When species are listed under the Act they are often restricted to a fraction of their historical range, in habitats where major ecological processes have been disrupted. Demographic characteristics and genetic structure of populations may be degraded. Stressors such as invasive species, diseases, climate change, and habitat loss and degradation can interact synergistically with severe consequences for species. While the Act mandates that recovery plans include an estimate of the cost to recover species, this does not signify that these funds will be allocated. A wide range of partners often contribute to the cost of recovery, including the Department of Defense, other Federal agencies, States, and non-governmental organizations. Funds actually dedicated to species recovery are typically a fraction of the estimated cost. Because recovery periods may cover multiple decades, annual costs are much lower than overall cost estimates. While our focus here is on recovery of the 15 listed species addressed in this recovery plan, implementation of recovery actions will also often benefit other listed and nonlisted species as well as human welfare.

Achieving the recovery criteria for these 15 species is expected to require, at minimum, approximately 50 to 95 years. The Draft Recovery Plan for 15 Species from the Island of Hawai'i included a cost estimate of $1,024,839,500 for the 50 to 95 years necessary to recover all 15 species. While we acknowledge all of the estimated costs of implementing recovery actions to recover these species, it is most relevant and accurate to focus on the costs over the first 20 years. Under the best circumstances, given the myriad of uncertainties associated with recovering listed species, estimating recovery costs over a longer period is difficult. In general, these uncertainties include: (1) emergence of new threats, (2) response of species to management, (3) innovations in methods / technologies to address threats, and (4) potential economies of scale.

We calculated the annual implementation cost for each recovery action and then multiplied these annual costs by 20 years (Table 11). Estimated costs include only project specific contract, staff, or operations costs in excess of base budgets. They do not include funds that support ongoing staff responsibilities. This recovery plan does not commit the Service or any partners to carry out a particular recovery action or expend the estimated funds. Estimated costs incorporate planning, design, implementation, and research, monitoring, and evaluation associated with specific actions. The high estimated cost to conserve and enhance populations is primarily due to the significant costs to control invasive species (Table 11). Actual costs may exceed the estimated costs if invasive species interdiction fails. Adaptive management will ensure that conservation strategies are effectively mitigating threats and meeting the objectives of this recovery plan. If not effective, additional planning and scientific research may be necessary to inform and develop new strategies.

Table 11. Recovery Actions common to all 15 species, their estimated cost (in Fiscal Year 2023 dollars) over a 20-year time horizon, and the priority of each recovery action.

Recovery Actions	Priority	Estimated Total Cost	Notes[1]
1. Determine the current distribution and status of the species and their habitats.	1	**$4,576,119**	Develop survey methodology for all species ($217,910); identify range, demographics, and genetic diversity ($4,358,209)
2. Protect populations and manage threats to habitat.	1	>**$149,057,791**	Identify sites ($477,612); prioritize sites ($477,612); develop microclimate models ($1,582,090); ensure long-term protection of species-specific sites from threats ($142,687,642); monitor and adaptively manage populations ($3,832,836)
3. Manage species-specific threats.	1	>**$47,598,925**	Develop and implement control programs for slugs ($5,865,672), rodents ($9,328,358), ants ($2,985,075), predatory wasps ($1,492,537), limoniid crane flies, and other invertebrates ($1,492,537), parasitoid wasps ($1,850,746), nonnative beetles and weevils ($4,029,851), leafhoppers ($2,537,313), invasive fishes ($2,733,731), Tahitian prawns ($1,791,045), game birds ($298,507), remove sedimentation ($954,746), and monitor and control diseases ($761,194); control other species-specific threats (TBD); monitoring and adaptive management ($11,477,612)
4. Expand the distribution of existing wild populations and establish new populations.	1	**$69,155,075**	Identify appropriate species ($1,402,985); identify translocation sites ($776,119); select populations based on IUCN standards ($1,268,657); prepare sites ($595,672); *in situ* propagation and captive rearing ($61,962,687); translocation ($1,895,224); evaluate feasibility of translocation outside historical habitat ($358,209); monitor populations ($895,522)

Recovery Actions	Priority	Estimated Total Cost	Notes[1]
5. Conduct additional research essential to recovery of the 15 species and restoring their habitats.	1	**$31,608,955**	Develop tools to enhance habitat and species survival and reproduction ($7,462,687) and improve species viability *in situ* and *ex situ* ($2,835,821); maintain studies on range, demographics, and dispersal ($5,671,642); threats to viability research ($3,283,582); develop tools for monitoring growth and status ($1,388,060); population viability analyses ($985,075); optimize translocation survival and success ($2,238,806); long-term genetic studies ($4,477,612); long-term monitoring of range, status, and trends ($1,761,194); monitor and maintain water quality ($1,504,478)
6. Implement regulations and policy to support species recovery.	2	**$3,925,373**	Program support for biosecurity ($447,761); public outreach, and enforcement of prohibited actions ($492,537); resolve state restrictions on invasive species removal ($1,194,030); provide land protections to anchialine pool complexes ($895,522); protections from dewatering and water diversion ($895,522)
Total Estimated Cost for First 20 Years of Recovery: $305,922,239			

[1]Complete recovery actions can be found above in section III. RECOVERY ACTIONS.

Priority 1 - an action that must be taken to prevent extinction or prevent the species from declining irreversibly in the foreseeable future.

Priority 2 - an action that must be taken to prevent a significant decline in species population or habitat quality.

Cost estimates are preliminary. Project-level details of recovery action implementation will be developed with partners in the RIS that will accompany this recovery plan. Implementation is subject to availability of funds and is at the discretion of partners.

Date of Recovery

If all actions are fully funded and implemented as outlined, including the full cooperation of all partners needed to achieve recovery, we estimate the earliest that the delisting criteria could be met would be between 2078 and 2118 for the various plant species, 2083 for the anchialine pool shrimp, and not likely before 2073 for the picture-wing fly.

For the 13 plant species, delisting is likely to require between 55 to 95 years, depending on the lifespan and recovery potential of each species. Short- and long-lived plants are identified in section II.B.1 (*Recovery Criteria – Plants*; Tables 4 to 7) and a species' recovery potential is identified by its recovery priority number (Table 1).

For each plant species, life span and biological requirements were factored into the estimated time to delisting. The delisting time for long-lived species is longer due to the time needed for plants to reach maturity as well as the time it takes for these species to be grown in nurseries. In contrast, the delisting time for short-lived species is shorter due to the time needed for plants to mature and reproduce both in the wild and in nurseries. Species with a low recovery potential may require additional time to restore habitat, reduce threats, or both, as well as additional time to allow these species to reach the population numbers specified by the recovery criteria. On the other hand, plants with high recovery potential may require less time for habitat restoration and threat control. The estimated time to recover these species includes a 10-year monitoring period for downlisting and a 20-year monitoring period for delisting during which populations must be stable, secure, and naturally reproducing.

