RECOVERY PLAN

MAUNA KEA SILVERSWORD

Argyroxiphium sandwicense ssp. sandwicense

U.S. Fish and Wildlife Service
Pacific Region
Portland, Oregon
January, 1994

RECOVERY PLAN FOR THE

MAUNA KEA SILVERSWORD

(ARGYROXIPHIUM SANDWICENSE SSP. SANDWICENSE)

Region 1
U.S. Fish and Wildlife Service
Portland, Oregon

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The recovery plan for the Mauna Kea silversword was prepared by Elizabeth Powell, P.O. Box 21491, U.P.R. Station, San Juan, Puerto Rico 00931-1491.

THIS IS THE COMPLETED RECOVERY PLAN FOR THE MAUNA KEA SILVERSWORD (ARGYROXIPHIUM SANDWICENSE SSP. SANDWICENSE). IT DELINEATES REASONABLE ACTIONS THAT ARE BELIEVED TO BE REQUIRED TO RECOVER AND/OR PROTECT THE SPECIES. OBJECTIVES WILL BE ATTAINED AND ANY NECESSARY FUNDS MADE AVAILABLE SUBJECT TO BUDGETARY AND OTHER CONSTRAINTS AFFECTING THE PARTIES INVOLVED, AS WELL AS THE NEED TO ADDRESS OTHER PRIORITIES. THIS RECOVERY PLAN DOES NOT NECESSARILY REPRESENT OFFICIAL POSITIONS OR APPROVALS OF THE COOPERATING AGENCIES, AND IT DOES NOT NECESSARILY REPRESENT THE VIEWS OF ALL INDIVIDUALS WHO PLAYED A ROLE IN PREPARING THE PLAN. IT IS SUBJECT TO MODIFICATION AS DICTATED BY NEW FINDINGS, CHANGES IN SPECIES STATUS, AND COMPLETION OF TASKS DESCRIBED IN THE PLAN.

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EXECUTIVE SUMMARY FOR THE MAUNA KEA SILVERSWORD RECOVERY PLAN

Current Species Status: The Mauna Kea silversword (*Argyroxiphium sandwicense* ssp. *sandwicense*) is federally listed as endangered without critical habitat. In 1991, the total population was estimated at 495 individuals, of which about 38 were naturally occurring.

Habitat Requirements and Limiting Factors: The Mauna Kea silversword is endemic to the alpine areas of Mauna Kea volcano on the island of Hawai'i. It historically occurred in several distinct vegetational and climatic zones: barren alpine cinder desert; scrub desert; original tree line of Mauna Kea, now alpine scrub with a number of native shrubs; and open māmane forest. Browsing and rooting by feral ungulates and the population's small size are the major threats to the silversword's survival.

Recovery Objective: Downlisting to threatened status.

Recovery Criteria: The subspecies should occur in at least three large sites on Mauna Kea, have an expanding population structure with ample evidence of consistent and high regeneration, be genetically diverse, have all known extant populations protected, and have no immediate threats in order to be considered no longer endangered.

Actions Needed for Downlisting:

1. Protect all extant individuals from feral ungulates, fire and human-related disturbances.

2. Monitor and research existing populations.

3. Develop and implement a program to enhance regeneration within existing populations.

4. Reestablish the silversword within areas of historic abundance, and verify recovery objectives.

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

Year	Need 1	Need 2	Need 3	Need 4	Total
1992	30	13	0	0	43
1993	193	34	31	0	258
1994	93	34	31	0	158
1995	68	34	31	0	133
1996	68	34	31	0	133
1997	68	34	24	0	126
1998	55	34	14	0	103
1999	30	34	14	0	78
2000	30	34	14	20	98
2001	30	34	14	20	98
2002	30	34	14	60	138
2003	30	13	7	60	110
2004	30	13	7	40	90
2005	30	13	7	70	120
2006	30	13	7	40	90
2007	18	13	7	40	78
Total	833	418	253	335	1839

Date of Recovery: 2007

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I. INTRODUCTION

BRIEF OVERVIEW

The Mauna Kea silversword (*Argyroxiphium sandwicense* subspecies *sandwicense*) (Asteraceae) is a giant rosette plant endemic to the alpine areas of Mauna Kea volcano on the island of Hawai'i. This subspecies was added to the federal list of endangered species without critical habitat by the U.S. Fish and Wildlife Service (Service) on March 21, 1986 (*Federal Register* Vol. 51, No. 55, pp. 9814-9820).

