

Recovery Plan for the Ka'u Silversword



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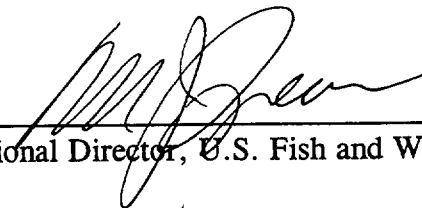
RECOVERY PLAN
FOR
THE KA`U SILVERSWORD

(Argyroxiphium kauense)

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Region 1
U.S. Fish and Wildlife Service
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Regional Director, U.S. Fish and Wildlife Service

Date: _____

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ACKNOWLEDGEMENTS

Part I of the original draft of the Ka'u Silversword recovery plan was prepared by Dr. Elizabeth Powell. Modifications have been made by the U.S. Fish and Wildlife Service.

EXECUTIVE SUMMARY OF THE RECOVERY PLAN FOR THE
KA'U SILVERSWORD (ARGYROXIPHIMUM KAUENSE)

Current Species Status: The Ka'u silversword (Argyroxiphium kauense) is federally listed as endangered. Currently there are only three known populations on the island of Hawai'i, one of which was artificially created by outplanting and consists of only five individuals. The total population contains fewer than 600 individuals and little natural regeneration is occurring.

Habitat Requirements and Limiting Factors: The Ka'u silversword occurs within two distinct habitats on the island of Hawai'i, Hawai'i; in moist openings and boggy areas within wet o'hia (Metrosideros polymorpha) forests, and in drier areas of smooth lava with a sparse soil layer within mesic, shrubby o'hia forests. The greatest threat to all three populations is the trampling, rooting and grazing of feral ungulates. Small population size and possible inbreeding depression, human disturbance, insects which prey on seeds, and volcanic eruptions are also possible threats.

Recovery Objective: Downlisting to threatened status.

Recovery Criteria: Tentatively, downlisting can be considered when there are at least 10 large, widespread populations, each consisting of at least 2,000 individuals. Population structures should be indicative of an expanding population, and consistent regeneration should be occurring. Populations should be genetically diverse and all threats must be controlled. These criteria should be revised periodically as more information becomes available.

Actions Needed:

1. Protect and manage current populations.
2. Conduct research on limiting factors.
3. Re-establish in former range.
4. Enhance current populations.
5. Re-evaluate recovery objectives.

Total Estimated Cost of Recovery (\$1,000):

<u>Year</u>	<u>Need 1</u>	<u>Need 2</u>	<u>Need 3</u>	<u>Need 4</u>	<u>Need 5</u>	<u>Total</u>
1996	11.0	0.0	0.0	0.0	0.0	11.0
1997	53.5	76.5	48.0	7.0	0.0	178.0
1998	83.6	76.5	67.5	0.0	0.0	227.6
1999	60.6	76.5	76.5	0.0	0.0	213.6
2000	30.6	76.5	67.0	0.0	0.0	174.1
2001	30.6	76.5	67.0	0.0	0.0	174.1
2002	30.6	59.5	57.0	0.0	0.0	147.1
2003	30.6	59.5	57.0	0.0	0.0	147.1
2004	30.6	59.5	57.0	0.0	0.0	147.1
2005	30.6	59.5	57.0	0.0	4.0	151.1
2006	30.6	59.5	57.0	0.0	4.0	151.1
2007	30.6	0.0	53.0	0.0	6.0	89.6
2008	30.6	0.0	31.0	0.0	0.0	61.6
2009	30.6	0.0	5.0	0.0	0.0	35.6
2010	30.6	0.0	5.0	0.0	0.0	35.6
2011	30.6	0.0	5.0	0.0	0.0	35.6
2012	30.6	0.0	5.0	0.0	0.0	35.6
2013	30.6	0.0	5.0	0.0	0.0	35.6
2014	30.6	0.0	5.0	0.0	0.0	35.6
Total	667.7	680.0	725.0	7.0	14.0	2086.7

Date of Recovery: Downlisting to threatened status can be initiated in 2014, if recovery criteria are met.

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* Appendix B is not included in the general distribution of this Plan due to the possibility that vandalism or unauthorized collection could be encouraged by the public release of this information. The U.S. Fish & Wildlife Service will consider requests for the maps on a case-by-case basis.

KA'U SILVERSWORD RECOVERY PLAN

I. INTRODUCTION

A. BRIEF OVERVIEW

The Ka'u silversword, Argyroxiphium kauense (Rock and Neal) Degener and Degener, is a giant rosette plant endemic to (i.e. found nowhere else) the active volcano of Mauna Loa on the island of Hawai'i. This species was added to the Federal list of endangered species without critical habitat by the U.S. Fish and Wildlife Service on May 7, 1993.

The Ka'u silversword may have once occurred in subalpine forests, bogs, and mountain parkland between 1,500 and 2,500 meters (5,000 and 8,000 feet) elevation in a band from the southwest rift to the northeast slope of Mauna Loa. The species is currently extant in only two known naturally occurring populations and one artificially created population, and has an estimated total population size of fewer than 600 plants. The decline of the Ka'u silversword is attributed to browsing by cattle (Bos taurus), goats (Capra hircus), and mouflon sheep (Ovis musimon), and to habitat disruption by feral pigs (Sus scrofa). The largest population is located on private land on Kahuku Ranch, which is controlled by the Trustees of the Damon Estate. A smaller population of the Ka'u silversword is located in the Upper Waiakea Forest Reserve, managed by the Hawai'i State Department of Land and Natural Resources (DLNR). A population of only five individuals established by outplanting is located in Hawaii Volcanoes National Park. A fourth population was last seen in 1986 in the Kapapala Forest Reserve. This population has not been relocated, but survey efforts have not been exhaustive, and some plants may still remain in this area. All known populations have been fenced to protect the plants from feral ungulates.

B. TAXONOMY

The Ka'u silversword is one of five species of the genus Argyroxiphium, which includes the silverswords and greenswords of Hawai'i. Silverswords, also called '*ahinahina* or *pohinahina* (Hawaiian for "very grey"), are rosette plants (i.e. leaves arranged in a circular cluster around a central point) endemic to the islands of Maui and Hawai'i. The genus Argyroxiphium is one of three related genera in the subtribe Madiinae of the sunflower family (Asteraceae) (Carr 1985). The taxa of the Hawaiian Madiinae are considered the most spectacular example of adaptive radiation in plants known to science (Carr and Kyhos 1981).

The Ka'u silversword was probably sighted by Archibald Menzies in 1794 during his ascent of Mauna Loa, but was not sufficiently described beyond, "strange looking plants, different from any we had before observed" (Wilson 1920). David Douglas may have collected the species on Mauna Loa in 1834, but he did not distinguish it from the Mauna Kea silversword that had been collected and described earlier (Hooker 1837). The species was also sighted by the U.S. Exploring Expedition in 1840 (Pickering 1854).

The silverswords of Mauna Kea and Mauna Loa were considered the same taxon (Argyroxiphium sandwicense) by Hillebrand (1888), Skottsberg (1926), and Keck (1936a). The single silversword specimen collected by Mann and Brigham (BISH 616) on Hualalai in 1864 was also considered to be A. sandwicense by Brigham (1909).

Rock and Neal (1957) determined that the silverswords from the Ka'u district of Mauna Loa were different from those of Mauna Kea and Haleakala and named the silversword from Ka'u Argyroxiphium sandwicense var. kauense Rock and Neal. They based their determination on a specimen collected by

Lester Bryan, "from the slopes of Mauna Loa above the Ka'u Forest Reserve in Kahuku." Degener and Degener (1957) raised the variety to species rank as Argyroxiphium kauense (Rock and Neal) Degener and Degener. This taxonomic determination has been followed by St. John (1973), Carr (1985), and Wagner *et al.* (1990). The Mann and Brigham specimen from Hualalai was annotated as being Argyroxiphium kauense by Gerald Carr in 1984.

Meyrat (1982) found that the silverswords from Kahuku Ranch, Ka'u District, and those from Upper Waiakea Forest Reserve, South Hilo District, of Mauna Loa differed significantly in five characters (plant length, leaf width, inflorescence length, number of capitula per raceme, and involucral bract length). He concluded that there was differentiation between the two populations, but did not have enough data to make a taxonomic judgement.

The holotype specimen (Bryan 25670) is located at the Bishop Museum Herbarium, Honolulu, Hawai'i and isotypes are located at both the Bishop Museum Herbarium, and at the Royal Botanic Gardens, Kew Herbarium, Kew, England.

C. SPECIES DESCRIPTION

The Ka'u silversword differs from the Mauna Kea silversword (Argyroxiphium sandwicense DC subspecies sandwicense) and the Haleakala silversword (Argyroxiphium sandwicense subspecies macrocephalum (A. Gray) Meyrat), primarily by having the vegetative rosette of leaves elevated on an erect stem. The leaves of the Ka'u silversword are longer and thinner than those of the Mauna Kea or Haleakala silverswords and are triangular rather than flat in cross-section. Leaf pubescence (hairiness) is somewhat sparser than that of the Mauna Kea or Haleakala silverswords; therefore, leaves of the Ka'u silversword appear silvery-grey rather than silver-white.

The Ka'u silversword is an erect rosette shrub, primarily with a single rosette, but occasionally branched. Leaves are pointed, 20 to 40 centimeters (8 to 16 inches) long, 3 to 7 millimeters (0.1 to 0.3 inches) wide at midpoint, and triangular in cross-section. The leaves are covered with a grayish-silver pubescence (downy hairs). Plants grow vegetatively for many years before flowering. Mature plants may be up to 1.3 meters (4.25 feet) tall and 40 to 80 centimeters (16 to 31 inches) in rosette diameter. Flowering generally occurs in July and August. The inflorescence (flowering stem) elongates from the apical meristem (growth tip) of the rosette and is 1 to 2 meters (about 3.3 to 6.5 feet) tall and 15 to 30 centimeters (6 to 12 inches) wide. The inflorescence usually has 100 to 350 capitula (flowering heads), each of which has between 50 to 200 florets (densely clustered small flowers). Ray florets usually number 3 to 11. Flowers are pale yellow, yellow with a rose tinge, rose, or sometimes wine-red. Fruits are dry, black, single-seeded achenes (thin-walled fruits) that are up to 1 centimeter (0.4 inch) long and 1.5 millimeter (0.06 inch) wide (Carr 1985, Meyrat 1982, Powell, unpublished data).

D. HISTORIC RANGE AND POPULATION STATUS

The Ka'u silversword has been frequently sighted and collected on Mauna Loa, but may have also existed on Hualalai in historic times (Carr 1985). Bryan (1974) indicated that silverswords occurred on Hualalai. Although oral reports of sightings of silverswords on Hualalai in recent times are intriguing, there is no hard evidence that silverswords are still extant on Hualalai.