- For short-lived plants with a high recovery potential (recovery priority number 3), delisting criteria could be achieved within 55 years: *Bidens micrantha* ssp. *ctenophylla*.
- For short-lived plants with a low recovery potential (recovery priority numbers 5 and 6), delisting criteria could be achieved within 65 years: *Bidens hillebrandiana* ssp. *hillebrandiana*, *Cyanea marksii*, *Cyanea tritomantha*, *Cyrtandra nanawaleensis*, *Cyrtandra wagneri*, *Phyllostegia floribunda*, *Schiedea diffusa* ssp. *macraei*, *Schiedea hawaiiensis*, and *Stenogyne cranwelliae*.
- For long-lived plants with a high recovery potential (recovery priority number 2), delisting criteria could be achieved within 85 years: *Pittosporum hawaiiense*, *Pritchardia lanigera*.
- For long-lived plants with a low recovery potential (recovery priority number 5), delisting criteria could be achieved within 95 years: *Melicope remyi*.

For *Vetericaris chaceorum,* delisting is not likely to be achieved for at least 60 years. For *V. chaceorum* to be recovered, anchialine pool complexes throughout the species' range will have to be occupied. To achieve this will require that known populations are protected and additional populations are established via translocation. Prior to attempting to establish new populations, additional details of the species' life history will be required. The 60 years estimated to recover this species includes monitoring periods of 20 years for downlisting and 30 years for delisting, as well as time to establish and protect additional populations in anchialine pool complexes.

For *Drosophila digressa*, delising is not likely to be achieved for at least 50 years and will require managing habitat, host plants, and predators throughout the species' range. The estimated time to recovery this species includes monitoring periods of at least 5 years for downlisting and at least 10 years for delisting that show populations are stable to increasing.

V. REFERENCES

A. LITERATURE CITED

Acly, M. 2003. The effects of introduced fish species on the endemic shrimp of anchialine ponds. Senior Thesis. University of Hawaiʻi at Hilo. 30 pp.

Alyokhin, A.V., P. Yang, and R.H. Messing. 2004. Oviposition of the invasive two-spotted leafhopper on an endemic tree: Effects of an alien weed, foliar pubescence, and habitat humidity. Journal of Insect Science 4:1–7.

Appelhans, M.S., K.R. Wood, W.L. Wagner. 2017. Reduction of the Hawaiian genus *Platydesma* into *Melicope* section Pelea (Rutaceae) and notes on the monophyly of the section. PhytoKeys 91:125–137.

Atkinson, I.A.E. and T.J. Atkinson. 2000. Land vertebrates as invasive species on islands served by the South Pacific regional environmental programme. Pages 19–84. *In* Invasive species in the Pacific: a technical review and draft regional strategy, South Pacific Regional Environment Programme, Apia, Samoa.

Baayen, R.P., Bonants, P.J.M., Verkley, G.C., Carroll, H.A., van der Aa, H.A., de Weerdt, M., van Brouwershaven, I.R., Schutte, G.C., Maccheroni Jr., W., Glienke, C., Azevedo, J.L. 2002. Nonpathogenic isolates of the citrus black spot fungus, *Guignardia citricarpa*, identified as a cosmopolitan endophyte of woody plants, *G. mangiferae* (*Phyllosticta capitalensis*). Phytopathology. Vol. 92:464–477.

Bailey-Brock, J.H. and R.E. Brock. 1993. Feeding, reproduction, and sense organs of the Hawaiian anchialine shrimp *Halocaridina rubra* (Atyidae). Pacific Science 47:338–355.

Ball, D.L., S. Lowe, M.K. Reeves, F. Amidon, and S.E. Miller. 2020. Hawaiʻi: mesic grasslands and shrublands. Pages 923–947. *In* Encyclopedia of the Worlds Biomes. M.I. Goldstein and D.A. DellaSala (Eds.). Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.11963-3.

Barnes, I., A. Fourie, M.J. Wingfield, T.C. Harrington, D.L. McNew, L.S. Sugiyama, B.C. Luiz, W.P. Heller, and L.M. Keith. 2018. New *Ceratocystis* species associated with rapid death of *Metrosideros polymorpha* in Hawaiʻi. Persoonia—Molecular Phylogeny and Evolution of Fungi 40:154–181.

Barrett, S.C.H. and J.R. Kohn. 1991. Genetic and evolutionary consequences of small population size in plants–implications for conservation. Pages 3–30. *In* Genetics and Conservation of Rare Plants. D.A. Falk and K.E. Holsinger (Eds.). Oxford University Press, New York, New York and Oxford, United Kingdom.

Bernard, R.F. and W.J. Mautz. 2016. Dietary overlap between the invasive coqui frog (*Eleutherodactylus coqui*) and the Hawaiian hoary bat (*Lasiurus cinereus semotus*) on the island of Hawaiʻi. Biological Invasions 18:3409–3418.

Borror, D.J., C.A. Triplehorn, and N.F. Johnson. 1989. Family Formicidae—Ants. Pages 737–741. *In* Introduction to the Study of Insects. Saunders College Publishing, Philadelphia, Pennsylvania.

Bozanic, J. 2004. Lua O Palahemo Cave, Ka Lae, Hawai‘i. Hawai‘i Speleological Survey Newsletter. NSS 22532RL.

Breininger, D.R., E.D. Stolen, D.J. Breininger, and R.D. Breininger. 2019. Sampling rare and elusive species: Florida east coast diamondback terrapin population abundance. Ecosphere 10:e02824.

Brock, R.E. 1985. An assessment of the conditions and future of the anchialine pond resources of the Hawaiian Islands. Appendix C. *In* U.S. Army Corps of Engineers, Honolulu District. Final Environmental Impact Statement U.S. Department of the Army Permit Application, Waikoloa Beach Resort, Waikoloa, South Kohala District, Island of Hawai‘i. September 1985. 504 pp.

Brock, R.E. 2004. Anchialine resources in two Hawai‘i State Natural Area Reserves: Ahihi Kinau, Maui Iisland and Manukā, Hawai‘i Island with recommendations for their management. Prepared for the U.S. Fish and Wildlife Service by Environmental Assessment, LLC.

Brock, R.E., J.E. Norris, D.A. Ziemann, and M.T. Lee. 1987. Characteristics of water quality in anchialine ponds of the Kona, Hawai‘i, coast. Pacific Science 41:200–208.

Brock, R.E. and A.K.H. Kam. 1997. Biological and water quality characteristics of anchialine resources in Kaloko-Honokōhau National Historical Park. National Park Service Cooperative Agreement CA8008-2-9004.

Brooks, F., B. Brennan, T. Marler, and M. Schmaedick. 2012. A resurging pest in the Hawaiian Islands: Phantasma scale. Pacific Pest Detector News. No. 9. March-May 2012.

Brown, J.K. and J.K. Smith. 2000. Wildland fire in ecosystems: effects of fire on flora. General Technical Report RMRS-GTR-42-vol.2, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Ogden, Utah. 257 pp.