The Mauna Kea Silversword may have been abundant on all slopes of Mauna Kea between 2600 and 3800 meters (8528 and 12,464 feet) elevation in prehistoric times. The decline of the silversword has been attributed to browsing by feral ungulates, particularly sheep (*Ovis aries*), mouflon (*Ovis musimon*), and goats (*Capra hircus*). Currently, the subspecies has been reduced to a single naturally occurring population. Between 1973 and 1982, the State of Hawai'i outplanted silverswords in three exclosures within the Mauna Kea Forest Reserve near Pu'u Nānaha at 2770 meters (9086 feet) elevation, near Skyline jeep trail at 2970 meters (9742 feet) elevation, and at Waipāhoehoe Gulch at 2800 meters (9184 feet) elevation. In 1991, the total population was estimated at about 495 individuals, of which about 38 were naturally occurring (i.e., unplanted).

The purposes of this recovery plan are to present information regarding the Mauna Kea silversword's range, population status, and life history and describe management actions needed to prevent the extinction of the silversword and to ultimately remove it from the list of endangered species.

TAXONOMY

The Mauna Kea silversword is the type species for the genus *Argyroxiphium*, which includes the Hawaiian silverswords and greenswords. The genus *Argyroxiphium* is one of three related Hawaiian genera placed in the subtribe Madiinae of the tribe Heliantheae of the family Asteraceae (Carr 1985). The genus consists of four extant and one extinct species of silverswords and greenswords endemic to the islands of Maui and Hawai'i of the Hawaiian Islands (Carr 1985). The Hawaiian name for the silverswords is 'āhinahina, which means "very gray" and is used for a number of unrelated plant species with silvery leaves.

The species was first collected by James Macrae in 1825. Macrae's specimens were sent to Augustin-Pyramus DeCandolle in Geneva who described the plant and gave it the name Argyroxiphium sandwicense (DeCandolle 1836). The lectotype specimen is located at the herbarium of the Lindley Collection, Botany School, Cambridge University, Cambridge, England. Isolectotypes reside at The Royal Botanic Gardens at Kew Herbarium and at Herbier DeCandolle, Herbarium Conservatorie et Jardin Botaniques, Geneve, Switzerland. David Douglas collected the Mauna Kea silversword in 1834 and sent specimens to W. J. Hooker at Kew Gardens. Hooker gave the specimen the name Argyrophyton douglasii in 1837, unaware that this name was superfluous (Hooker 1837).

In 1852, Asa Gray described the Haleakalā silversword endemic to the island of Maui and named it Argyroxiphium macrocephalum (Gray 1852). The similarity in vegetative features between Mauna Kea silversword and the Haleakalā silversword has led several authors to consider these taxa as the same species. Keck (1936) placed both silverswords under Argyroxiphium sandwicense DC. St. John (1973) also considered the two taxa to be the same. Based on a morphometric analysis, Meyrat et al. (1984) designated Mauna Kea silversword and the Haleakalā silverswords as subspecies of Argyroxiphium sandwicense. Carr (1985) followed this nomenclature in his monograph of the Hawaiian Madiinae. This nomenclature was also accepted by Wagner et al. (1990). The Service accepts the designation of Mauna Kea silversword at the subspecies level.

The Mauna Kea silversword is distinguished from the Haleakalā silversword by a high frequency of branching; taller, thinner inflorescences; green bracts subtending flower heads; fewer ray florets; and obvious pappus on disk achenes.

In addition to the specimens mentioned above, specimens of the Mauna Kea silversword are located at the following herbaria: University of Hawai'i, Honolulu, HI; Bishop Museum, Honolulu, HI; New York Botanical Garden, New York, NY; Gray Herbarium, Cambridge, MA; U. S. National Herbarium, Washington, DC; Field Museum of Natural History, Chicago, IL; Botanischer Garten und Botanisches Museum, Berlin, Germany; California Academy of Sciences, San Francisco, CA.