The historic range of the Ka'u silversword on Mauna Loa may have included moist kipukas (islands of older vegetation surrounded by more recent lava flows) and subalpine forests, bogs, and mountain parkland in a band around the mountain from about 1,500 to 2,500 meters (5,000 to 8,000 feet) elevation

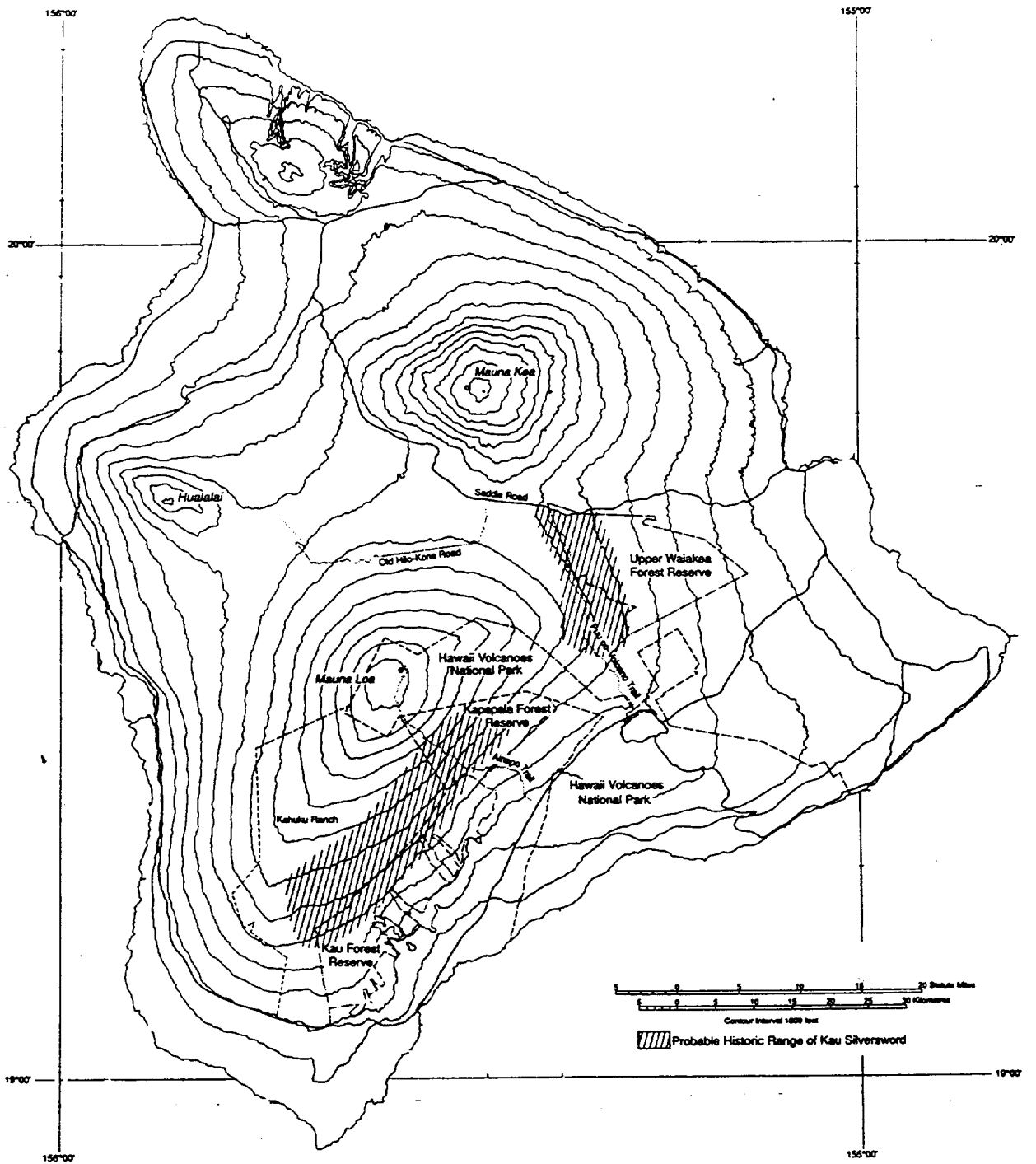


Figure 1. Map of Hawai'i island, Hawai'i, showing the probable historic range of the Ka'u silversword.

from Kipuka 'Akala near the southwest rift, Ka'u District, to the northeast slope in the Upper Waiakea Forest Reserve, South Hilo District (Figure 1). No collections or sightings of naturally occurring silverswords are recorded from Hawai'i Volcanoes National Park or between Hawai'i Volcanoes National Park and the Upper Waiakea Forest Reserve. Silverswords were also never recorded from the northwest slope to the southwest rift of Mauna Loa. A single individual of the Ka'u silversword was known to exist on the north slope of Mauna Loa among mined cinder cones along the old Hilo-Kona Road at about 2,400 meters (7,900 feet) elevation. The plant was fenced in the past, and probably had been planted. The silversword stood about 1 meter (3.3 feet) tall and had died without flowering by 1985 (E. Powell, personal observation 1985).

The Ka'u silversword was probably sighted by Archibald Menzies in 1794, who wrote about his trip to the summit of Mauna Loa along the 'Ainapo trail above Kapapala, "In this day's march we saw many strange looking plants, different from any we had before observed, but very few of them being either in flower or seed, it was not possible to make out what they were" (Wilson 1920). Because the month was February, no silverswords would have been in flower, and certainly, for a botanist, the silversword, because of its unique growth form, would have qualified as a "strange looking plant." It is odd, however, that Menzies did not determine that the silversword, if indeed that was what he saw, was a member of the sunflower family. The species was also seen by David Douglas, who while camping near the "Line of Shrubs" on Mauna Loa in 1834 wrote, "We collected some small stems of a heath-like plant, which, with the dried stalks of the same species of Compositae which I observed on Mauna Kuah, afforded a tolerably good fire" (Hooker 1837).

An 1840 painting by Titian Ramsay Peale (Volcano of "Kaulea Pele" as seen from the side of "Mauna Loa" looking S.E., November 21, 1840, American

Museum of Natural History), clearly depicts the Ka‘u silversword with its elevated stalk and elongated inflorescence. The painting represents members of the U.S. Exploring Expedition ascending Mauna Loa, probably on the ‘Ainapo Trail above Kapapala. The landscape shown is weathered pahoehoe (smooth lava) shrubland with a few short stature o‘hia (Metrosideros polymorpha) and scattered koa (Acacia koa) trees.

The Ka‘u silversword was collected by C.N. Forbes, "above Kapapala, Ka‘u," in 1911. Silverswords were sighted along the ‘Ainapo trail in 1932 at about 2,400 meters (7,700 feet) elevation (Bryan 1974). Silverswords were collected near ‘Ainapo in 1942 at about 2,400 meters (7,750 feet) elevation and in 1974 at about 2,200 meters (7,200 feet) elevation (These specimens are in the Hawai‘i Volcanoes National Park Research Herbarium). In 1973, it was reported that "Scattered pockets of plants cover an estimated 45 to 50 acres" in Kapapala between about 2,500 to 2,800 meters (8,000 and 9,000 feet) elevation (Landgraf 1973). In 1974, about a dozen silverswords were seen from a helicopter, "sparsely scattered over the landscape," at an estimated elevation of 2,300 meters (7,500 feet) (Reeser 1974a). Also in 1974, six live and three dead silverswords were found at about 2,200 meters (7,200 feet) elevation, southwest of the ‘Ainapo trail (Reeser 1974b). The live plants had been severely browsed by goats.

During work on the U.S. Fish and Wildlife Service Hawai‘i Forest Bird Survey in 1979, 105 live and 55 dead Ka‘u silverswords were found between about 1,950 and 2,250 meters (6,390 and 7,330 feet) elevation in the Kapapala Forest Reserve (R. Warshauer, personal communication 1985). The largest live silversword was about 20 centimeters (8 inches) tall; most of the live plants found were between 5 and 7 centimeters (2 and 3 inches) tall. Notes of the survey indicate that cattle, goats, and pigs were common below about 2,150 meters (7,000 feet) elevation (R. Warshauer, personal communication

1985). Two small plants of the Ka'u silversword were found by Jack Lockwood east of the 'Ainapo trail at about 2,300 meters (7,600 feet) elevation in 1986 (Paty 1990).

The Ka'u silversword was first collected at Keapohina on Kahuku Ranch in 1922, and collected again in 1956 (Bryan 25670, BISH), 1963 (Meinecke, BISH 72301), and 1966 (Carlquist 2110, BISH). Other collections from this site were made in 1974, 1977, and 1978. In 1974, this population was considered, "a magnificent colony...the colony may number several thousand plants" (Degener et. al 1976). By 1984, the population had severely declined due to browsing by mouflon sheep and probably numbered less than 2,000 plants, most of which were seedlings. Most of the large individuals that were present in 1982 were dead by 1984. The Ka'u silversword was extant at this site in 1991 (Joan Canfield, U.S. Fish and Wildlife Service, personal communication 1992).

It is unknown if the Ka'u silversword naturally occurred in the area of Hawai'i Volcanoes National Park, or on the east slope of Mauna Loa in the area of the Keauhou Ranch and surrounding Kulani. It is also unknown if the silversword was widely distributed on the northeast slope of Mauna Loa in the Upper Waiakea Forest Reserve. However, Lester Bryan (1974) noted that he saw silverswords, "in a grass covered wet kipuka," in the Upper Waiakea Forest Reserve in 1960. Bryan notes that the plants were found, "a short distance makai (east)," along the Powerline Road. A large open bog system occurs just east of the Powerline Road in the area indicated by Bryan. There were no silverswords in this bog system in 1984 (E. Powell, personal observation 1984), with the exception of a single bog in the Upper Waiakea Forest Reserve at about 1,620 meters (5,260 feet) elevation. In 1977 and 1978, the silverswords of this bog were studied by Alain Meyrat (1982, Meyrat et al. 1984). Photographs taken in 1977 at this site indicated that the silversword

population was large and dominated by mature plants. In 1981, 88 mostly small silverswords were noted by a botanical survey of the bog (Clarke 1982). Only 5 percent of the plants noted were taller than 23 centimeters (9 inches). In 1982, 48 silverswords were counted (Cuddihy 1983). In 1983, 55 plants were found (Wakida 1983) (Table 1). In 1984, the bog site was fenced, but the large silverswords had already disappeared.

Table 1. Number of Ka'u silverswords in Upper Waiakea population, 1981 to 1992. nd = no data recorded, unpub. = unpublished.

Year	Total # of plants	# with \leq 15 cm diameter	# with $>$ 15 cm diameter	# of flowering plants	Reference
1981	88	65	23	0	Corn, 1983
1982	48	44	4	0	Cuddihy, 1983
1983	55	nd	nd	0	Wakida, 1983
1984	20	18	2	0	Powell, unpub.
1985	71	38	33	0	Powell, unpub.
1986	86	46	40	0	Powell, unpub.
1987	86	37	49	0	Powell, unpub.
1988	85	29	53	3	Powell, unpub.
1989	80	20	57	3	Powell, unpub.
1990	86	20	66	0	Powell, unpub.
1991	119	47	54	8	Powell, unpub.
1992	176	114	62	0	Powell, unpub.

Although it is possible that the Ka'u silversword occurred in other bogs throughout the Upper Waiakea Forest Reserve from the Saddle Road to Keauhou Ranch in the past, none of the bogs between Kulani and the Saddle Road had silverswords in 1979 (Jim Jacobi, U.S. Fish and Wildlife Service,

personal communication 1992). The Ka'u silversword has been sighted along the Pu'u O'o-Volcano Trail, but it is uncertain whether the silversword occurred there naturally or if seed was intentionally scattered along the trail (Kaoru Sunada, private citizen, personal communication 1985).

E. CURRENT RANGE AND POPULATION STATUS

Maps or descriptions of the exact locations of known individuals will not be included in this Plan due to the possibility that vandalism or unauthorized collection could be encouraged by the public release of this information. The U.S. Fish and Wildlife Service will consider requests for Appendix B, which contains site specific maps, on a case-by-case basis.

The Ka'u silversword currently occurs in two known naturally occurring locations on Mauna Loa; on Kahuku Ranch at Keapohina, and in the Upper Waiakea Forest Reserve. The species has been planted in Hawai'i Volcanoes National Park. The largest naturally occurring population is at Keapohina in subalpine open mesic o'hia forest. In 1991, the population numbered less than 400 plants, and an estimated 90 percent were less than 15 centimeters (6 inches) in rosette diameter. No plants with a rosette diameter of over 30 centimeters (12 inches) were found (J. Canfield, personal communication 1992).