Browning, J.H., M.K. Reeves, F. Amidon, and S.E. Miller. 2020. Hawai‘i: The wetland system of Hawai‘i. Pages 211–234. *In* Encyclopedia of the World’s Biomes. M.I. Goldstein and D.A. DellaSala (Eds.). Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.11915-3.

Capps, K.A., C.B. Turner, M.T. Booth, D.L. Lombardozzi, S.H. McArt, D. Chai, and N.G. Hairston, Jr. 2009. Behavioral responses of the endemic shrimp *Halocaridina rubra* (Malacostraca: Atyidae) to an introduced fish, *Gambusia affinis* (Actinopterygii: Poeciliidae) and implications for the trophic structure of Hawaiian anchialine ponds. Pacific Science 63:27–37.

Carey, C.C., M.P. Ching, S.M. Collins, A.M. Early, W.W. Fetzer, D. Chai, and N.G. Hairston, Jr. 2011. Predator-dependent diel migration by Halocaridina rubra shrimp (Malacostraca: Atyidae) in Hawaiian anchialine pools. Aquatic Ecology 45:35–41.

Carson, H.L. 1986. Drosophila populations in the Olaʻa Tract, Hawaii Volcanoes National Park, 1971–1986. *In* Proceedings of the Sixth Conference in Natural Sciences, Hawaii Volcanoes National Park. Cooperative National Park Resources Unit, Department of Botany, University of Hawaiʻi. Honolulu, Hawaiʻi. 7 pp.

Chai, D.K. 1993. Biophysical inventory and assessment of anchialine pools along the Waiakea Coast, Hilo, Hawaiʻi. Master's Thesis. University of Hawaiʻi at Mānoa. 97 pp.

Chai, D.K., L.W. Cuddihy, and C.P. Stone. 1989. An inventory and assessment of anchialine pools in Hawaiʻi Volcanoes National Park from Wahaʻula to Kaʻaha, Puna and Kaʻu, Hawaiʻi. Technical Report 69. 37 pp.

Chan, J.G. 1995. A biological assessment of the anchialine ponds along the shoreline of Manukā, Kaʻu, island of Hawaiʻi. Prepared for Department of Land and Natural Resources, State of Hawaiʻi. 34 pp.

Chapin, M.H., K.R. Wood, S.P. Perlman, and M. Maunder. 2004. A review of the conservation status of the endemic *Pritchardia* palms of Hawaii. Oryx 38:273–281.

Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer, and A.S. Unnikrishnan. 2013. Sea level change. Pages 1137–1138. *In* Climate change 2013: The physical science basis. Contribution of working group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. T. F. Stocker, D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Zia, V. Bex, and P.M. Midgley (Eds.). Cambridge University Press, Cambridge, United Kingdom and New York, New York.

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.

Clarke, G. and L.W. Cuddihy. 1980. A botanical reconnaissance of the Na Pali Coast trail: Kee beach to Kalalau Valley (April 9–11, 1980). Pages C-14 to C-20. *In* Hawaii Department of Land and Natural Resources, Division of Forestry and Wildlife (Ed.). Hilo, Hawaiʻi.

Cole, R.F., L.L. Loope, A.C. Medeiros, J.A. Raikes, and C.S. Wood. 1995. Conservation implications of introduced game birds in high-elevation Hawaiian shrubland. Conservation Biology 9:306–313.

[CSU] Colorado State University, Center for Environmental Management of Military Lands. 2015. Biennial report for Pōhakuloa Training Area, Island of Hawaiʻi, 01 Oct. 2013–30 Sep 2015. Recovery Permit TE-40123A-2. United States Army Garrison, Pōhakuloa Training Area, Natural Resources Program.

Cuddihy, L.W. and C.P. Stone. 1990. Alteration of Native Hawaiian vegetation: effects of humans, their activities and introductions. University of Hawaiʻi Cooperative National Park Resources Studies Unit, Honolulu, Hawaiʻi. 138 pp.

Culliney, J.L. 1988. Livestock in paradise. Pages 335–338. *In* Islands in a Far Sea: Nature and Man in Hawaii. The Sierra Club, San Francisco, California.

D'Antonio, C.M. and P.M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics 23:63–87.

Degener, O., I. Degener, E. Sherff, and B.C. Stone. 1960. *In* Flora Hawaiiensis; the new illustrated flora of the Hawaiian Islands, Book 6, Family 179, *Platydesma remyi*. O. Degener and I. Degener (Eds.). Honolulu, Hawaiʻi.

[DLNR] Department of Land and Natural Resources. 2002. Kipahoehoe Natural Area Reserve management plan. State of Hawaiʻi, Division of Forestry and Wildlife, Natural Area Reserves System. 19 pp. + appendices.

[DLNR] Department of Land and Natural Resources. 2015. Hawaii's State Wildlife Action Plan. Prepared by H.T. Harvey and Associates, Honolulu, Hawaiʻi. 893 pp.

[DLNR] State of Hawaiʻi Department of Land and Natural Resources. 2023. Aquatic invasive species. Available online at: https://dlnr.hawaii.gov/hisc/info/invasive-species-profiles/coqui/. Accessed April 10, 2023.

Dudley, B.D., R.A. MacKenzie, T.S. Sakihara, H. Dulaiova, C.A. Waters, F. Hughes, and R. Ostertag. 2014. Influences of N-fixing and Non-N-fixing vegetation and invasive fish on water chemistry of Hawaiian anchialine ponds. Pacific Science 68:509–523.

Dudley, B.D., R.A. MacKenzie, T.S. Sakihara, M.H. Riney, and R. Ostertag. 2017. Effects of invasion at two trophic levels on diet, body condition, and population size structure of Hawaiian red shrimp. Ecosphere 8:e01682.

Duenas, M.A., H.J. Ruffhead, N.H. Wakefield, P.D. Roberts, D.J. Hemming, and H. Diaz-Soltero. 2018. The role played by invasive species in interactions with endangered and threatened species in the United States: a systematic review. Biodiversity and Conservation eDoc. 13 pp.

Ellstrand, N.C. 1992. Gene flow by pollen: implications for plant conservation genetics. Oikos 63:77–86.

Esri. 2021. World Hillshade [basemap]. Scale Not Given. World Topographic Map. June 13, 2013. World Topographic Map - Overview (arcgis.com) Accessed March 5, 2021.

Foote, D. and H.L. Carson. 1995. *Drosophila* as monitors of change in Hawaiian ecosystems. Pages 368–372. *In* Our living resources: A report to the nation on the distribution, abundancy, and health of U.S. plants, animals, and ecosystems. E.T. LaRoe, G.S. Farris, C.E. Puckett, P.D. Doran, and M.J. Mac (Eds.). U.S. National Biological Service, Washington, D.C.

Fransen, C.H.J.M, S. DeGrave, and T.S. Sakihara. 2013. New records of *Vetericaris chaceorum* (Decapoda, Procarididea) from Hawaiʻi. Crustaceana 86:625–631.