DESCRIPTION

The Mauna Kea silversword is a giant rosette plant. The plant grows as a ball-shaped basal rosette composed of narrow lance-shaped leaves that may be up to 39 centimeters (15.35 inches) long and up to 1.5 centimeters (.59 inches) wide at the midpoint. Leaves are coated with silvery hairs. Branched (polycarpic) individuals produce a tight cluster of rosettes of various sizes. The entire cluster may be up to 150 centimeters (59.06 inches) in diameter. Unbranched (monocarpic) individuals produce a single large rosette, of up to 75 centimeters (29.53 inches) in diameter. Individual plants may live from 3 to over 50 years before flowering. At flowering, monocarpic individuals produce a single large raceme, up to 300 centimeters (118.11 inches) in height, and have numerous short branches, each terminating in a single capitula of flowers. After flowering, the entire plant dies. Polycarpic individuals produce one inflorescence for each rosette, and each rosette dies after flowering. Flowering may occur over several years before all rosettes of polycarpic individuals are exhausted. The inflorescence stalk, the bracts that subtend the pedicels, and the involucre bracts are all covered with sticky glandular hairs that emit a faint sweet odor. Flower heads (capitula) are 2 centimeters (.79 inches) in diameter, and have white to pink ray florets and pink to maroon disk florets. Each floret produces a single fruit, an achene, which may or may not contain a single seed. Achenes are black, 1 centimeter (.39 inches) long, and have a pappus of 1 to 6 short scales.

HISTORIC RANGE AND POPULATION STATUS

The Mauna Kea silversword probably only occurred on Mauna Kea. However, there are some historical and recent suggestions that a similar taxon may have occurred on Hualālai and on Mauna Loa (Carr 1985; Hooker 1837). Specimens from these sites are incomplete, making a definitive diagnosis impossible at this time.

Fragments and the remains of a whole plant wrapped in tapa cloth and prepared like an object of worship were recovered from the prehistoric Hawaiian adze quarry, Keanakāko'i, on the south slope of Mauna Kea (Allen 1981). However, it is unknown how the ancient Hawaiians used the silversword or whether the Hawaiians had any impact on the populations of the Mauna Kea silversword in prehistoric times (Allen 1981).

There are no records of the extent or density of the Mauna Kea silversword population prior to the introduction of ungulates to the island of Hawai'i in 1793 and 1794. The Mauna Kea silversword may have already been in decline due to browsing by feral ungulates by the time the silversword was first collected by James Macrae in 1825. Macrae noted in his diary that he found the remains of dead sheep near the summit of Mauna Kea on the same day that he encountered the silversword (Wilson 1922).

David Douglas made the second known collection of the Mauna Kea silversword in 1834. The silversword was collected again in 1841 by the U.S. Exploring Expedition. None of these early collectors noted the numbers or density of silverswords they encountered on Mauna Kea. The notes of both Macrae and Douglas indicated that the silversword grew above treeline in areas of scarce vegetation, and that the silversword's presence marked the uppermost elevational limit of plants on Mauna Kea. Pickering (1854) of the U.S. Exploring Expedition noted that the silversword grew from about 3080 meters (10,000 feet) to 3700 meters (12,000 feet) elevation.

The route that Macrae and Douglas used to climb Mauna Kea is unknown. It is likely, however, that these botanists used the ancient Humu'ula trail on the southeast to south slope of Mauna Kea to reach the summit area (Allen 1981). Macrae and Douglas may have collected the silversword in the vicinity of the ancient adze quarry. The U.S. Exploring Expedition apparently ascended Mauna Kea by way of the Wailuku Gulch and their collection may have been made on the cinder deserts banking the gulches at the head of the Wailuku River.

The earliest indication of abundance of the Mauna Kea silversword was made by Alexander (1892). He wrote, "The beautiful silversword once so abundant is nearly extinct except in the most rugged and inaccessible places." After 1900, the silversword continued to be sighted and collected on the south, northeast, northwest, and west slopes of Mauna Kea. The most frequent sightings were made in the vicinity of Pōhakuloa Gulch, the adze quarry at Keanakāko'i, in gulches at the head of the Wailuku River, and along the 'Umikoa trail. The most recent sighting of Mauna Kea silversword on the south slope of Mauna Kea was made between 1970 and 1972 (Stephen Porter, personal communication). The north slope of Mauna Kea was apparently little visited by pre-contact Hawaiians and not visited by early explorers of Mauna Kea. No recorded collections or sightings were made on the north slope of the mountain. The silversword may have occurred in this region, but was eliminated at an early date. The only known naturally occurring population occurs on cliff faces of the Waipāhoehoe Gulch.

The probable original range of the Mauna Kea silversword may have encircled Mauna Kea from about 2600 meters (8528 feet) to 3800 meters (12,464 feet) elevation (Figure 1). The highest concentration of plants may have occurred between 3000 meters (9840 feet) and 3400 meters (11,152 feet) elevation on the east, southeast, and south slopes of Mauna Kea. The silversword was probably eliminated from open areas below treeline and up to treeline, if ever abundant in this range, before it was eliminated from open cinder flats and cones at higher elevations. Because rocky cliff faces were the areas least accessible to browsing ungulates, plants in these areas persisted longest.