The Upper Waiakea population occurs in an open bog within the Upper Waiakea Forest Reserve. In 1992, the population at this site numbered about 176 individuals, 65 percent of which were less than 15 centimeters (6 inches) in rosette diameter (Table 1). In August, 1993, two flowering individuals were seen in this population (John Matsuhara, Hawaii Department of Education, personal communication 1993).

In 1975, 18 Ka'u silversword plants that were grown from seed collected at Keapohina were planted in Hawai'i Volcanoes National Park at about 2,060 meters (6,700 feet) elevation (Reeser 1975). In 1980, most, but not all, of the planted silverswords within the National Park were removed. Between 1984 and 1992, 12 Ka'u silverswords have been found at this site. In 1992, five individuals of the original planted population were still alive (Powell, unpublished data). In 1995, only one planted individual was observed (Tim Tunnison, National Park Service, personal communication 1995).

The Ka'u silversword may still exist in the Kapapala Forest Reserve. No plants were found by a 1990 ground survey of an area near the 'Ainapo trail where silverswords had been found as recently as 1986 (J. Canfield, personal communication 1992), but this survey did not cover the area where they were seen during the 1976 Hawaii Forest Bird Survey (Carolyn Corn, DOFAW, personal communication 1993).

F. LIFE HISTORY

Relatively little is known about the Ka'u silversword population at Keapohina. However, the silversword population in the Upper Waiakea Forest Reserve has been monitored since 1985. In 1984, a portion of the extant Upper Waiakea population was fenced. Within the fenced area, approximately 20 silverswords were observed in 1984, but no careful census was taken. In 1985, the fenced area was mapped and individual silverswords were numbered. Population censuses from 1985 to 1992 are provided in Table 1.

The species is monocarpic, that is, the single, non-flowering rosette grows for a number of years, and then produces a tall inflorescence; after fruit set, the entire plant dies.

The majority of individuals of the Ka'u silversword are unbranched plants. Occasionally, however, branching may be noted. In the Upper Waiakea population, only 4 of the 86 plants in 1990 had more than a single rosette (that is, were branched). Three of these had two rosettes and one plant had three rosettes. At Keapohina, 62 of the 205 plants examined in 1984 were branched. About 44 of the branched silverswords had suffered browse damage to the apical meristem (Powell, unpublished data). Branching is a common response to mechanical (browse) damage to the apical meristem in monocarpic silverswords, but may also be a trait with a genetic component (Powell, 1992a). Adult Ka'u silverswords that have branched in response to browse damage may produce small flowering stalks. Silversword fruits either contain a single seed with a potentially viable embryo, or the embryo is absent, no seed has developed, and the fruit is empty (inviolate). Fruits collected in 1991 from inflorescences of branched individuals were inviolate (J. Canfield, personal communication 1992). Fruits collected in 1984 from Keapohina were primarily from the small inflorescences produced on browsed plants, and the number of fruits that had seeds with embryos was low (Table 2).

The Ka'u silversword probably reproduces only by seed; there is no evidence of vegetative reproduction. The Mauna Kea and Haleakala silverswords are primarily self-incompatible (Carr *et al.* 1986; Powell 1992a). The low seed set found for certain individuals of the Ka'u silversword also indicates that this species is at least partially self-incompatible (Table 2). Plant number 1 (Table 2) at the Hawai'i Volcanoes National Park site flowered alone in 1986, and no embryo-filled fruits were found in a random sample of fruits collected from it. Plant number 3 at the Hawai'i Volcanoes National Park flowered alone in 1989, but this plant set about 2 percent embryo-filled fruits. This indicates that some plants are capable of setting a small quantity of seed by self-fertilization.

Table 2. Seed set of plants of the Ka'u silversword, in three populations.

Year	Plant #	# of fruits examined	% fruits w/ embryo filled seed	% fruits damaged by seed parasites	Collection type
Upper Waiakea Forest Reserve:					
1977	-	190	0	0	Herbarium KA-26B, HAW
1979	-	107	58	0	Herbarium KA-99, HAW
1988	51	212	27	0	Live by E. Powell
1988	55	332	35	0	Live by E. Powell
1988	57	455	0	0	Live by E. Powell
Keapohina:					
1963	-	713	1	3	Herbarium BISH 72301
1978	-	110	12	4	Herbarium KR-92, HAW
1984	-	4912	0.6	61	Live by E. Powell
Hawaii Volcanoes National Park:					
1986	1	1037	0	1	Live by E. Powell
1989	3	1602	2	26	Live by E. Powell

In the Upper Waiakea population, three plants flowered in 1988 (Table 2). Plants numbered 55 and 51 set 35 percent and 27 percent seed, respectively; yet, plant number 57 set no seed in the sample collected. Plant number 57 flowered much later than the other two and was probably unable to cross-pollinate with them. The abundant seed set exhibited by plants numbered 55 and 51 indicates that effective pollinators were available in the environment, even though no silverswords had flowered in that location between 1981 and 1988 (Table 1). Flying insects, including native bees (Nesoprosope sp.), non-native flies, and native moths (Agrotis sp.), are typical pollinators of the Mauna Kea silversword (Powell 1992a) and may also be pollinators of the Ka'u silversword.

Fruits (achenes) are sometimes parasitized by native Tephritis sp. flies. The flies lay eggs in unopened capitula and their larvae consume both fertile and non-fertile immature fruits. The larvae then pupate among the developing fruits. Little or no parasitism has been found in most Ka'u silversword fruit samples. However, a sample from the Keapohina population showed high fruit parasitism (Table 2). Fruit parasitism may be infrequent, and fruit parasites may attack only certain plants or certain capitula during the flowering season. Fruit parasites do not significantly depress seed set in the Mauna Kea silversword unless the amount of parasitism is very high (Powell 1992a). It is unknown whether fruit parasitism significantly affects reproduction of the Ka'u silversword. Tephritis sp. flies are associated species with the Mauna Kea and Haleakala silverswords as well, and may have co-evolved with silverswords.

In the Upper Waiakea population, seedlings are most frequently found in Sphagnum sp. moss beds within 2 meters (6.5 feet) of a plant that flowered in the previous year. Fruit dispersal is probably restricted to areas immediately surrounding parent plants. Fruits are shed from September to October. Seeds probably germinate in late winter and early spring, during periods of high

rainfall. Seeds of the Mauna Kea silversword do not exhibit long-term dormancy (Powell, 1992a), and it appears that the seeds of the Ka'u silversword are also incapable of long-term dormancy. Between 1981 and 1990, the number of plants found in the Upper Waiakea Forest Reserve silversword bog was reasonably stable. This suggests that plants were not recruited into the population from seeds that were dormant in the soil or vegetation layers since the last recorded flowering in 1978. It is most likely that differences in numbers of plants between years (as well as the single low number of plants in 1984) (Table 1) reflect human census errors, rather than actual fluctuations in population size.

In August, 1992, about 75 seedlings, some of which had just germinated and had only cotyledons (first leaves of a seedling), were found on Sphagnum sp. beds in the Upper Waiakea bog within 2 meters (6.5 feet) of six of the eight plants that flowered in 1991 (Powell, unpublished data). The presence of Sphagnum appears to be critical for the germination of silverswords in the bog habitat. The Sphagnum beds may provide a moist environment for seedling germination and establishment. In 1984 at Keapohina, numerous seedlings were found in the soil in areas where large plants had existed in previous years (E. Powell, personal observation 1984).

Between 1985 and 1992, in the Upper Waiakea population, the mortality of small seedlings (plants with a rosette diameter of 1 to 6 centimeters (0.4 to 2.4 inches)) was about 25 percent. Mortality of large seedlings (plants between 7 and 12 centimeters (2.8 to 4.7 inches) in rosette diameter)) was about 10 percent. Juvenile plants of 13 to 18 centimeters (5 to 7 inches) in rosette diameter had a mortality of about 5 percent. Mortality was zero for all non-flowering plants larger than 18 centimeters (7 inches) in diameter (Powell, unpublished data).

Small seedlings (plants less than 6 centimeters (2.4 inches) in diameter) grew an average of less than 1 centimeter (0.4 inch) per year in rosette diameter in the Upper Waiakea population. Plants between 6 and 12 centimeters (2.4 to 4.7 inches) in rosette diameter grew at an average rate of about 2 centimeters (0.8 inch) per year. Plants over 12 centimeters (4.7 inches) in rosette diameter grew an average of 4 to 6 centimeters (1.6 to 2.4 inches) per year (Powell, unpublished data). Plant height and rosette diameter are directly related. In general, plants in 1990 had 0.6 centimeters (0.2 inch) in height for every 1 centimeter (0.4 inch) in rosette diameter (Powell, unpublished data).

Between 1988 and 1991, flowering plants in the Upper Waiakea population ranged from 40 to 70 centimeters (16 to 28 inches) in rosette diameter and inflorescences were between 100 and 194 centimeters (3.3 and 6.4 feet) in height from the water surface (Powell, unpublished data). Based on the average growth rate of plants in the Upper Waiakea population, plants of 40 centimeters (16 inches) in rosette diameter may be about 20 years of age. Plants 70 centimeters (28 inches) in rosette diameter may be about 25 years of age (Powell, unpublished data).

G. HABITAT DESCRIPTION

The Keapohina population occurs in moist open forest with short stature o'hia trees and an understory of shrubs, grasses, and herbs. The substrate is a'a (rough) lava with well developed soil. The annual mean rainfall in the Keapohina area is about 10 to 15 centimeters (3.9 to 5.9 inches), but moisture is also available to the silverswords as condensation from frequent afternoon fogs. Dominant shrubs are Styphelia tameiameia, Coprosma ernodeoides, Vaccinium reticulatum, Dubautia ciliolata, and Geranium cuneatum.

The population in the Upper Waiakea Forest Reserve occurs in a bog dominated by Carex montis-eeka, Carex alligata, Rhynchospora chinensis, Juncus ssp., and Deschampsia nubigena. Decumbent (sprawling) shrubs (Styphelia tameiameiae, Vaccinium spp., Coprosma spp.), as well as the rare Plantago hawaiiensis, which were found in the bog in 1981 (Clarke 1982), were not present in 1992 (E. Powell, personal observation 1992).

The silverswords found in the Kapapala Forest Reserve in the past were on weathered, old pahoehoe (smooth) lava with pockets of soil, in subalpine mountain parkland vegetation dominated by shrubby o'hia and scattered shrubs, particularly Styphelia tameiameiae, Vaccinium reticulatum, and Dodonaea viscosa. Table 3 summarizes associated plant species.

The historic range of the Ka'u silversword may have corresponded with a mean annual rainfall of about 100 to 300 centimeters (39 to 118 inches). Rainfall of about 100 to 150 centimeters (39 to 59 inches) currently occurs on the south slope of Mauna Loa in the Ka'u district from 1,500 to 2,100 meters (5,000 to 7,000 feet) elevation (Giambella et al. 1986). On the east slope of Mauna Loa in South Hilo District from 1,500 to 2,500 meters (about 5,000 to 8,000 feet) elevation, mean annual rainfall is between 150 and 300 centimeters (59 and 118 inches) (Giambella et al. 1986).

Plants at Keapohina occupy a different habitat and are probably faced with a different set of physiological limitations than plants in the Upper Waiakea Forest Reserve bog. The Ka'u silverswords that grew in the subalpine areas of Kapapala Forest Reserve occupied a third, probably more arid, habitat although boggy patches do occur in the Reserve. It is possible that plants in each of these three habitats were genetically differentiated ecotypes. It is also possible that a cline, or continuum of genetically different plants, occupied the original

Table 3. List of plant species associated with populations of the Ka'u silversword.