Friday, J.B., C. Yanger, and A. Mokiao-Lee. 2022. Rapid ʻōhiʻa death, website. University of Hawaiʻi, College of Tropical Agriculture and Human Resources, Honolulu, Hawai'i. https://cms.ctahr.hawaii.edu/rod/. Accessed August 25, 2022.

Funasaki, G.Y., P.L. Lai, L.M. Nakahara, J.W. Beardsley, and A.K. Ota. 1988. A review of biological control introductions in Hawaii: 1890 to 1985. Proceedings of the Hawaiian Entomological Society 28:105–160.

Gagne, A.C., E.C. Gagne, A.B. Mohammad, and L. Boddy. 2011. Host shifts in fungi caused by climate change? Fungal ecology. 4:184–190.

Gambino, P., A.C. Medeiros, and L.L. Loope. 1987. Introduced vespids *Paravespula pensylvanica* prey on Maui's endemic arthropod fauna. Journal of Tropical Ecology 3:169–170.

Gambino, P., A.C. Medeiros, and L.L. Loope. 1990. Invasion and colonization of upper elevations of East Maui (Hawaii) by *Paravespula pensylvanica* (Hymenoptera: Vespidae). Annals of the Entomological Society of America 83:1088–1095.

[GAO] Government Accountability Office. 2006. Endangered species recovery. GAO-06-463R. April 6, 2006. 27 pp.

Giambelluca, T.W., M.A. Nullet, M.A. Rifgley, P.R. Eyre, J.E.T. Moncur, and S. Price. 1991. Drought in Hawaii. Report 87: State of Hawaiʻi Department of Land and Natural Resources, Commission on Water Resource Management. 177 pp.

Giffin, J. 2003. Puʻuwaʻawaʻa biological assessment. Puʻuwaʻawaʻa, North Kona, Hawaii. State of Hawaiʻi. Department of Land and Natural Resources. Division of Forestry and Wildlife. 94 pp.

Grimaldi, D. and J. Jaenike. 1884. Competition in natural populations of mycophagous *Drosophila*. Ecology 65:1113–1120.

Guerrant, Jr., E.O., P.L. Fiedler, K. Havens, and M. Maunder. 2004. Revised genetic sampling guidelines for conservation collections of rare and endangered plants. Appendix 1. Pages 419–438. *In Ex Situ* Plant Conservation. Supporting Species Survival in the Wild. E. O. Guerrant, Jr., K. Havens, and M. Maunder, (Eds.). Island Press. Washington, D.C.

Hardy, D.E. and K.Y. Kaneshiro. 1968. New picture-winged *Drosophila* from Hawaii. Studies in Genetics 4:171–262.

Harrison, S. and E. Bruna. 1999. Habitat fragmentation and large-scale conservation: what do we know for sure? Ecography 22:225–232.

Hartl, D.L. and A.G. Clark. 1989. Principles of population genetics. Fourth Edition. Sinauer Associates, Inc., Sunderland, Massachusetts. 628 pp.

Hawaii Department of Agriculture, Plant Industry Division. 2022. Coconut rhinoceros beetle information. January 12, 2014. http://hdoa.hawaii.gov/pi/main/crb/. Accessed August 25, 2022.

Hawaii Statewide Geographic Information System Program. 2022. Coastlines [Vector Data]. November 15, 2020. http://geoportal.hawaii.gov/ datasets/coastline. Accessed August 25, 2022.

Havird, J.C., J.R. Weeks, S. Hau, and S.R. Santos. 2013. Invasive fishes in the Hawaiian anchialine ecosystem: investigating potential predator avoidance by endemic organisms. Hydrobiologia 716:189–201.

[HDOH] Hawaiʻi State Department of Health. Clean Water Branch. Polluted Runoff Control Program. 2021. Hawaiʻi nonpoint source management plan 2021-2025. 117 pp. https://health.hawaii.gov/cwb/files/2021/04/2021-HI-NPS-Management-Plan.pdf. Accessed September 2, 2022.

[HDOH] Hawaiʻi State Department of Health. Clean Water Branch. 2022. https://health.hawaii.gov/cwb/clean-water-branch-home-page/polluted-runoff-control-program/. Accessed September 2, 2022.

Hess, S.C. 2008. Wild sheep and deer in Hawaii — a threat to fragile ecosystems. Fact Sheet. USGS Pacific Islands Ecosystems Research Center. 4 pp.

Holthuis, L.B. 1973. Caridean shrimps found in land-locked saltwater pools at four Indo-west Pacific localities (Sinai Peninsula, Funafuti Atoll, Maui, and Hawaiʻi Islands), with the description of one new genus and four new species. Zoology Verhadenlingen 128:3–55.

Howarth, F.G. and A.C. Medeiros. 1989. Nonnative invertebrates. Pages 82–87. *In* Conservation Biology in Hawaiʻi. C.P. Stone and D.B. Stone (Eds.). University of Hawaiʻi Cooperative National Park Resources Studies Unit, Honolulu, Hawaiʻi.

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

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

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

Iwai, T.Y., M. Yamamoto, A. Tagawa, and L. Wada. 2009. Notes on the effectiveness of several trapping devices for estimating population density of the red shrimp opaeʻula (*Halocaridina rubra*) in a limestone anchialine 'test' pool on Oʻahu, Hawaiʻi. Hawaii Division of Aquatic Resources and U.S. Fish and Wildlife Service. Unpublished. 10 pp.

Javar-Salas, C., R. Peʻa, F. Amidon, M.K. Reeves, and S.E. Miller. 2020. Hawaiian islands dry forest. Pages 295–327. *In* Encyclopedia of the Worlds Biomes. M.I. Goldstein and D.A. DellaSala (Eds.). Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.11890-1.

Joe, S.M. and C.D. Daehler. 2008. Invasive slugs as under-appreciated obstacles to rare plant restoration: evidence from the Hawaiian Islands. Biological invasions 10:245–255.

Jones, V.P., P. Anderson-Wong, P.A. Follett, P. Yang, D.M. Westcott, J.S. Hu, and D.E. Ullman. 2000. Feeding damage of the introduced leafhopper *Sophonia rufofascia* (Homoptera: Cicadellidae) to plants in forests and watersheds of the Hawaiian Islands. Environmental Entomology 29:171–180.

Kaneshiro, K.Y. 2006. Dynamics of sexual selection in the Hawaiian Drosophiladae: A paradigm for evolutionary change. Proceedings from the Hawaiian Entomological Society 38:1–19.

Kaneshiro, K.Y. and K. Kaneshiro. 1995. Draft listing proposal for 18 species of Hawaiian picture-wing *Drosophila*. Submitted to the U. S. Fish and Wildlife Service, Pacific Islands Fish and Wildlife Office, Honolulu, Hawaiʻi. 47 pp.

Kensley, B. and D. Williams. 1986. New shrimps (Families Procarididae and Atyidae) from a submerged lava tube on Hawaiʻi. Journal of Crustacean Biology 6:417–437.