CURRENT RANGE AND POPULATION STATUS

Since 1972, no reported sightings have been made of naturally occurring Mauna Kea silversword outside of the Waipāhoehoe Gulch (frequently erroneously called Wailuku Gulch in recent publications due to mapping error). No accurate census of the naturally occurring individuals that remained at Waipāhoehoe was made prior to the construction of the exclosures and the outplanting of Mauna Kea silversword within the exclosure sites.

Table 1 gives the 1991 census of naturally occurring and outplanted individuals for the five sites at which the Mauna Kea silversword occurs. Individuals that are the progeny of outplanted individuals have been counted as part of the planted population in order to separate the reestablished from the naturally occurring populations of the Mauna Kea silversword at Waipāhoehoe.

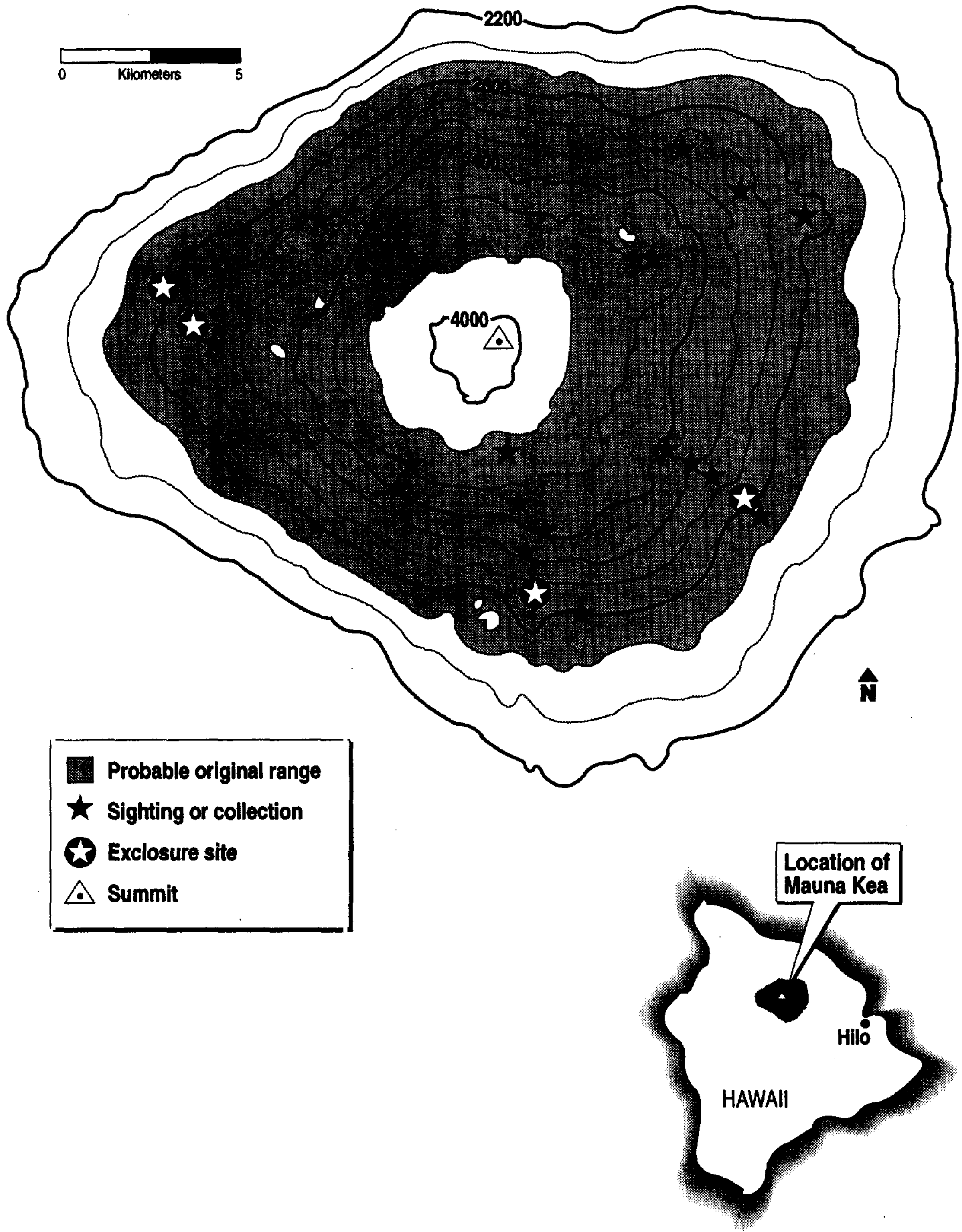

FIGURE 1. Map of the upper slopes of Mauna Kea, Hawaii, showing the probable original range of Mauna Kea silversword, locations, sightings and collections, and locations of silversword exclosures. Countour interval is 300 meters.

TABLE 1. Number of plants in five populations in four stage classes in 1991 (Powell, unpublished).

Population	Stage Class* Seedling	Juvenile	Adult	Flowering	Total
Naturally Occurring	12	12	12	2	38
Waipāhoehoe					
1973-1982 Outplants	124	101	67	62	354
1987 Outplants	0	24	8	0	32
Skyline					
1979 Outplants	8	6	9	3	26
1987-1991 Outplants	5	11	1	0	17
Pu'u Nānaha					
1979 Outplants	0	0	7	3	10
1991 Outplants	1	3	0	0	4
Halepōhaku					
1991 Outplants	1	13	0	0	14
Totals	151	170	104	70	495

* Stage class is based on rosette diameter in centimeters. Seedlings are plants 1 to 10 centimeters (.394 to 3.94 inches) in diameter; Juveniles are plants 11 to 29 centimeters (4.33 to 11.42 inches) in diameter; Adults are plants 30 centimeters (11.81 inches) or more in rosette diameter. Flowering plants are those flowering regardless of rosette diameter.

The 1991 census indicates that there were a total of 38 naturally occurring individuals at Waipāhoehoe. Nineteen of these individuals were found within the exclosure area, growing on steep cliffs or waterfall ledges. The remaining 19 individuals were found on the cliff walls above and outside the exclosure fence line within the Waipāhoehoe Gulch up to 3200 meters (10,496 feet) elevation. Six naturally occurring individuals died after flowering from 1984 to 1991 (Powell, unpublished).

The numbers of individuals in adult, juvenile, and seedling size classes are summarized in Table 1 for each of the populations in 1991. The outplanted population at Waipāhoehoe is the largest of the three outplanted populations. Since 1985, 125 individuals have died in this area and 260 individuals have been recruited into the population. At Skyline, 12 individuals have died since 1985 and 15 seedlings have become established. Five individuals of the Pu'u Nānaha population have flowered since they were outplanted in 1979 (Powell, unpublished).