Species	Status
Keapohina area:	
<u>Coprosma ernodeoides</u>	native
<u>Dubautia ciliolata</u>	"
<u>Geranium cuneatum</u>	"
<u>Metrosideros polymorpha</u>	"
<u>Styphelia tameiameiae</u>	"
<u>Vaccinium reticulatum</u>	"
Waiakea area: *	
<u>Asplenium fragile</u> var. <u>insulare</u>	proposed endangered ¹
<u>Carex montis-eeka</u>	native
<u>Carex alligata</u>	"
<u>Coprosma</u> spp.	"
<u>Deschampsia nubigena</u>	"
<u>Juncus</u> spp.	"
<u>Plantago hawaiiensis</u>	endangered ²
<u>Rhynchospora chinensis</u>	native
<u>Silene hawaiiensis</u>	endangered ²
<u>Sphagnum</u> spp.	native
<u>Styphelia tameiameiae</u>	"
<u>Vaccinium</u> spp.	"
Kapapala area (past sightings):	
<u>Dodonaea viscosa</u>	indigenous
<u>Metrosideros polymorpha</u>	native
<u>Styphelia tameiameiae</u>	"
<u>Vaccinium reticulatum</u>	"

indigenous = native to Hawaii, but also found elsewhere

Proposed endangered = proposed to be added to the Federal list of Endangered Species

* - the plants listed for the Waiakea area are not representative of the original community because the area has been extensively damaged by feral pigs

1 - Recovery of this taxon will be addressed in the Ferns Recovery Plan

2 - Recovery of this taxon will be addressed in the Big Island Plants Recovery Plan

range of the species. The two extant natural populations may be the only surviving genotypes of such a cline. It is also possible that the Ka'u silversword exhibits plasticity in its ability to survive in different habitats, and silverswords from any habitat would be able to colonize the other sites.

H. REASONS FOR DECLINE AND CURRENT THREATS

Browsing by feral and domesticated ungulates has been identified as the primary reason for the decline of the Ka'u silversword. Mouflon sheep were introduced to Kahuku Ranch in 1968 (J. Canfield, personal communication 1992) and have steadily increased in numbers there (Mitchell 1981; Cuddihy and Stone 1990). Severe browse damage to Ka'u silverswords was noted in 1984 (E. Powell, personal observation 1984). Although a 1 hectare (2.5 acre) area of the Keapohina population was fenced by Kahuku Ranch personnel in 1982 to protect the silverswords, mouflon were able to gain entry to the fenced area. The mouflon apparently preferred the silversword and Machaerina mariscoides plants as browse species, as these two species were the only plants in the area that were severely browsed in 1984 (E. Powell, personal observation 1984). In 1991, browse damage to Astelia sp. was noted (J. Canfield, personal communication 1992).

Cattle and goats were introduced to Hawai'i Island as early as 1794, and may have browsed in areas that are now within Kahuku Ranch, Kapapala Forest Reserve, and Hawai'i Volcanoes National Park prior to 1850 (Cuddihy and Stone 1990). It is highly likely that cattle in lower elevations and goats in the higher elevation forest eliminated silverswords in many accessible areas in the Kapapala Forest Reserve and on Kahuku Ranch. By the early 1900's, much attention was given to the poor state of forests on Mauna Loa due to feral ungulates (Morris 1967). Cattle grazed portions of the Hawai'i Volcanoes National Park until the 1940's, and goats are still common in higher elevation

areas of Mauna Loa (Tomich 1986). Cattle still graze on Kahuku Ranch, and feral goats are still common in the Kapapala Forest Reserve. Also, mouflon are expanding their range toward the Kapapala Reserve and may further threaten any silverswords still present there.

Feral pigs are currently a major threat to the Ka'u silversword both at Keapohina and in the Upper Waiakea Forest Reserve. Rooting by feral pigs disrupts natural vegetation and uproots and damages small silversword plants. Rooting by pigs is particularly destructive in bogs (Medeiros et al. 1991).

At Keapohina, rooting by feral pigs and browsing by mouflon sheep have interacted to rapidly damage the silversword population. Feral pigs dig up areas where small seedlings are establishing and uproot adult plants. Browsing mouflon sheep and goats feed on the apical meristem and central leaves of adult plants. If browse damage to the apical meristem is severe, the plant may branch, but most plants die. Between 1982 and 1984, the population at Keapohina was severely damaged by browsing mouflon sheep and rooting by pigs.

In the Upper Waiakea Forest Reserve, silverswords were probably eliminated by goat browsing or pig rooting and browsing in most bogs prior to 1979, as silverswords were not noted in the U.S. Fish and Wildlife Service Hawai'i Forest Bird Survey of the area. The remaining silversword population suffered severe decline between 1978 and 1981. Photographs taken in 1978 indicate that the bog was being damaged at that time by extensive pig rooting. By 1981, pig damage was identified as the most serious threat to the silverswords, although 10 percent of the plants clearly showed browse damage (Clarke 1982). Goats may have gained access to the population and caused this damage or pigs may have browsed the silverswords. By 1982, only 48 plants were found in the bog (Cuddihy 1983). The largest live plant had a

rosette diameter of about 13 centimeters (5 inches). Continued pig damage was noted, and plant species noted as common in the bog in 1981 were scarce. Although immediate fencing of the bog had been planned in 1981 (Clarke 1982), it was not possible to erect fencing until 1984. Although about one-third of the bog was fenced in 1984, pigs continued to severely damage surrounding bog areas. Pig trails occur along the fence line and all areas outside the enclosure have been severely impacted by pig rooting. Recent pig damage to the bog has been noted every year from 1984 to 1992 (Cuddihy 1983; E. Powell, personal observation 1992; J. Matsuhara, personal communication 1993). Mouflon sheep were observed in the Upper Waiakea Forest Reserve near the Powerline Road for the first time in 1992. If these animals become abundant in the Forest Reserve, the current fence may be too short to prevent the mouflon from entering the bog and destroying the remaining silverswords.

Feral pigs still occur in Hawai'i Volcanoes National Park in the area where the Ka'u silverswords were planted. In 1992, pig damage to vegetation was evident near the remaining silverswords. In fact, pigs may have destroyed one plant that was missing in an area that was damaged by pigs between the 1991 and 1992 censuses (Powell, unpublished data).

Insects (including fruit parasites), drought, human disturbance, alien plants and disease have all been suggested as probable threats to the Ka'u silversword (U.S. Fish and Wildlife Service, 1990). Ungulate damage to the species has been so severe and population numbers have declined so rapidly that other possible threats are currently of lesser importance, but may become more significant if population sizes continue to drop. The single most serious threat to the immediate survival of the Ka'u silversword is that posed by feral and domestic ungulates, including cattle, goats, pigs, and mouflon sheep.

Populations of the Ka'u silversword may have been eliminated by lava flows from Mauna Loa in historic times (Keck 1936b). Lava flows and the damage caused by feral ungulates may have combined to hasten the endangerment of the Ka'u silversword. However, the fact that the Ka'u silversword is endemic to Mauna Loa, an active volcano, indicates that the species was able to survive thousands of years of eruptive activity. Before feral and domestic ungulates arrived on Mauna Loa, the silversword apparently sustained a widespread population in dynamic equilibrium between chance extinctions of some populations from lava flows and founding of new populations in developing kipukas.

Small population size and localization are major threats to the survival of a species. In 1984, a lava flow from Mauna Loa came within about 2 kilometers (1.2 miles) of the silversword bog in the Upper Waiakea Forest Reserve. Because that silversword population is confined to a single bog, the population is vulnerable to chance lava flows, fires, or other natural disasters. Even an extended drought could drive the population to extinction. The Keapohina population is also threatened by lava flows from Mauna Loa, or potentially by fire, hurricane damage, or earthquakes. A widespread species is less likely to become extinct due to lava flows, other natural disasters, or even human disturbance. It is almost certain that this species was historically widespread.

Matrix modelling of the Mauna Kea silversword population showed that small populations of silverswords are probably unable to sustain enough flowering to ensure regeneration (Powell 1992a). The small populations of the Ka'u silversword found between 1922 and 1986 in the Kapapala Forest Reserve may have been the remnants of larger populations in the past. Unless a silversword population is able to sustain enough flowering for cross-pollination to occur, plants may flower and die over time without regenerating, and the population

may become extinct. Because any extant populations in the Kapapala Forest Reserve are probably still under browsing pressure by goats, it is unlikely that any viable populations currently occur in that area.

I. CONSERVATION EFFORTS

In 1975, 18 Ka'u silverswords were planted in an old goat corral at the end of the Mauna Loa Strip Road in Hawai'i Volcanoes National Park by the National Park Service as part of a Silversword Restoration Project (Reeser 1975). After determining that there was no evidence that Ka'u silverswords ever occurred in the Park area, Park Service personnel decided to remove the planted silverswords. As of 1995, only one of these silverswords remains.

In 1982, the largest population of silverswords at Keapohina was fenced to protect plants from browsing animals. Although the fence undoubtedly afforded some protection, mouflon sheep are able to jump the 1.4 meter (4.5 foot) fence and pigs were able to gain access through gaps under the fence. In 1984, portions of the fence had fallen and animals had gained full access to the site. In 1992, the fence was reinforced by Kahuku Ranch and DLNR personnel (J. Canfield, personal communication 1992). All efforts to protect the silversword at Keapohina have been accomplished because of the concern of the Damon Estate, Kahuku Ranch and DOFAW personnel.

In 1984, a 0.12 hectare (0.3 acre) area in the Upper Waiakea Forest Reserve was fenced by DLNR, with the help of Sierra Club volunteers. Although it covers only one-third of the bog, the fence was placed to protect the largest number of silverswords in the bog area (Wakida 1984). This fenced area is designated by DLNR as a Plant Sanctuary. Unfortunately, feral pigs had already severely damaged the bog prior to fencing and continue to disrupt unfenced areas of the bog extensively. Some species of native plants that

previously occurred in the bog (for instance, Plantago hawaiiensis) were not protected by the fenced area and are no longer extant there (E. Powell, personal observation 1985).

The taxonomic and biosystematic relationships of the Ka'u silversword have been studied by Gerald D. Carr (1985), University of Hawai'i, Manoa, and his student, Alain Meyrat (1982, Meyrat *et al.* 1984). The demography of the Ka'u silversword in the Upper Waiakea Forest Reserve has been studied by Elizabeth Powell.

J. RECOVERY STRATEGY

Recovery of the Ka'u silversword should begin with securing habitat and stabilizing the current populations through negotiations with the Damon Estate, the State of Hawai'i and the National Park Service. Control of ungulates through improved fencing and hunting programs and monitoring of populations are of utmost importance. Reduction of human related disturbance and an investigation of the effects of alien plants on growth and reproduction are also important recovery activities. A research program should also be initiated to determine the physiological and environmental factors influencing habitat preferences; assess the factors limiting germination and seedling establishment and those influencing reproductive biology; determine the need for genetic management; study associated insects and causes of mortality; and to develop methods to reduce other threats that may be discovered.

An effort to re-establish the Ka'u Silversword in its former range should also be initiated, including the selection and protection of sites for re-establishment, cross-pollination of existing plants, collection and storage of seed, nursery propagation, seeding and/or transplantation of nursery grown plants, and monitoring and refinement of the program. If the above protection measures

fail to reverse the decline of existing populations, an augmentation program including seeding and transplant of nursery grown plants should be considered. Finally, a re-evaluation of the recovery objectives in this Plan should be conducted.