Kim, J.Y., E.E. Naboa, F. Amidon, and S.E. Miller. 2020. Hawaiian islands coastal ecosystems: past, present, and future. Pages 157–174. *In* Reference Module in Earth Systems and Environmental Sciences. Elsevier, Inc. https://doi.org/10.1016/B978-0-12-409548-9.12418-2.

Krushelnycky, P.D., L.L. Loope, and N.J. Reimer. 2005. The ecology, policy, and management of ants in Hawaii. Proceedings of the Hawaiian Entomological Society 37:1–25.

Krushelnycky, P.D. and R.G. Gillespie. 2010. Sampling across space and time to validate natural experiments: an example with ant invasions in Hawaii. Biological Invasions 12:643–655.

Krushelnycky, P.D., C.S. Ogura-Yamada, K.M. Kanegawa, K.Y. Kaneshiro, and K.N. Magnacca. 2017. Quantifying the effects of an invasive thief ant on the reproductive success of rare Hawaiian picture-winged flies. Biological Conservation 215:254–259.

Lach, L. 2008. Floral visitation patterns of two invasive ant species and their effects on other Hymenopteran visitors. Ecological Entomology 33:155–160.

Lande, R. 1988. Genetics and demography in biological conservation. Science 241:1455–1460.

Levin, D.A., J. Francisco-Ortega, and R.K. Jansen. 1996. Hybridization and the extinction of rare plant species. Conservation Biology 10:10–16.

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 World's Biomes. M.I. Goldstein and D.A. DellaSala. Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.11930-X.

Maciolek, J.A. and R.E. Brock. 1974. Aquatic survey of the Kona coast ponds, Hawaiʻi Island. Sea Grant Advisory Report UNIHI-SEAGRANT-AR-74-04. University of Hawaiʻi at Mānoa, Honolulu, Hawaii.

Maciolek, J.A. 1983. Distribution and biology of Indo-pacific insular hypogeal shrimps. Bulletin of Marine Science 33:606–618.

Maciolek, J.A. 1984. Exotic fishes in Hawaii and other islands of Oceania. Pages 131–161. *In* Distribution and management of exotic fishes. W.R. Courtenay and J.R. Stauffer, Jr. (Eds.). Johns-Hopkins University Press, Baltimore, Maryland.

Magnacca, K.N., D. Foote, and P.M. O'Grady. 2008. A review of the endemic Hawaiian Drosophilidae and their host plants. Zootaxa 1728:1–58.

Mangel, M. and C. Tier. 1994. Four facts every conservation biologist should know about persistence. Ecology 75:607–614.

Marrack, L., C. Wiggins, J.J. Marra, A. Genz, R. Most, K. Falinski, and E. Conklin. 2021. Assessing the spatial–temporal response of groundwater-fed anchialine ecosystems to sea-level rise for coastal zone management. Aquatic Conservation 31:853–859.

Medeiros, A.C., L.L. Loope, and R.A. Holt. 1986. Status of native flowering plant species on the south slope of Haleakala, East Maui, Hawaii. Cooperative National Park Resources Studies Unit, University of Hawaiʻi at Manoa, Department of Botany, Honolulu, Hawaiʻi. 240 pp.

Mitchell, C., C. Ogura, D.W. Meadows, A. Kane, L. Strommer, S. Fretz, D. Leonard, and A. McClung. 2005. Hawaiʻi's Comprehensive Wildlife Conservation Strategy. Department of Land and Natural Resources. Honolulu, Hawaiʻi. 722 p.

Montgomery, S.L. 1975. Comparative breeding site ecology and the adaptive radiation of picture-winged Drosophila (Diptera: Drosophilidae) in Hawaii. Proceedings of the Hawaiian Entomological Society XXII:65–103.

Nafus, D.M. 1993. Extinction, biological control, and insect conservation on islands. Pages 139–154. *In* Perspectives on Insect Conservation. K.J. Gaston, T.R. New, and M.J. Samways (Eds.). Intercept Ltd. Andover, Maryland.

Nelson, J., M.K. Reeves, F. Amidon, and S.E. Miller. 2020. Hawaiʻi wet grassland and shrubland. Pages 900–922. *In* Encyclopedia of the Worlds Biomes. M. I. Goldstein and D. A. DellaSala (Eds.). Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.11962-1.

Newman, D. and D. Pilson. 1997. Increased probability of extinction due to decreased genetic effective population size: experimental populations of *Clarkia pulchella*. Evolution 51:354–362.

Nicholls, R.J. and A. Cazenave. 2010. Sea-level rise and its impact on coastal zone. Science 328:1517–1520.

[NIDIS] National Integrated Drought Information System. 2020. Available online at: https://www.drought.gov/drought/states/hawaii. Accessed August 24, 2020.

[NMFS and USFWS] National Marine Fisheries Service and U.S. Fish and Wildlife Service. 2018. Interim recovery planning guidelines, Version 1.4. 123 p.

[OISC] Oʻahu Invasive Species Committee. 2021. Coconut rhinoceros beetle. https://www.oahuisc.org/coconut-rhinoceros-beetle/. Accessed March 8, 2021.

Orians, C.M. 2000. The effects of hybridization in plants on secondary chemistry: implications for the ecology and evolution of plant-herbivore interactions. American Journal of Botany 87:1749–1756.

Parris, A., P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obseysekera, A. Sallenger, and J. Weiss. 2012. Global sea level rise scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1. 37 pp.

Pavlik, B. 1996. Defining and measuring success. Pages 127–155. *In* Restoring Diversity: Strategies for Reintroduction of Endangered Plants. D. A. Falk, C. I. Millar, and M. Olwell (Eds.). Island Press, Washington, D.C.

Peʻa, R., C. Javar-Salas, M.K. Reeves, F. Amidon, and S.E. Miller. 2020. Hawaiʻi dry grasslands and shrublands. Pages 880–890. *In* Encyclopedia of the Worlds Biomes. M.I. Goldstein and D.A. DellaSala (Eds.). Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.11961-X.

Perkins, R.C.L. 1913. Introduction. Being a review of the land fauna of Hawaii. Pages xv–ccxxvii. *In* Fauna Hawaiiensis. Volume 1, part 6. Cambridge University Press, Cambridge, UK.

Phillipson, C., M.K. Reeves, F. Amidon, and S.E. Miller. 2020. Hawaiʻi: anthropogenic changes—the developed system of Hawaiʻi. Pages 243–262. *In* Encyclopedia of the Worlds Biomes. M.I. Goldstein and D.A. DellaSala (Eds.). Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.12061-5.

Pimm, S.L., H.L. Jones, and J. Diamond. 1988. On the risk of extinction. The American Naturalist 132:757–785.

Pratt, L. and L. Abbott. 1996. Distribution and abundance of alien and native plant species in Kaloko-Honokōhau National Historical Park. Cooperative National Park Resources Studies Unit, University of Hawaiʻi at Mānoa, Technical report 103. 89 pp.