Due to regeneration since 1987, the reestablished population at Waipāhoehoe that was outplanted between 1973 and 1982 has a larger number of seedlings and juveniles than adult and flowering plants. This is the only population of those outplanted prior to 1987 that has shown high regeneration. In the naturally occurring population, the numbers of seedlings, juveniles and adult plants are equal.

LIFE HISTORY

The original population of the Mauna Kea silversword may have consisted of primarily monocarpic, unbranched individuals. However, there is some historical evidence that branched, polycarpic individuals existed in other now extinct populations (Hartt and Neal 1940). About 25 percent of the 38 individuals of the naturally occurring population at Waipāhoehoe Gulch is branched. Two of the three plants that flowered in 1973 were polycarpic (Sunada 1974). The seeds from these polycarpic individuals were used extensively to generate the planted populations. Polycarpy in the Mauna Kea silversword appears to be, at least partially, an inherited trait. In 1991, about 80 percent of the planted populations was made up of polycarpic individuals (Powell, unpublished).

Reproduction in the Mauna Kea silversword is by seed. Monocarpic individuals produce one large basal rosette of leaves from one apical meristem. This meristem produces a single inflorescence at flowering. After fruit set, the entire plant dies.

Polycarpic individuals have several rosettes that are connected to a common tap root. Each rosette has a terminal apical meristem and each rosette can produce an inflorescence and die independently from the other rosettes on the same plant. Because the number of rosettes per individual appears to be determinate, repeated flowering by polycarpic individuals results in the eventual death of the individual. In the planted populations, the number of rosettes of individuals with a rosette diameter of 300 millimeters (11.7 inches) or more ranges from 1 to 54, with an average of about 9 rosettes per individual. The number of inflorescences produced per flowering individual per year ranges between 1 and 15 and averages about 2.2 inflorescences per flowering plant per year. Flowering may occur for up to 6 years before a polycarpic individual dies (Powell, unpublished). However, about 70 percent of the plants that have died after flowering at Waipāhoehoe since 1985 died after flowering once. Eighty percent of branched plants that flower in a given year flower again in the next year.