II. RECOVERY

STATUS SUMMARY

The current total population of the Ka‘u silversword numbers fewer than 600 individuals. One "large" natural population of about 400 individuals (Keapohina), one small natural population of about 176 individuals (Waiakea), and one artificially created occurrence of one individual are known. The Waiakea and Keapohina populations may be able to regenerate and grow in numbers, if current threats are permanently removed and no new threats are introduced.

A. RECOVERY OBJECTIVES AND CRITERIA

1. Objectives

The ultimate recovery objective is to remove the Ka‘u silversword from the list of threatened and endangered species. However, given its presently depleted state and uncertain future condition, it is not possible to establish specific delisting criteria at this time. As general criteria, in order for the Ka‘u silversword to be delisted, the species may need to number over 100,000 individuals and occur widely over its former range on Mauna Loa. For the silversword to reach this population number and wide range, complete protection of the former range from ungulates would be needed. Silverswords would need to be re-introduced to a large number of sites throughout the former range, particularly on the south and east slopes of Mauna Loa. Lava flows from active Mauna Loa will always be a threat to the silversword, and this threat cannot be removed. However, if the species is sufficiently widespread and capable of regenerating naturally, the silversword should be able to survive chance lava flows that may eliminate some populations in the future.

The recovery objective supported in this plan is to down-list the Ka‘u silversword to threatened status.

2. Criteria

Downlisting to threatened will be considered when:

- a. there are at least ten populations throughout the historic range, each with a minimum of 2,000 plants,
- b. population demographic structures are indicative of increasing numbers,
- c. the populations are completely protected from feral ungulates, and
- d. the populations are genetically diverse and show consistent regeneration.

These numbers were chosen because, based on current information, they are believed to be adequate to preserve the majority of existing genetic diversity and to protect against extinction due to catastrophic events, especially lava flows. These objectives should be revised as often as warranted by new information.

Because the largest population of the silversword and a large portion of the former range occurs on private land, cooperation with the Damon Estate is essential for the success of recovery efforts.

B. STEP-DOWN OUTLINE

1. Protect and manage existing populations of the Ka'u silversword.
 11. Protect habitat on Kahuku Ranch, in the Waiakea Forest Reserve, at Volcanoes National Park and in other areas of Mauna Loa.
 111. Secure habitat on Kahuku Ranch.
 112. Secure habitat in the Upper Waiakea and Kapapala Forest Reserves.
 113. Secure habitat in Volcano National Park.
 12. Manage habitat.
 121. Control ungulates at current sites.
 1211. Enhance and maintain fencing at current sites.
 12111. Enhance and maintain fencing at Keapohina.
 12112. Enhance, enlarge and maintain fence in Upper Waiakea Forest Reserve.
 1212. Eradicate or reduce ungulate populations in areas surrounding fenced sites.
 122. Identify other extant populations and manage threats.
 123. Reduce human-related disturbance of silversword sites.
 1231. Post warning signs on fences.
 1232. Prepare and distribute news releases, posters, brochures and other educational materials.
 124. Map and monitor all individuals.
 1241. Map and monitor Waiakea individuals.
 1242. Map and monitor Keapohina individuals.

- 1243. Map and monitor all newly established individuals.
 - 125. Determine the effect of alien plants on Ka'u silversword growth and reproduction.
2. Develop a research program on the ecology of the Ka'u silversword.
 - 21. Determine the physiological and environmental factors affecting the habitat preferences of silverswords.
 - 22. Assess the factors limiting germination and seedling establishment.
 - 23. Assess factors influencing reproductive biology.
 - 24. Develop and implement techniques for genetic management, as needed.
 - 25. Research and monitor insect/disease damage
 - 26. Determine causes of pre-flowering mortality.
 - 27. Develop methods to reduce other threats to populations as needed.
 3. Re-establish the Ka'u silversword in areas of former abundance.
 - 31. Select sites to re-establish silverswords.
 - 311. Conduct ground surveys of Upper Waiakea Forest Reserve for intact open bogs and grassy kipukas suitable for re-establishing silverswords.
 - 312. Choose sites on Kahuku Ranch and in the Kapapala Forest Reserve.
 - 313. Consider re-establishment sites in other areas of the historical range.
 - 32. Protect new sites.
 - 33. Control ungulates at new sites.

- 331. Construct and maintain fencing at new sites.
- 332. Reduce ungulate populations in areas around new sites.
- 34. Conduct a seeding program at the new sites.
 - 341. Implement cross-pollination for plants that will flower.
 - 342. Collect seeds from fruiting individuals in each population.
 - 343. Develop methods to maintain seed viability until seed is used in seeding or outplanting programs.
 - 344. Seed at chosen sites.
 - 3441. Choose microsites to be seeded based on knowledge of factors limiting germination and establishment.
 - 3442. Seed protected sites.
 - 3443. Monitor seeded sites and record germination and establishment results.
 - 345. Review seeding success annually and change methods as needed to enhance germination and establishment in protected sites.
- 35. If necessary, transplant nursery grown seedlings to re-establishment sites.
 - 351. Determine best methods for greenhouse propagation of the Ka'u silversword.
 - 352. Propagate silverswords for transplant into reintroduction sites.
 - 353. Transplant to re-establishment areas.
 - 3531. Choose appropriate microsites for outplanting.
 - 3532. Outplant seedlings.

- 3533. Monitor outplanting sites, record survival results, and re-plant if necessary.
 - 354. Review outplanting success annually and change methods as needed to enhance survival.
4. Enhance current populations.
- 41. Develop a plan to enhance Ka‘u silversword populations.
 - 411. Select sites to be enhanced.
 - 4111. Determine if enhancement is needed.
 - 4112. Identify areas to expand.
 - 412. Spread seed.
 - 413. Transplant seedlings if necessary.
 - 414. Monitor success of seeding and transplanting.
 - 415. Maintain records of all enhancement activities.
5. Periodically re-evaluate recovery objectives.
- 51. Estimate the number of individuals required for long term survival.
 - 52. Estimate the number of populations needed for long term survival.
 - 53. Revise recovery objectives.

C. STEP-DOWN NARRATIVE

1. Protect and manage existing populations of the Ka‘u silversword.

Current populations should be protected, and threats to them should be controlled.

11. Protect habitat on Kahuku Ranch, in the Waiakea Forest Reserve, at Volcanoes National Park and in other areas of Mauna Loa.

Ka‘u silversword habitat must be secured in perpetuity through agreements with the owners of current habitat, and through consideration of a Mauna Loa wildlife and plant preserve. The creation of a large State Natural Area Reserve or a U.S. Fish and Wildlife Refuge that includes part of Kahuku Ranch including Keapohina from the border of the Ka‘u Forest Reserve to about 3,100 meters (10,000 feet), Ka‘u Forest Reserve and Kapapala Forest Reserve, would be one of the most effective ways to preserve the Ka‘u silversword and provide an undisturbed and protected natural environment for recovery of the species. The designated area would need to be fenced and ungulates totally eliminated within the preserve. The preserve would not only protect the current and former habitat of the Ka‘u silversword and allow it to recover in its original range, but also the habitat of several endangered birds, including the Hawaiian goose, Nesochen (Branta) sandvicensis (Nene), Hawaiian hawk, Buteo solitarius (‘Io), ‘Akiapola‘au, Hemignathus munroi, Hawai‘i creeper, Oreomystis mana, ‘Akepa, Loxops coccineus, and nesting sites of the dark-rumped petrel, Pterodroma phaeopygia sandwichensis (‘Ua‘u). Mesic o‘hia forests and mountain parkland habitats on Mauna Loa would also be protected, including the rare plants identified in Table 3.

111. Secure habitat on Kahuku Ranch.

Negotiate with Damon Estate for management of Ka‘u silversword habitat via a long-term easement, cooperative agreement, lease or fee purchase.

112. Secure habitat in the Upper Waiakea and Kapapala Forest Reserves.

Negotiate an agreement with DLNR for long-term protection and management of Ka‘u Silversword habitat in these areas.

113. Secure habitat in Volcano National Park.

An agreement should be reached with the National Park Service for implementation of management actions in Hawaii Volcanoes National Park.

12. Manage habitat.

Ka'u silversword habitat must be actively managed to control threats to the population. For each population, a management plan that includes the following actions should be developed and implemented:

121. Control ungulates at current sites.

The three known populations of the Ka'u silversword must be immediately protected from feral and domestic ungulates. No other recovery efforts outlined here will be possible, and the Ka'u silversword will certainly become extinct, if the threat of browsing and rooting animals is not immediately removed from all extant populations. Although all three populations of silverswords are currently protected by fences, fencing may not be adequate to keep out mouflon sheep. The populations are very small, and further disturbance or loss of individuals to browsing or rooting animals only increases the chance of extinction of the silversword.

1211. Enhance and maintain fencing at current sites.

The current fencing at all three sites is not adequate to keep out all feral ungulates, and should be enhanced. Plans for regular maintenance should be made.

12111. Enhance and maintain fencing at Keapohina.

Fencing must be raised and anchored at Keapohina to prevent the entry of feral pigs and mouflon sheep to the silversword site. Regular maintenance must be scheduled. Fencing may also need to be expanded if the current enclosure is deemed insufficient for natural expansion of the population.

12112. Enhance, enlarge and maintain fence in Upper Waiakea Forest Reserve.

The fenced area in Upper Waiakea Forest Reserve should be enlarged to include the entire bog site, as well as the adjacent bog, and needs to be increased in height to prevent the entry of mouflon sheep. Regular maintenance should be scheduled.

1212. Eradicate or reduce ungulate populations in areas surrounding fenced sites.

Eradication or reduction of browsing and rooting animals is essential. Reduction of ungulate populations in the vicinity of silverswords, combined with the fencing of the plant populations, will afford a degree of protection to extant silverswords in the short term. However, fences cannot permanently protect the silverswords because fences fall or decay, remnant animals reproduce, and animals migrate into the site from other areas. As long as ungulates are a threat to the silversword, fences will need to be frequently inspected and maintained, and animals will need to be hunted to keep ungulate populations at a minimum. The effort to maintain fences and continually keep animal populations under control may be greater than if animals are eradicated initially.

Ultimately, one of the most important tasks to protect the Ka'u silversword from extinction will be to permanently remove all ungulates from the silversword's current and former range. Ungulates degrade all Hawaiian ecosystems in which they occur (Cuddihy and Stone 1990). Browsing and grazing animals remove native plants, including tree and shrub species, causing the composition of vegetation to change rapidly. Alien plants spread in areas disturbed by ungulates and, depending on the severity of the disturbance, may totally replace the native vegetation. In some habitats, the changes caused by feral and domestic ungulates may become permanent: climate and soils are altered, native plant species are outcompeted by aggressive alien plant species and native plant species become extinct (Cuddihy and Stone 1990). Restoration of such habitats may be prohibitively expensive or impossible (Jacobi and Scott

1985). Currently, much of the upland parkland of Mauna Loa at Keapohina, and forest systems in the Upper Waiakea Forest Reserve are dominated by native vegetation (Jacobi and Scott 1985). If mouflon sheep and feral pigs are not removed from these environments, the remaining native forests and parklands of Mauna Loa may become severely damaged within a short period of time. In the mesic o'hia forests and mountain parkland of subalpine and alpine Mauna Loa, the benefits of ungulate eradication would extend beyond the immediate protection of the Ka'u silversword to the preservation of the entire native forest ecosystem and watershed on Mauna Loa.