Reed, J.M., L.S. Milles, J.B. Dunning, Jr., E.S. Menges, K.S. McKelvey, R. Fryer, S.R. Beissinger, M.-C. Anstett, and P. Miller. 2002. Emerging issues in population viability analysis. Conservation Biology 16:7–19.

Reimer, N.J. 1993. Distribution and impact of alien ants in vulnerable Hawaiian ecosystems. Pages 11–22. *In* Exotic Ants: Biology, Impact, and Control of Introduced Species. D.F. Williams (Ed.). Westview Press, Boulder, Colorado.

Rhymer, J.M. and D. Simberloff. 1996. Extinction by hybridization and introgression. Annual Review of Ecology and Systematics 27:83–109.

Rodrigues, K.F., T.N. Sieber, C.R. Grunig, and O. Holdenrieder. 2004. Characterization of *Guignardia mangiferae* isolated from tropical plants based on morphology, ISSR-PCR amplifications and ITS1-5.8S-ITS2 sequences. Mycolology Research 108: 45–52.

Rossetto, E.F.S. and M.A. Caraballo-Ortiz. 2020. Splitting the *Pisonia* birdcatcher tree: re-establishment of *Ceodes* and *Rockia* (Nyctaginaceae, Pisonieae). PhytoKeys 152:121–136.

Sakihara, T.S. 2012. A diel comparison of the unique faunal assemblage in remote anchialine pools on Hawaiʻi Island. Pacific Science 66:83–95.

Sakihara, T.S. 2017. Trip Report Kahuku, TMK (3) 9-2-001:75, Hawaiʻi Island April 24–25, 2017.

Science Panel. 2005. Notes from meeting to assess risk for 12 species of Hawaiian picture-wing flies proposed for listing as endangered. Pacific Islands Fish and Wildlife Office, Honolulu, Hawaiʻi. 27 pp.

Shaffer, M.L. and M.A. Stein. 2000. Safeguarding our precious heritage. Pages 301–321. *In* Precious Heritage: the Status of Biodiversity in the United States. B.A. Stein, L.S. Kutner, and J.S. Adams (Eds.). Oxford University Press, New York, New York.

Sherff, E. 1939. Additional studies of the Hawaiian Euphorbiaceae. Field Museum Natural History, Botany Series 17:547–558.

Shizuma, L., J. Randall, M. Lamson, S. Breining, and T. Sakihara. 2016. Manukā natural area reserve huakaʻi, August 27, 2016. *In* Summary report of the 2016 Hawaiian anchialine ecosystems meeting. State of Hawaiʻi Department of Land and Natural Resources.

Smith, C.W. 1985. Impact of alien plants on Hawaiʻi's native biota. Pages 180–250. *In* Hawaiʻi's Terrestrial Ecosystems: Preservation and Management. C.P. Stone and J.M. Scott (Eds.). University of Hawaiʻi, Cooperative National Park Resources Studies Unit. Honolulu, Hawaii.

Smith, C.W. and T. Tunison. 1991. Fire and alien plants in Hawaiʻi: research and management implications for native systems. *In* Alien Plant Invasions in Native Ecosystems of Hawaiʻi: Management and Research. C.P. Stone, C.W. Smith, and T. Tunison (Eds.), University of Hawaiʻi Cooperative National Park Resources Studies Unit. Honolulu, Hawaiʻi.

Smith, D.R., N.L. Allan, C.P. McGowan, J.A. Szymanski, S.R. Oetker, ,and H.M. Bell. 2018. Development of a species status assessment process for decisions under the US Endangered Species Act. Journal of Fish and Wildlife Management 9:302-320.

Smithsonian Institution. 2022. Checklist of the Flora of the Hawaiian Islands. https://naturalhistory2.si.edu/botany/hawaiianflora/. Accessed August 25, 2022.

Spieth, H.T. 1974. Courtship behavior in Drosophila. Annual Review of Entomology19:385–405.

Staples, G.W. and R.H. Cowie (Eds.). 2001. Hawaii's Invasive Species. A guide to invasive plants and animals in the Hawaiian Islands. Mutual Publishing and Bishop Museum Press. Honolulu, Hawaii. xii + 116 p.

Starr, F., K. Starr, and L. Loope. 2003. *Omalanthus populifolius*. Queensland poplar. Euphorbiaceae. www.hear.org/starr/hiplants/reports/pdf/omalanthus_populifolius.pdf. Accessed May 28, 2020.

State of Hawai‘i. 2017. Hawaii interagency biosecurity plan 2017–2027. 114 pp. https://dlnr.hawaii.gov/hisc/files/2017/02/Hawaii-Interagency-Biosecurity-Plan.pdf. Accessed August 25, 2022.

Stone, C.P. 1985. Alien animals in Hawaii's native ecosystems―toward controlling the adverse effects of introduced vertebrates. Pages 251–297. *In* Hawai‘i's Terrestrial Ecosystems: Preservation and Management. Proceedings of a symposium held June 5–6, 1984 at Hawaii Volcanoes National Park. C.P. Stone, and J.M. Scott, (Eds.). University of Hawai‘i, Cooperative National Park Resources Studies Unit. Honolulu, Hawaii.

Street, J.H., K.L. Knee, E.E. Grossman, and A. Paytan. 2008. Submarine groundwater discharge and nutrient addition to the coastal zone and coral reefs of leeward Hawai‘i. Marine Chemistry 109:355–376.

Swezey, O.H. 1927. Palm seed Scolytids in Hawaii (Col.), Proceedings of the Hawaiian Entomology Society, VII, No1, June 1928.

Traill, L.W., B.W. Brook, R.R. Frankham, and C.J.A. Bradshaw. 2010. Pragmatic population viability targets in a rapidly changing world. Biological Conservation 143:28–34.

Tunison, J.T., C.M. D’Antonio, and R.K. Loh. 2002. Fire and invasive plants in Hawai‘i Volcanoes National Park. Pages 122–130. *In* Proceedings of the Invasive Species Workshop: the Role of Fire in the Control and Spread of Invasive Species, Fire Conference 2000: the First National Congress on Fire Ecology, Prevention, and Management, K.E.M. Galley and T.P. Wilson (Eds.). Tall Timbers Research Station, Tallahassee, Florida.

[USFWS] U.S. Fish and Wildlife Service. 2012. Endangered and threatened wildlife and plants; listing 15 species on Hawaii Island as endangered and designating critical habitat for 3 species; proposed rule. Federal Register 77(201):63928–64018.

[USFWS] U.S. Fish and Wildlife Service. 2013. Endangered and threatened wildlife and plants; determination of endangered species status for 15 species on Hawaii Island; final rule. Federal Register 78(209):64638–64690.

[USFWS] U.S. Fish and Wildlife Service. 2016. Endangered and threatened wildlife and plants; endangered status for 49 species from the Hawaiian Islands; final rule. Federal Register 81:67786–67860.

[USFWS] U.S. Fish and Wildlife Service. 2018. Endangered and threatened wildlife and plants; designation of critical habitat for three plant species on Hawaii Island; final rule. Federal Register 83(162):42362–42435.