The estimated age at flowering of an individual in the planted populations ranges from 6 to 30 years. Individuals have flowered at Waipāhoehoe within 2 years of planting and at a minimum size of 300 millimeters (11.7 inches) in diameter. Flowering generally occurs between the months of June and August. Flowers are visited by a variety of native and non-native insects. Native bee pollinators include Nesoprosopis cf. volcanica and N.

pubescens. Native moth pollinators include *Scotorytha* sp. and an undescribed species of *Agrotis.*

The Mauna Kea silversword is primarily self-incompatible. Plants that flower in the absence of other flowering individuals produce few achenes that contain seeds (seed set). However, in 1986, the seed set at Waipāhoehoe in capitula that were experimentally prevented from being pollinated by insects was extremely low (0.4 percent). This level of seed set is contrasted to about 2.6 percent seed set found in open-pollinated flower heads in 1986 (Table 2). Capitula that were artificially cross-pollinated in 1986 set about 24 percent seed (Powell 1992). The increase in seed set shown by artificial cross-pollination suggests that higher pollinator activity would result in higher seed set in Mauna Kea silversword populations.

Achenes ripen within approximately one month after the plant flowers are shed from inflorescences in the immediate vicinity of the mother plant. Dispersal of achenes is accomplished by wind or water. Table 2 shows percent seed set in achene samples collected from flowering plants of various years at Waipāhoehoe. Achene samples collected from plants since 1978 indicate that seed set at Waipāhoehoe is currently lower than the seed set found in the two naturally occurring individuals that flowered in 1973.

The Mauna Kea silversword has a life history that predisposes it to decline in small populations. In small populations, few plants may flower in any given flowering season. Flowering plants may not flower simultaneously or be in close proximity with one another, which makes cross-pollination difficult or impossible. If pollinator activity is low, seed set will probably also be low, and the probability of regeneration will be reduced. Unfavorable environmental conditions during or after flowering may also hamper regeneration. Flowering plants are constantly being removed from the population by death, even in years when seedling establishment is low. In small populations, the loss of any individual that is unable to reproduce is critical. Large populations are buffered against these losses by their sheer numbers. Small populations are not buffered from chance or chronic adverse environmental conditions that may prevent regeneration. Therefore, small populations may be more susceptible to rapid extinction. None of the existing populations of the Mauna Kea silversword may be large enough to survive over long periods of time.

TABLE 2. Percent seed set of Waipāhoehoe Gulch seed collections (Powell 1992).

Year of Collection	Number of Plants Sampled	Number of Seeds Examined	Percent Seed Set
1973	2	4,071	9.8
1978	nd	518	1.5
1982	nd	4,541	4.8
1983	9	4,550	1.4
1984	3	1,451	2.3
1985	11	32,722	1.1
1986	15	28,655	2.6
1987	21	29,034	1.9
1988	21	33,750	5.7

HABITAT DESCRIPTION

The area of the probable original range of the Mauna Kea silversword includes several distinct vegetational and climatic zones of Mauna Kea. The upper region from 3400 to 3800 meters (11,152 to 12,464 feet) elevation is barren alpine cinder desert. The surface is covered with glaciated and unglaciated block lava and cinders. Mosses, lichens, and grasses (*Trisetum glomeratum* and _Agrostis sandwicensis_) grow in widely scattered patches in the shelter of or on the sheltered surface of rocks. The annual mean rainfall in this region is 450 millimeters (17.55 inches) and the annual mean temperature is 5° to 7° C (Mueller-Dombois and Krajina 1968).

The region between 3200 and 3400 meters (10,496 to 11,152 feet) elevation is scrub desert. The substrate is also block lava and cinders. The annual mean rainfall is 475 millimeters (18.53 inches) and annual mean temperature is 8° C. Low-growing pūkiawe (_Styphelia tameiameiae_) shrubs are found in this region, as well as widely scattered grasses, ferns, and herbaceous perennials.