122. Identify other extant populations and manage threats.

Individual plants or pockets of remnant populations may still exist on Kahuku Ranch, and in the Kapapala and Upper Waiakea Forest Reserves, and discovery and management of such populations would help to reach the downlisting goal of 10 populations. Thorough ground searches need to be made of areas where silverswords may still exist. Any plants or populations discovered from these searches must be immediately protected from ungulates by appropriate fencing and included in other management tasks. Fencing should be sufficient to exclude feral ungulates and should include areas large enough to allow for natural silversword population expansion. Regular maintenance should be scheduled.

123. Reduce human-related disturbance of silversword sites.

Human-related disturbances to silverswords have probably been minimal in the past. However, excessive trampling of sites where seedlings are abundant should be minimized. This is especially true in the Upper Waiakea bog site, since bogs are sensitive to changes caused by trampling, and because tiny silversword seedlings are difficult to see. Signs should be posted on the fence lines at both sites prohibiting entry to the enclosure. Entry should be restricted to persons involved in silversword restoration and research. The creation of trails and roads, and the clearing of areas near silverswords may increase the number and abundance of alien weeds that may adversely affect silversword regeneration and establishment. These

activities should be prevented. Any activity that increases the hazard of fire should also be prevented.

In order to gain support for recovery efforts for the Ka'u silversword and to inform the public of the need to preserve endangered Hawaiian species, a public education program should be initiated. The program should focus on local people, legislators, government agencies, civic and service groups, and landowners.

1231. Post warning signs on fences.

Restricted entry signs should be prominently displayed on fencing, and should briefly explain the need for the restriction.

1232. Prepare and distribute news releases, posters, brochures and other educational materials.

Materials suitable for distribution to the media, schools, various service groups, government agencies, legislators, and the public should be prepared. Television and radio programs, magazine and newspaper articles, videos, films, brochures, posters, displays, and pamphlets could all be used to inform the public about the Ka'u silversword in particular, and the endangered Hawaiian biota in general. The education of both children and adults on conservation issues in Hawai'i is vitally important (Gagné and Gill 1989; Stone and Machlis 1989).

Displays focusing on endangered Hawaiian plants, including the Ka'u silversword, could be produced and exhibited in places frequented by local people. Such places could include airports, shopping centers, parks, botanic gardens, museums, and National Park visitor centers. Because of the possibility of vandalism or unauthorized collection, care should be taken to avoid releasing site specific information.

124. Map and monitor all individuals.

Long-term monitoring will be necessary to keep track of recovery and should expand to include new individuals and

populations as they are discovered or established. Monitoring should also include observations on ungulate and insect damage, encroachment of alien plants, and condition of fence or other protective barriers. Monitoring at each site will likely be conducted by different individuals. Researchers should ensure that their counting and measuring methodologies are comparable.

1241. Map and monitor Waiakea individuals.

Detailed counts and rosette diameter measurements of all plants should be made annually or every 2 years, as needed. Extreme care must be taken not to harm or trample tiny seedlings. Well-established plants (≥ 12 centimeters in rosette diameter) should be mapped (or tagged) for future record-keeping. Plants that appear likely to flower within the next few years (rosette diameter ≥ 30 centimeters) should be noted and monitored closely for flowering (see Task 341).

1242. Map and monitor Keapohina individuals.

See narrative under task # 1241.

1243. Map and monitor all newly established individuals.

New individuals that are found or established through natural regeneration, re-establishment of populations, or augmentation should also be monitored.

125. Determine the effect of alien plants on Ka'u silversword growth and reproduction and control if necessary.

Alien plants may be a threat to the Ka'u silversword. Alien plants already occur within the silversword site in the Upper Waiakea Forest Reserve. The effect these plants have on the growth and reproduction of the Ka'u silversword is unknown. Research aimed at determining the effect of these plants on silverswords should be conducted. Control of alien plants should only be undertaken if it has been determined that the presence of alien plants is more detrimental to the survival of the silversword than control of such plants would be. Herbicide spraying and trampling of sensitive bog habitats by persons

removing alien plants may cause more damage to silversword populations and habitats than the alien plants themselves.

2. Develop a research program on the ecology of the Ka'u silversword.

The ecology of the Ka'u silversword is mostly unknown. A research program focusing on those aspects of the ecology of the Ka'u silversword relevant to population augmentation and re-establishment should be started as soon as possible. The research program should include both field and greenhouse observations and experiments. The program must use the fewest possible seeds or plants of the Ka'u silversword, and be non-destructive of extant plants and silversword habitats.

21. Determine the physiological and environmental factors affecting the habitat preferences of silverswords.

The Ka'u silversword occupied three, or perhaps more, distinct habitats in the past. It is unknown whether the silverswords in each habitat were genetically differentiated, or whether the progeny of a Ka'u silversword that exists in one habitat could thrive in another. Seed from Keapohina was used to propagate plants that were planted in subalpine parkland in Hawai'i Volcanoes National Park, a site that is more arid than Keapohina. The plants grew and flowered in that habitat. However, it is unknown whether the population at Keapohina and the population in the Upper Waiakea Forest Reserve bog represent true ecotypes (or even varieties) of the Ka'u silversword. This question could be addressed by conducting reciprocal transplants of greenhouse-grown silverswords from each population into each habitat.

It is possible that the response of silverswords from different habitats may not be "symmetrical". For example, silverswords from the bog site in the Upper Waiakea Forest Reserve may not thrive in the mountain parkland of the Kapapala Forest Reserve, while silverswords from Keapohina do. These relationships need to be understood before cross-pollination, seeding, or outplanting programs are begun that could genetically mix the silverswords from either site. Genetic mixing between populations may be eventually necessary in a genetic management program, but it should be carefully determined that the resulting silverswords will be adapted to life in the variety of habitats in which the Ka'u silversword will be re-established.

Fog drip may be an important moisture source in dry areas, and experimental misting for establishing new individuals should be investigated.

22. Assess the factors limiting germination and seedling establishment.

In places where silverswords are artificially re-established, suitable conditions for seedling germination and establishment must be present. It is important to know what factors limit silversword regeneration in all of its habitats. Water appears to be a critical factor for the germination of the seeds of the Mauna Kea silversword (Powell, unpublished data), and the presence of sufficient water may also be critical for the establishment of Ka'u silverswords. The presence of sufficient water may be partially a result of the type of soil or microhabitat a seed encounters. In arid habitats, such as in the subalpine parkland of Kapapala Forest Reserve, water is probably more critical for silversword seedling establishment than in the wet forests and bogs of Kahuku Ranch and the Upper Waiakea Forest Reserve.

23. Assess the factors influencing reproductive biology.

The factors limiting seed set in the Ka'u silversword are also unknown. The pollinator spectrum at all three silversword sites should be studied. The life histories of the insect pollinators should also be understood, including any threats to the pollinator which may need to be controlled. Any changes that affect pollinator numbers or effectiveness can affect the ability of the silversword to reproduce in the long term. An investigation of the maximum distance between flowering individuals which will still allow for effective cross-pollination should be included in this study. In the short term, artificial cross-pollination can produce the seed needed for re-establishment and research programs, as well as increase the possibility of regeneration in the existing populations. In the long term, native insect pollinators will be needed to amply cross-pollinate flowering silverswords in both existing and re-established populations.

24. Develop and implement techniques for genetic management, as needed.

In self-incompatible plants such as the silversword, close relatedness between plants can mean that plants do not cross-fertilize, even if cross-pollinated. As a population becomes more inbred, reproduction can become increasingly difficult, or even cease altogether. The genetic diversity remaining in the two naturally-occurring populations is probably adequate to avoid inbreeding depression, provided cross-

pollination programs and re-establishment programs strive to use as many flowering plants as possible to generate seed (see Task 34).

A program of genetic management should be adopted if natural population sizes continue to decline before re-establishment is begun, or if a limited number of individuals is used for re-establishment programs. The entire population, or a large proportion of individuals, could be evaluated by random amplified polymorphic DNA (RAPD) techniques, which have been recently used for the Mauna Kea silversword (Friar et al. 1994).

25. Research and monitor insect/disease damage.

Native Tephritis sp. flies can damage seeds of the Ka'u silversword. However, these flies are associated with the Mauna Kea and Haleakala silverswords as well and probably co-evolved with silverswords. The effect of these flies on the Ka'u silversword is unknown and needs to be studied. The effects to the silversword of any non-native herbivorous insects or disease should be carefully noted and remedial actions taken in severe cases.

26. Determine causes of pre-flowering mortality.

Threats to the populations or to individuals will need to be evaluated periodically and methods to reduce such threats devised. Pre-flowering mortality of adult individuals is probably the greatest demographic threat to the populations. The causes of pre-flowering mortality should be determined and methods devised to reduce mortality as much as possible.

27. Develop methods to reduce other threats to populations as needed.

Current methods for controlling the known threats to the Ka'u silversword may prove to be inadequate, and other threats may be discovered as more information becomes available. Research projects addressing these issues should be initiated as needed.

3. Re-establish the Ka'u silversword in areas of former abundance.

The core of the recovery effort for the Ka'u silversword should focus on both removing threats and re-establishing plants in areas of former abundance. It will probably take several years to learn all that is needed about the ecology and propagation of the Ka'u silversword to formulate a realistic re-

establishment plan. In the meantime, what is known about other silverswords (particularly the Mauna Kea silversword) can be used to design a re-establishment program. The following tasks should be implemented in order to save as much of the remaining genetic diversity as possible, and to begin, as best we can, the re-establishment that is required to reach the downlisting objective of 10 populations with at least 2,000 individuals in each.

31. Select sites to re-establish silverswords.

Historical records of sightings and collections can be used to select sites in which to re-establish the Ka'u silversword. Sites should be chosen on the basis of their relative lack of disturbance and their potential ability to support silverswords. Sites should be chosen on Kahuku Ranch, in the Kapapala and Upper Waiakea Forest Reserves, and any other suitable areas within the historical range of the species, possibly including Hualalai. Sites that cover several hectares (perhaps 20 hectares or more) should be chosen over sites that cover less than 0.5 hectare, unless the smaller sites are more numerous, closely spaced, and less disturbed than the larger sites. Attention should also be given to decreasing the possibility of hybridization with other closely related species when choosing sites. Sites chosen for silversword re-establishment will need to be either seeded, outplanted, or both.

311. Conduct ground surveys of Upper Waiakea Forest Reserve for intact open bogs and grassy kipukas suitable for reestablishing silverswords.

The Upper Waiakea Forest Reserve should be surveyed for intact bogs that may support the silversword. Sites chosen in the Upper Waiakea Forest Reserve should be wet, open bogs, dominated by native grasses and sedges. Intact Sphagnum beds must be present.

312. Choose sites on Kahuku Ranch and in the Kapapala Forest Reserve.

Sites chosen on Kahuku Ranch should include large portions or entire kipukas of open mesic o'hia forest at proper elevations. Sites in the Kapapala Forest Reserve should be close to where silverswords had been sighted or collected in the past.

313. Consider re-establishment sites in other areas of the historical range.

Silversword re-establishment in other areas of the historical range should also be considered. Although it is uncertain whether the Ka'u silversword occurred on Hualalai Mountain, silverswords of an undetermined species did occur there in historic times. A complete search of Hualalai for extant silverswords should be made and any discovered plants positively identified to species before silverswords are re-established on Hualalai.

32. Protect new sites.

Sites for new populations should be protected through purchase or agreement with the landowners.

33. Control ungulates at new sites.

Ungulates at the new sites should be controlled through fencing and hunting.