[USFWS] U.S. Fish and Wildlife Service. 2019. Recovery outline for of Hawaiʻi Island. 25 pp. Available at: https://ecos.fws.gov/docs/recovery_plan/Hawaii_Island_Recovery_Outline_20191031.pdf.

[USFWS] U.S. Fish and Wildlife Service. 2023a. Endangered and threatened wildlife and plants; designation of critical habitat for 12 species, and not prudent determination for 2 species, on Hawaiʻi island. Federal Register 88:18756–18821.

[USFWS] U.S. Fish and Wildlife Service. 2023b. Species Report for anchialine pool shrimp (*Vetericaris chaceorum*). Pacific Islands Fish and Wildlife Office, Pacific Region 1, Portland, Oregon. 34 pp.

[USFWS] U.S. Fish and Wildlife Service. 2023c. Species report for *Bidens hillebrandiana* ssp. *hillebrandiana* (koʻokoʻolau). Pacific Islands Fish and Wildlife Office, Pacific Region 1, Portland, Oregon. 31 pp.

[USFWS] U.S. Fish and Wildlife Service. 2023d. Species report for *Bidens micrantha* ssp. *ctenophylla* (koʻokoʻolau). Pacific Islands Fish and Wildlife Office, Pacific Region 1, Portland, Oregon. 35 pp.

[USFWS] U.S. Fish and Wildlife Service. 2023e. Species report for *Cyanea marksii* (hāhā). Pacific Islands Fish and Wildlife Office, Pacific Region 1, Portland, Oregon. 27 pp.

[USFWS] U.S. Fish and Wildlife Service. 2023f. Species report for *Cyanea tritomantha* (ʻakū). Pacific Islands Fish and Wildlife Office, Pacific Region 1, Portland, Oregon. 38 pp.

[USFWS] U.S. Fish and Wildlife Service. 2023g. Species Report for *Cyrtandra nanawaleensis* (haʻiwale or kanawao keʻokeʻo). Pacific Islands Fish and Wildlife Office, Pacific Region 1, Portland, Oregon. 34 pp.

[USFWS] U.S. Fish and Wildlife Service. 2023h. Species Report for *Cyrtandra wagneri* (haʻiwale or kanawao keʻokeʻo). Pacific Islands Fish and Wildlife Office, Pacific Region 1, Portland, Oregon. 33 pp.

[USFWS] U.S. Fish and Wildlife Service. 2023i. Species report for Hawaiian picture-wing fly, *Drosophila digressa*. Version 1. Pacific Islands Fish and Wildlife Office, Pacific Region 1, Portland, Oregon. 44 pp.

[USFWS] U.S. Fish and Wildlife Service. 2023j. Species Report for *Phyllostegia floribunda*. Pacific Islands Fish and Wildlife Office, Pacific Region 1, Portland, Oregon. 36 pp.

[USFWS] U.S. Fish and Wildlife Service. 2023k. Species report for *Pittosporum hawaiiense* (hōʻawa). Pacific Islands Fish and Wildlife Office, Pacific Region 1, Portland, Oregon. 30 pp.

[USFWS] U.S. Fish and Wildlife Service. 2023l. Species report for *Platydesma remyi* (no common name). Pacific Islands Fish and Wildlife Office, Pacific Region 1, Portland, Oregon. 30 pp.

[USFWS] U.S. Fish and Wildlife Service. 2023m. Species report for *Pritchardia lanigera* (loulu). Pacific Islands Fish and Wildlife Office, Pacific Region 1, Portland, Oregon. 31 pp.

[USFWS] U.S. Fish and Wildlife Service. 2023n. Species report for *Schiedea diffusa* ssp. *macraei*. Pacific Islands Fish and Wildlife Office, Pacific Region 1, Portland, Oregon. 21 pp.

[USFWS] U.S. Fish and Wildlife Service. 2023o. Species report for *Schiedea hawaiiensis* (no common name). Pacific Islands Fish and Wildlife Office, Pacific Region 1, Portland, Oregon. 26 pp.

[USFWS] U.S. Fish and Wildlife Service. 2023p. Species report for *Stenogyne cranwelliae* (no common name). Pacific Islands Fish and Wildlife Office, Pacific Region 1, Portland, Oregon. 23 pp.

van Riper, S.G. and C. van Riper, III. 1982. A Field Guide to the Mammals in Hawaii. The Oriental Publishing Company, Honolulu, Hawaiʻi. 68 pp.

Vitousek, P.M., L.L. Loope, and C.P. Stone. 1987. Introduced species in Hawaii: Biological effects and opportunities for ecological research. Trends in Ecology and Evolution 2:224–227.

Vitousek, P.M. 1992. Effects of alien plants on native ecosystems. Pages 29–41. *In* Alien Plant Invasions in Native Ecosystems of Hawaii. B.C. Stone, C.W. Smith and J.T. Tunison (Eds.). University of Hawaiʻi Press. Honolulu, Hawaiʻi.

Vitousek, P.M., C.M. D'Antonio, L. L. Loope, M. Rejnanek, and R. Westerbrooks. 1997. Introduced species: a significant component of human-caused global change. New Zealand Journal of Ecology 21:1–16.

Wagner, W.L., D.R. Herbst, and S.H. Sohmer. 1999. Manual of the flowering plants of Hawaiʻi. 2 volumes. University of Hawaiʻi and Bishop Museum Press. Honolulu, Hawaii. 1,948 pp.

Wehr, N.H., S.C. Hess, and C.M. Litton. 2018. Biology and impacts of Pacific Islands invasive species. 14. *Sus scrofa*, the feral pig (Artiodactyla: Suidae). Pacific Science 72:177–198.

Weese, D.A. and S.R. Santos. 2009. Genetic identification of source populations for an aquarium-traded invertebrate. Animal Conservation. 13–19.

Wiegner, T., J. Beets, W. Dudley, L. Muehlstein, and M. Parsons. 2006. A review of coastal monitoring data for developments in West Hawaiʻi. Prepared for County of Hawaiʻi. 116 pp.

Williams, S.J. 2013. Sea-level rise implications for coastal regions. Journal of Coastal Research 63:184–196.

Woolbright, L.L., A.H. Hara, C.M. Jacobsen, W.J. Mautz, and F.L. Benevides. 2006. Population densities of the coqui, *Eleutherodactylus coqui* (Anura:Leptodactylidae) in newly invaded Hawai'i and in native Puerto Rico. Journal of Herpetology 40:122–126.

Wolf, S., B. Hartl, C. Carroll, M.C. Neel, and D.N. Greenwald. 2015. Beyond PVA: why recovery under the Endangered Species Act is more than population viability. BioScience 65:200–207.

Yamamoto, M.N. and A.W. Tagawa. 2000. Hawai'i's native and exotic freshwater animals. Mutual Publishing. Honolulu, Hawai'i. 200 pp.

Yamamoto, M.N., T.Y. Iwai, Jr., and A.W. Tagawa. 2015. Hawaiian anchialine pools: windows to a hidden world. Mutual Publishing. Honolulu, Hawai'i. 124 pp.