The region between 2900 and 3200 meters (9512 and 10,496 feet) elevation may have been the area of the original treeline of Mauna Kea. This area is now alpine scrub characterized by the native shrubs pūkiawe, 'ōhelo (_Vaccinium_ sp.), and na'ena'e or kūpaoa (_Dubautia_ species). The substrate is lava outcrops and ash. Annual mean rainfall in this region is about 500 millimeters (19.5 inches) and annual mean temperature is about 10° C. The Skyline exclosure occurs in this region. The Skyline exclosure also contains planted māmane (_Sophora chrysophylla_) trees, as well as an abundance of the alien weed, mullein (_Verbascum thapsus_).

Open māmane forest begins between 2600 and 2900 meters (8528 and 9512 feet) elevation. The soil in this region is mostly ash with lava outcrops. Māmane is the dominant tree in this region. The understory consists of pūkiawe, 'ōhelo, pilo (_Coprosma_ species), na'ena'e or kūpaoa, ferns, and native and non-native grasses. The annual mean rainfall is between 500 and 800 millimeters (19.5 and 31.2 inches) a year, and annual mean temperature is about 11° C. This is the region in which both the Pu'u Nānaha and Waipāhoehoe exclosures occur. The Pu'u Nānaha exclosure area receives less rainfall (380 millimeters/year (=14.82 inches/year)) than the Waipāhoehoe exclosure (700 millimeters/year (=27.3 inches/year)) (Scowcroft and Giffin 1983). Māmane has been planted within the Pu'u Nānaha exclosure, but is also the dominant tree species outside of the exclosure. The understory within the Pu'u Nānaha exclosure consists primarily of native and non-native grasses and herbs. The vegetation in the Waipāhoehoe exclosure is dominated by māmane in the lower areas and by pūkiawe throughout. Other common shrubs are 'ōhelo, kūkaenēnē (Coprosma ernodeoides), Geranium sp., Dubautia arborea, and Dubautia ciliolata. Among the common grasses are sweet vernal grass (Anthoxanthum ordoratum), hairy oatgrass (Danthonia pilosa), and piliuka or he'upueo (Trisetum glomeratum). The most common fern is kīlau or bracken fern (Pteridum aquilinum var. decompositum). The three exclosures occur within regions that may have once supported large populations of the Mauna Kea silversword.

REASONS FOR DECLINE AND CURRENT THREATS

Browsing by feral sheep has been implicated as a major factor contributing to the decline of the Mauna Kea silversword (Powell 1992). Sheep and other ungulates were introduced to the island of Hawai'i in 1793 and 1794. These animals rapidly increased in number and by the early 1800's had spread throughout the island (Kramer 1971). James Macrae noted the presence of dead sheep on Mauna Kea in 1825 (Wilson 1922). The sheep preferred to browse at treeline, but due to hunting pressures by humans and feral dogs (Canis familiaris), sheep were driven into the high elevation cinder deserts of Mauna Kea above treeline (Giffin 1976). These cinder deserts may have been the primary habitat of the silversword.

Because water is scarce on Mauna Kea and the leaves of the silversword are succulent, the Mauna Kea silversword may have been selectively browsed by feral sheep. The presence of sheep on Mauna Kea has radically altered the natural vegetation (Warner 1960). Browsing by sheep has also been implicated as contributing to the decline in elevation of treeline on Mauna Kea (Scowcroft and Giffin 1983).

Bishop (1852) estimated that there were 3,000 feral sheep on the island of Hawai'i in 1851. Until 1921, feral dogs preyed upon the feral sheep (Tomich 1969). When the dogs were eliminated in 1921, the number of sheep apparently rose rapidly. By 1937, there were an estimated 40,000 sheep on Mauna Kea alone (Bryan 1937). The increase in sheep on Mauna Kea after 1921 corresponds to the rapid disappearance of silverswords from areas of early sightings and collections. After 1921, most sightings and collections of live silverswords were made only from cliffs in Pōhakuloa, Waikahalulu, and Waipāhoehoe Gulches. After 1935, no further sightings of live plants were made from Pōhakuloa, although between 1970 and 1972 silverswords were sighted in Waikalulu Gulch (S. Porter, personal communication).

Due to sheep drives beginning in 1936, public hunting, and a possible disease, feral sheep on Mauna Kea were nearly eliminated by 1950, but numbers rose again, because the sheep were protected and maintained as a sport game animal in the Mauna Kea Forest Reserve until 1981. In 1981, the State of Hawai'i was ordered by a federal judge to remove all sheep from the critical habitat of the palila (Loxioides (= Psittirostra) bailleui), an endangered bird, which occurs within the Mauna Kea Forest Reserve (Figure 1).