331. Construct and maintain fencing at new sites.

All sites chosen for re-establishing silverswords will need to be fenced from feral pigs, goats, cattle and mouflon sheep. The entire bog or kipuka that is chosen should be fenced. Fencing in every case should cover as much of the habitat site as possible and be as non-destructive to the bog or forest habitat as possible. Larger areas in open habitats should be fenced, whereas, in more forested habitats, smaller fenced areas may be adequate in the short term. Fences will need to be regularly inspected and maintained. Animals that enter fenced sites will need to be immediately eliminated or removed. Dispersal of silversword seeds is not restricted by fenced boundaries, and plants that could have potentially established in a site may be destroyed by feral animals in incompletely fenced sites. Fencing many small sites versus large tracts will inhibit the ability of the silversword to maintain a genetically diverse population. Small populations that are sufficiently isolated from other such populations will eventually become inbred, particularly if the genetic diversity of the founding individuals of the population is small. A viable population able to survive the

inevitable unpredictable events of the future will need to be genetically diverse and widespread.

332. Reduce ungulate populations in areas around new sites.

See narrative under task # 1212.

34. Conduct a seeding program at the new sites.

In order to re-establish the Ka'u silversword in its historical range, seed will need to be produced and collected from the current populations, stored and then planted into suitable microsites. This will be accomplished by implementing a carefully conducted program of cross-pollination, seed collection, storage and planting.

The cross-pollination program would begin with annual visits to the Waiakea, Keapohina and Volcano populations, and later, to any newly established (or discovered) populations, to note growth and the possibility of flowering. This information should be collected during the annual monitoring visits described in Task 124, thus minimizing unnecessary site visits.

341. Implement cross-pollination for plants that will flower.

When plants in each population or site reach about 35 centimeters (14 inches) or larger, flowering may occur the following year. Flowering usually occurs in July and early August. Annually, in June, and perhaps weekly from late May to early July, flowering size plants should be visited. If flowering is certain or likely to occur, plans must be made to cross-pollinate the flowering silversword with other flowering plants in the population and to ultimately collect ripe fruits. Cross-pollinations should be carefully planned. Unless results of Task 21 indicate otherwise, cross-pollination should occur within populations rather than between them. The goal for creating seed for re-establishment should always be to produce as genetically diverse seed as possible. As many of the plants flowering each year as possible should be involved in the cross-pollination. Each plant should act as both male and female during cross-pollination, if possible. If only two plants flower, all seeds produced from cross-pollination will be genetic siblings. If only three plants flower in a population in a single season, all the seeds produced will be genetic half-siblings. Seeds representing only genetic siblings and half-siblings should

be separately stored, labeled and used in conjunction with seeds collected in other seasons. It will also be important to keep track of the success of different genotypes. This task is not broken down into separate tasks for each population due to the likelihood that the same group of trained individuals will be conducting cross-pollinations at all three sites.

342. Collect seeds from fruiting individuals in each population.

Seed resulting from cross-pollinations should be collected as needed for use in re-establishment. Care should be taken to leave an adequate amount of seed for regeneration. The collected seed can also provide a short term back-up for a portion of the genetic diversity in each population in case of catastrophic loss.

Fruits should be collected from cross-pollinated and from naturally pollinated flowering plants in the population. Fruits should be ripe, but not yet dispersed, when gathered. Fruits may be ready for collection in early September to early October. Populations will need to be visited weekly during this period so that fruits can be collected at the correct time. Fruits will need to be stored so that long-term viability is maximized.

343. Develop methods to maintain seed viability until seed is used in seeding or outplanting programs.

Fruits of the Mauna Kea silversword have remained viable for several years when kept dry and refrigerated (Powell, unpublished data). The methods that yield the largest number of established Ka'u silversword plants will need to be developed.

344. Seed at chosen sites.

Large populations that will have over 500 adult plants (greater than 18 centimeters in rosette diameter) should be established in each site. Silverswords should be planted in large clusters or bands that are connected to other clusters or bands, if at all possible. Isolated plants or clusters may not cross-pollinate. However, if the genetic variability in each re-established cluster or population is high, isolated clusters and populations may be capable of persisting. Strict measures to guard against the introduction of alien plants, insects and pathogens to the populations must be followed.

Accurate records of sites, genetic stock used, methods used and success of seeding are essential. Seeded sites should be monitored monthly for germination and establishment. Seeding methods that minimize outplant mortality will need to be devised. In order to create a population structure that approaches the natural one, this task should continue for a minimum of 10 years.

3441. Choose microsites to be seeded based on knowledge of factors limiting germination and establishment.

Seeding microsites should be chosen carefully, given knowledge of factors limiting germination and establishment. In bog sites, Sphagnum beds should be seeded. In other sites, a careful assessment and identification of moist microsites will probably be needed for seeding success. This task should be conducted as a prerequisite to seeding every year, since microsite conditions may shift from year to year.

3442. Seed protected sites.

Place seed in chosen microsites in enclosed re-establishment areas. Optimal planting season needs to be determined, but the wetter part of the year is likely best.

3443. Monitor seeded sites and record germination and establishment results.

Monitor seeded sites monthly and record germination and establishment results. Accurate records should be kept, in order to evaluate the success of the program.

345. Review seeding success annually and change methods as needed to enhance germination and establishment in protected sites.

Methods will need to be constantly evaluated and changed to compensate for environmental changes, unexpected events, variation in habitats, and other problems that may arise. The generation time of the Ka'u silversword may be about 20 years. It may take 15 years or more from the time a re-establishment

program is initiated until plants reach flowering size. During that period of time, detailed monitoring of seeding success should reveal problems in re-establishment such as: the site chosen may be poor, seeding may have occurred too early or too late in a season, seed may have been of inferior quality, or plants involved in cross-pollination may have been genetically related. The overall success of seeding should be re-evaluated annually, and methods changed, as needed, to produce the greatest number of established seedlings.

35. If necessary, transplant nursery grown seedlings to re-establishment sites.

Greenhouse growing and outplanting of silverswords is expensive and time consuming. In addition, the greenhouse may artificially select for genotypes that grow best in the greenhouse environment (Powell 1992a), but may not survive best in natural environments. However, growing silverswords in the greenhouse may generate more live plants for fewer available seeds than *in situ* seeding. The Mauna Kea silversword was re-established at Waipahoehoe from outplants (Powell 1992a).

The Ka'u silversword may need to be propagated for re-introduction if after several years, seeding efforts are unsuccessful, or appear unlikely to allow achievement of recovery goals within a reasonable amount of time. Greenhouse propagation and outplanting, if conducted, would require the development of propagation and monitoring programs, choice of microsites for transplants, maintenance of accurate records and periodic review of methods and their success. Outplanting may need to continue over 10 or more years to obtain the population size and structure desired.

351. Determine best methods for greenhouse propagation of the Ka'u silversword.

Information gained from the propagation of the Mauna Kea silversword may be useful in Ka'u silversword propagation, but species-specific information is also needed.

352. Propagate silverswords for transplant into re-introduction sites.

Seed for propagated plants would be produced using the same cross-pollination techniques described in Task 34, to maximize

genetic diversity. Sufficient numbers of plants for transplantation and replacement of failed transplants would be necessary.

353. Transplant to re-establishment areas.

A successful transplant effort will require choosing appropriate microsites, monitoring sites for survival of transplants, and keeping careful records of all outplantings and results.

3531. Choose appropriate microsites for outplanting.

See narrative under task # 3451.

3532. Outplant seedlings.

Transplant nursery grown plants into chosen microsites, using experience gained from Mauna Kea silversword transplant. Silverswords should be outplanted during periods of precipitation rather than during dry periods. Plants need to be at least 20 centimeters (8 inches) in rosette diameter when outplanted. Outplants may need to be watered and/or treated with root growth-stimulating hormones to prevent transplant shock. Extreme caution must be used to avoid introducing alien plants or insects, diseases or other pathogens into the populations when transplanting. Accurate records of all outplanting activities and results should be kept in order to evaluate the success of the program.

3533. Monitor outplanting sites, record survival results, and re-plant if necessary.

Monitor outplanting sites monthly and record survival results. Any transplants that do not survive to maturity should be replaced with genetically similar nursery-grown plants, unless the genotype proves to be poorly adapted to the location.

354. Review outplanting success annually and change methods as needed to enhance survival.

Methods will need to be constantly evaluated and changed to compensate for environmental changes, unexpected events,

variation in habitats, and other problems that may arise. The overall success of transplanting efforts should be re-evaluated annually, and methods changed, as needed, to produce the greatest number of established plants.

4. Enhance current populations.

It is hoped that the control of current threats will allow enough natural regeneration for recovery to take place. However, if the populations do not reproduce sufficiently on their own, artificial augmentation may be necessary. In order to reduce the possibility of introducing insects, alien plants or pathogens into the wild populations, scattering seed in good microsites should be emphasized. Outplanting of nursery raised seedlings should only be done as a last resort and under strict guidelines that eliminate the possibility of introducing alien plants, insects or pathogens into the wild populations. The artificially established population at Volcano National Park is on land outside the known historical range of the species, and is not suitable as a site for augmentation and/or establishing new subpopulations.

41. Develop a plan to enhance Ka'u silversword populations.

If needed, a detailed population enhancement plan that addresses the specific genetic stock to be used and the precise location of all seeding and or transplanting should be developed when enough information of the site-specific needs of this species has been obtained.

411. Select sites to be enhanced.

The Waiakea and/or Keapohina sites may need to be enhanced if sufficient natural generation does not occur. Any others that are discovered should be evaluated and included in enhancement plans if necessary.

4111. Determine if enhancement is needed.

If the populations do not increase successfully on their own, the possibility of enhancement should be studied. A careful review of all the potential problems associated with enhancement must be conducted before the decision to begin can be made.

4112. Identify areas to expand.

Specific areas for seeding/and or transplantation of nursery raised stock within the Waiakea and/or Keapohina exclosures should be identified if enhancement is necessary.

412. Spread seed.

Once microsites have been chosen, seeding should begin, using methodologies indicated in Task 3.

413. Transplant seedlings, if necessary.

If absolutely necessary, outplanting of nursery raised plants can be done, in one or both natural populations, using techniques indicated in Task 35.

414. Monitor success of seeding and transplanting.

Seeding and transplant sites should be monitored monthly, and results recorded.

415. Maintain records of all enhancement activities.

Careful records of the source of seeds and nursery grown plants as well as the location and success of plantings should be maintained.

5. Periodically re-evaluate recovery objectives.

An important role for research is to re-evaluate the stated recovery objectives in this plan. Recovery objectives may need to be changed and methods altered as information becomes available about the Ka'u silversword.

51. Estimate the number of individuals required for long term survival.

Methods to evaluate the viability of a silversword population need to be devised for the Ka'u silversword. A growing population should show a net increase in number of plants over time; however, the population structure should also be stable. A population that is increasing in net numbers, but is declining in the number of pre-flowering adults, may be in danger of extinction. Population structure stability and population

growth of silverswords can be analyzed using transition matrix models (Powell 1992a). Transition matrix models can be used to predict long-term population decline or increase using short-term demographic data. These models use the current population structure and the probability of each individual plant making the transition from one life or growth stage to another to predict the future of the population. These simple models can also be used to identify sensitive stages of the life cycle and identify the amount of regeneration needed to produce the amount of growth or the population stability desired.

Silverswords probably originally occurred in populations that grew slowly, if at all. The entire species was probably made up of a number of dynamic populations. Some populations probably declined in numbers, while others increased or remained the same. However, re-established populations of the Ka'u silversword should show slow natural increase over time. Ka'u silversword densities can be compared to densities reported for the Haleakala silversword (Loope and Crivellone 1986) and the Eke silversword (Powell 1992b).

52. Estimate the number of populations needed for long term survival.

A model of the number of populations needed to safeguard against long term catastrophic events should be constructed.