In Litteris References

Conry, P.J. 2012. Letter regarding response to request for comments on USFWS species assessment and listing priority assignment forms. April 9, 2012. 1 p.

Kaneshiro, K.Y. 2006. Telephone call to document information regarding certain behavior of picture-wing flies and how it may affect predation of picture-wing flies by *Vespula* sp. wasps. Service record: 1-2-2006-L-111. 2 pp.

Kaneshiro, K.Y. 2013. Peer Review by Dr. Ken Kaneshiro for *Drosophila digressa*. Received by the U.S. Fish and Wildlife Service, Pacific Fish and Wildlife Office, Honolulu, Hawai'i. February 6, 2013. 5 pp.

Kessler, C. 2011. Ungulate distribution in the Hawaiian Islands. 1 p.

Kinzie, R.A. 2010. Comments on proposal to list 15 species on Hawai'i Island. December 4, 2010. 6 pp.

Lau, C.J. 2012. Testimony of Colin J. Lau regarding proposed rule regarding endangered and threatened wildlife and plants, dated December 13, 2012. 4 pp.

Magnacca, K. 2005. Email from Hawaiian *Drosophila* expert Karl Magnacca to Fish and Wildlife Service biologist Mike Richardson regarding tipulid flies and *Drosophila* host plants; and scolytid beetle and rat effects on *Pritchardia* palm seeds, December 7, 2005.

Magnacca, K. 2006. Comments received on U.S. Fish and Wildlife Service Species Assessment and Listing Priority Assignment Form for *Drosophila digressa*. 18 pp.

Magnacca, K. 2012. Comments received on the endangered and threatened wildlife and plants: listing 15 species on Hawaii island as endangered and designating critical habitat for 3 species. Received December 17, 2012. 1 p.

Magnacca, K.N. 2015. Letter to USFWS on proposed rule to list *Hylaeus* bee species. November 24, 2015. 2 pp.

Magnacca, K.N. 2019. Email correspondence between Drs. K.N. Magnacca and D.M. Sether, USFWS, Pacific Islands Fish and Wildlife Office. Honolulu, Hawaii regarding *Drosophila* and *Hylaeus* surveys and current distribution of species. Received November 14, 2019.

Magnacca, K.N. 2023. Email correspondence between K.N. Magnacca and J.P. Vetter regarding updates to Species Report for *Drosophila digressa*. Received Jan 30, 2023.

McDaniel, S. 2023. Email correspondence between S. McDaniel, Hawaiʻi Volcanoes National Park, and L. Weisenberger, USFWS, Pacific Islands Fish and Wildlife Office. Honolulu, Hawaii. Received January 20, 2023. 2 pp.

Montgomery, S. 2005. Email correspondence on *Drosophila mulli* between S. Montgomery and M. Richardson, USFWS, Pacific Islands Fish and Wildlife Office. Honolulu, Hawaii. December 7, 2005.

Richardson, M. 2012. Trip report for field visit to Lua O Palahemo, Ka Lae, Hawaii, dated June 28, 2012.

Sakihara, T.S. 2012. Comments on Federal Register 77:201 63928–64018, dated December 2012. 5 pp.

Sakihara, T.S. 2020. Email to the USFWS, Pacific Islands Fish and Wildlife Office. Honolulu, Hawaii, regarding information on *Procaris hawaiana* and *Vetericaris chaceorum*, dated March 16, 2020. 4 pp.

Wada, L. 2010. Trip report—field memo—Lua o Palahemo survey, dated July 27, 2010. 2 pp.

Wada, L. 2013. Electronic mail message regarding a few of Christa's questions for you or Sakihara (subject: Manukā), dated February 25 to March 11, 2013. 10 pp.

Wada, L. 2016. Memo regarding presence/absence of anchialine pool shrimp in surveys, dated August 4, 2016. 1 p.

Wada, L. 2018. Memo regarding probable impact from non-native fish in anchialine pools. August 16, 2018. 1 p.

Wada, L. 2021. Memo to file re: threats to anchialine pool shrimp. USFWS, Pacific Islands Fish and Wildlife Office, Honolulu, Hawaiʻi. February 25, 2021.

Yamamoto, M.N. 2015. Letter recommending the listing of *Procaris hawaiana* to be listed as endangered throughout its range. November 16, 2015. 2 pp.

APPENDIX A

List of species with their corresponding Species Report and Habitat Status Assessment.

Species	Species Report	Habitat Status Assessment(s)
PLANTS		
Bidens hillebrandiana ssp. *hillebrandiana*	USFWS 2023c	Kim et al. 2020
Bidens micrantha ssp. *ctenophylla*	USFWS 2023d	Pe‘a et al. 2020; Javar-Salas et al. 2020; Phillipson et al. 2020
Cyanea marksii	USFWS 2023e	Clark et al. 2020
Cyanea tritomantha	USFWS 2023f	Clark et al. 2020; Nelson et al. 2020
Cyrtandra nanawaleensis	USFWS 2023g	Lowe et al. 2020; Ball et al. 2020; Clark et al. 2020
Cyrtandra wagneri	USFWS 2023h	Clark et al. 2020
Melicope remyi	USFWS 2023l	Clark et al. 2020
Phyllostegia floribunda	USFWS 2023j	Lowe et al. 2020; Ball et al. 2020; Clark et al. 2020; Nelson et al. 2020
Pittosporum hawaiiense	USFWS 2023k	Javar-Salas et al. 2020; Lowe et al. 2020; Clark et al. 2020
Pritchardia lanigera	USFWS 2023m	Ball et al. 2020; Clark et al. 2020; Nelson et al. 2020
Schiedea diffusa ssp. *macraei*	USFWS 2023n	Clark et al. 2020
Schiedea hawaiiensis	USFWS 2023o	Javar-Salas et al. 2020
Stenogyne cranwelliae	USFWS 2023p	Clark et al. 2020
INVERTEBRATES		
Drosophila digressa	USFWS 2023i	Clark et al. 2020; Lowe et al. 2020
Vetericaris chaceorum	USFWS 2023b	Browning et al. 2020; Kim et al. 2020

APPENDIX B

Summary of comments on the Draft Recovery Plan for 15 Species from the Island of Hawai‘i.

On November 8, 2022, we released the Draft Recovery Plan for 15 Hawai‘i Island Species for a 60-day comment period for local, territorial, nongovernmental organizations, State and Federal agencies, and the public. The comment period closed January 9, 2023.

One comment was received.

The reviewer commented that fire should be considered a threat to any species in a vegetation community with continuous fuels. Multiple fires have occurred during drought periods in wet forest, the east rift zone [reference to Kīlaeua]. The reviewer suggested adding fire as a threat to additional species in Table 2.

We appreciate your comment and have included fire as a threat to *Pittosporum hawaiiense* (hō‘awa).

In addition, we incorporated new factual information provided throughout the final recovery plan, as appropriate.