53. Revise recovery objectives.

Recovery objectives should be revised if new information suggests that the current objectives are inadequate.

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III. IMPLEMENTATION SCHEDULE

The Implementation Schedule that follows outlines actions and estimated cost for the Ka'u silversword recovery program, as set forth in this recovery plan. It is a guide for meeting the objectives discussed in Part II of this Plan. This schedule indicates task priority, task numbers, task descriptions, duration of tasks, the agencies responsible for committing funds, and lastly, estimated costs. The agencies responsible for committing funds are not, necessarily, the entities that will actually carry out the tasks. When more than one agency is listed as the responsible party, an asterisk is used to identify the lead entity.

The actions identified in the implementation schedule, when accomplished, should protect habitat for the species, stabilize the existing populations and increase the population sizes and numbers of the Ka'u silversword. Monetary needs for all parties involved are identified to reach this point.

Priorities in Column 1 of the following implementation schedule are assigned as follows:

- Priority 1 - An action that must be taken to prevent extinction or to prevent the species from declining irreversibly.
- Priority 2 - An action that must be taken to prevent a significant decline in species population/ habitat quality, or some other significant negative impact short of extinction.
- Priority 3 - All other actions necessary to provide for full recovery of the species.

Key to Acronyms Used in Implementation Schedule

- ES - U.S. Fish and Wildlife Service, Ecological Services, Honolulu, Hawaii
- DOFAW - Hawaii Department of Land & Natural Resources, Division of Forestry and Wildlife
- DAMON - Damon Estate
- NBS - National Biological Survey
- NPS - National Park Service, Hawaii Volcanoes National Park

Key to Other Codes Used in Implementation Schedule

- C - Continuous task
- O - Ongoing (already begun as of writing of plan)
- TBD - To be determined

Recovery Plan Implementation Schedule for the Ka'u silversword

PRIOR- ITY #	TASK #	TASK DESCRIPTION	TASK DURA- TION (YRS)	RESPONSIBLE PARTY	TOTAL COST	COST ESTIMATES (\$1,000'S)						
						FY 1996	FY 1997	FY1998	FY 1999	FY 2000	FY 2001	FY 2002

Secure habitat:

1	111	Secure habitat on Kahuku Ranch	2	* ES DAMON	0.5 0.5		0.25 0.25	0.25 0.25				
1	112	Secure habitat in Waiakea and Kapapala Forest Reserves	2	* ES DOFAW	0.5 0.5		0.25 0.25	0.25 0.25				
1	113	Secure habitat in Volcano National Park	2	* ES NPS	0.5 0.5		0.25 0.25	0.25 0.25				

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Manage habitat:

1	12111	Enhance and maintain fencing at Keapohina	C	* DOFAW ES DAMON	26 26 10			10 10 2	1 1 0.5	1 1 0.5	1 1 0.5	1 1 0.5
1	12112	Enhance and maintain Waiakea fencing	C	* DOFAW ES	27 27		10 10	1 1	1 1	1 1	1 1	1 1
1	1212	Eradicate feral ungulates in areas around exclosures	C	* DOFAW ES DAMON	95 95 19	5 5 1	5 5 1	5 5 1	5 5 1	5 5 1	5 5 1	5 5 1
1	122	Identify other extant populations and manage threats	C	* DOFAW ES	30 30			15 15	15 15	TBD TBD		
1	1241	Map and monitor Waiakea individuals	C	* DOFAW ES	9.5 9.5			1 1	0.5 0.5	0.5 0.5	0.5 0.5	0.5 0.5

Recovery Plan Implementation Schedule for the Ka'u silversword

PRIOR- ITY #	TASK #	TASK DESCRIPTION	TASK DURA- TION (YRS)	RESPONSIBLE PARTY	TOTAL COST	COST ESTIMATES (\$1,000'S)						
						FY 1996	FY 1997	FY1998	FY 1999	FY 2000	FY 2001	FY 2002
1	1242	Map and monitor Keapohnia individuals	C	* DOFAW	9.5		1	0.5	0.5	0.5	0.5	0.5
				ES	9.5		1	0.5	0.5	0.5	0.5	0.5
				DAMON	2.2		0.5	0.1	0.1	0.1	0.1	0.1
1	1243	Map and monitor newly established individuals	C	* DOFAW	TBD							
				ES	TBD							
1	125	Determine effect of alien plants on the Ka'u silversword	C	* DOFAW	180		10	10	10	10	10	10
				NPS	36		2	2	2	2	2	2
				ES	18		1	1	1	1	1	1
2	1231	Post warning signs on fences	1	* DOFAW	0.5		0.5					
				ES	0.5		0.5					
				DAMON	0.5		0.5					
3	1232	Prepare and distribute educational materials	2	* DOFAW	2		1	1				
				ES	2		1	1				
		NEED 1 (Secure and manage current sites)			667.7	11	53.5	83.6	60.6	30.6	30.6	30.6
2	21	Determine the environmental factors affecting habitat preference	10	* DOFAW	20		2	2	2	2	2	2
				NBS	140		14	14	14	14	14	14
				ES	10		1	1	1	1	1	1
2	22	Assess the factors limiting germination and establishment	10	* DOFAW	20		2	2	2	2	2	2
				NBS	140		14	14	14	14	14	14
				ES	10		1	1	1	1	1	1
2	23	Assess the factors influencing reproductive biology	10	* DOFAW	20		2	2	2	2	2	2
				NBS	140		14	14	14	14	14	14
				ES	10		1	1	1	1	1	1

Recovery Plan Implementation Schedule for the Ka'u silversword

PRIOR- ITY #	TASK #	TASK DESCRIPTION	TASK DURA- TION (YRS)	RESPONSIBLE PARTY	TOTAL COST	COST ESTIMATES (\$1,000'S)						
						FY 1996	FY 1997	FY1998	FY 1999	FY 2000	FY 2001	FY 2002
2	24	Develop genetic management techniques as needed	5	* NBS	35		7	7	7	7	7	
				* DOFAW	5		1	1	1	1	1	
				ES	2.5		0.5	0.5	0.5	0.5	0.5	
2	25	Research /monitor insect and disease damage	5	* DOFAW	35		7	7	7	7	7	
				NBS	5		1	1	1	1	1	
				ES	2.5		0.5	0.5	0.5	0.5	0.5	
2	26	Determine causes of pre-flowering mortality	10	* DOFAW	70		7	7	7	7	7	7
				NBS	10		1	1	1	1	1	1
				ES	5		0.5	0.5	0.5	0.5	0.5	0.5
2	27	Develop methods to reduce other threats, as necessary	5	* DOFAW	TBD			TBD				
				NBS	TBD			TBD				
				ES	TBD			TBD				
		NEED 2 (Conduct essential research)			680	0	76.5	76.5	76.5	76.5	76.5	59.5
2	311	Choose sites in the Upper Waiakea Forest Reserve	1	* DOFAW	5			5				
				ES	5			5				
2	312	Choose sites on Kahuku Ranch and in Kapapala Forest Reserve	1	* DOFAW	10				10			
				ES	10				10			
2	313	Consider sites in other areas of the historical range	1	* DOFAW	10				10			
				ES	10				10			
2	32	Protect the new sites	2	* ES	5			2.5	2.5			
				DOFAW	5			2.5	2.5			
				DAMON	5			2.5	2.5			

Recovery Plan Implementation Schedule for the Ka'u silversword

PRIOR- ITY #	TASK #	TASK DESCRIPTION	TASK DURA- TION (YRS)	RESPONSIBLE PARTY	TOTAL COST	COST ESTIMATES (\$1,000'S)							
						FY 1996	FY 1997	FY1998	FY 1999	FY 2000	FY 2001	FY 2002	
2	331	Construct and maintain fencing at new sites	2	* DOFAW ES DAMON	TBD TBD TBD				TBD TBD TBD				
2	332	Reduce ungulate populations through hunting	C	* DOFAW ES DAMON	TBD TBD TBD				TBD TBD TBD				
2	341	Implement cross-pollination for plants that will flower	10	* DOFAW ES	10 10		1 1	1 1	1 1	1 1	1 1	1 1	1 1
2	342	Collect ripe seed from fruiting plants in each population	10	* DOFAW ES	10 10		1 1	1 1	1 1	1 1	1 1	1 1	1 1
2	343	Develop methods for seed storage	3	* DOFAW ES	6 6		2 2	2 2	2 2				
2	3441	Choose microsites to be seeded	10	* DOFAW ES	5 5				0.5 0.5	0.5 0.5	0.5 0.5	0.5 0.5	0.5 0.5
2	3442	Seed protected sites	10	* DOFAW ES	100 20				10 2	10 2	10 2	10 2	10 2
2	3443	Monitor seeded sites and record success	C	* DOFAW ES	16 8				1 0.5	1 0.5	1 0.5	1 0.5	1 0.5
2	345	Review seeding success and change methods, as necessary	C	* DOFAW ES	7.5 7.5					0.5 0.5	0.5 0.5	0.5 0.5	0.5 0.5

Recovery Plan Implementation Schedule for the Ka'u silversword

PRIOR- ITY #	TASK #	TASK DESCRIPTION	TASK DURA- TION (YRS)	RESPONSIBLE PARTY	TOTAL COST	COST ESTIMATES (\$1,000'S)						
						FY 1996	FY 1997	FY1998	FY 1999	FY 2000	FY 2001	FY 2002
2	351	Determine best methods for greenhouse propagation	5	* DOFAW	25		5	5	5	5	5	
				NBS	25		5	5	5	5	5	
2	352	Propagate plants for re-establishment	10	* DOFAW	200			20	20	20	20	20
				ES	20			2	2	2	2	2
2	3531	Choose microsites for outplanting	10	* DOFAW	5				0.5	0.5	0.5	0.5
				ES	5				0.5	0.5	0.5	0.5
2	3532	Outplant seedlings	10	* DOFAW	100				10	10	10	10
				ES	20				2	2	2	2
2	3533	Monitor outplanted sites and record success	C	* DOFAW	16				1	1	1	1
				ES	8				0.5	0.5	0.5	0.5
2	354	Review outplanting success and change methods, as necessary	C	* DOFAW	7.5					0.5	0.5	0.5
				ES	7.5					0.5	0.5	0.5
NEED 3 (Re-establish in former range)					725	0	48	67.5	76.5	67	67	57
2	4111	Determine need to enhance current populations	1	* DOFAW	5							
				ES	2							
2	4112	Identify specific areas to expand	1	* DOFAW	TBD							
				ES	TBD							

Recovery Plan Implementation Schedule for the Ka'u silversword

PRIOR- ITY #	TASK #	TASK DESCRIPTION	TASK DURA- TION (YRS)	RESPONSIBLE PARTY	TOTAL COST	COST ESTIMATES (\$1,000'S)						
						FY 1996	FY 1997	FY1998	FY 1999	FY 2000	FY 2001	FY 2002
2	412	Spread seed	10	* DOFAW ES	TBD TBD							
2	413	Transplant seedlings if necessary	10	* DOFAW ES	TBD TBD							
2	414	Monitor success of seeding and transplanting	C	* DOFAW ES	TBD TBD							
2	415	Maintain records of all enhancement activities	C	* DOFAW ES	TBD TBD							
		NEED 4 (Enhance current populations)			7	0	0	0	0	0	0	0
3	51	Estimate # of plants & populations needed for long term survival	3	* NBS DOFAW ES	6 6							
3	52	Revise recovery objectives	1	* ES DOFAW	1 1							
		NEED 5 (Validate recovery objectives)			14	0	0	0	0	0	0	0
TOTAL COST					2086.7	11	178	227.6	213.6	174.1	174.1	147.1

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