Mouflon sheep were introduced to the island of Hawai'i in 1958 and used in a hybridization program with feral sheep. A total of 193 mouflon sheep and hybrids were released from pens at Kahinahina and Pu'u Lā'au between 1962 and 1966. Mouflon sheep also browse silverswords. At Waipāhoehoe, the fences built in 1972 and 1975 to exclude feral sheep from areas where the Mauna Kea silversword was reintroduced did not completely exclude mouflon which, unlike the feral sheep, were able to jump the fences and damage plants. In 1987, the State of Hawai'i was required to remove mouflon sheep, hybrid sheep, and any remaining feral sheep and goats from the critical habitat of the palila by January 1988. As long as sheep remain within the Mauna Kea Forest Reserve, they present a threat to the Mauna Kea silversword.

Feral pigs (Sus scrofa) and goats also damage the silversword on Mauna Kea. Feral pigs apparently do not browse directly on silverswords. Rooting by pigs, however, uproots and kills plants. Goats have been known to feed on silverswords in Haleakalā Crater (Loope and Crivellone 1986) and may have seriously impacted the Mauna Kea silversword in the past. Because goats are now rare on Mauna Kea, the effect of goats on the Mauna Kea silversword is probably small, yet potentially significant.

Insect damage has also been suggested as a factor in the decline of the Mauna Kea silversword (Bryan 1948). The major insect predator of the Mauna Kea silversword is a native fly, Tephritis arborea. Adult T. arborea lay eggs within unopened Mauna Kea silversword capitula. Larvae feed on developing achenes and pupate within the capitula. Larvae appear to feed indiscriminately on achenes that do not have developing seeds and those that do. At Waipāhoehoe, there was no relationship between achene damage by larvae and seed set in 1987 (Powell 1992). At Waipāhoehoe, the fly larvae also feed on plant species related to the silversword, Dubautia arborea and D. linearis. Because this fly is an endemic insect that has apparently co-evolved with the silversword, it may not be a critical threat to the long-term survival of the Mauna Kea silversword.

Collection of silversword plants by humans has been, and is currently, a potential threat to the Mauna Kea silversword. The paucity of herbarium specimens of the Mauna Kea silversword, however, suggests that the species was never heavily collected for scientific purposes. Plants were occasionally removed from Mauna Kea for ornamental purposes in the 1920's, but these removals were probably not performed on a large scale. In areas where the silversword populations had already declined to a few individuals, removals may have represented a large reduction or the final elimination of a population. Between September 1987 and July 1988, three adult plants were removed from the Skyline population. This removal may affect the survival potential of this already small population.

Collections that have occurred at Waipāhoehoe since 1973 that did not kill or seriously damage whole plants, such as the removal of seed for propagation purposes and the removal of individual leaves and flower heads for scientific purposes, have probably not impacted the population significantly.

The other major threats to the survival of the Mauna Kea silversword are those relating to the population's small size. Except for the 38 remaining naturally occurring individuals, most of the planted populations are made up of siblings, half-siblings or the progeny of sibling or half-sibling crosses. Both the outplanted and naturally occurring populations are, therefore, expected to have low genetic heterogeneity. A population with low genetic heterogeneity may have low mating success or low seed viability (Ledig 1986). Five of 16 reciprocal crosses made between 10 plants in 1986 set few or no seed in one direction of the cross. This indicates that the plants involved in these three crosses share a self-incompatibility allele that prevents reproduction between related individuals (Powell 1992).

Small populations with low genetic variability are in danger of further losing variability through stochastic events and genetic drift. Because the Mauna Kea silversword population is so small, insect pollinators that may have been dependent on the silversword in the past may now be rare, or certain important insect pollinators may be extinct. Furthermore, the three populations are localized and, therefore, vulnerable to natural disasters, such as fire (Waipāhoehoe or Pu'u Nānaha) or heavy impact by feral animals or man.

CONSERVATION EFFORTS

In 1909, the upper slopes of Mauna Kea above about 2400 meters (7872 feet) elevation were declared a Forest Reserve. The vegetation of Mauna Kea was not protected until 1935, when a fence was constructed along the lower boundary of the Forest Reserve. In an effort to protect the forests of Mauna Kea, feral sheep were actively removed from the Forest Reserve from 1936 to 1950.

The Hawai'i Department of Land and Natural Resources (DLNR) Division of Forestry and Wildlife (DOFAW) has been actively involved in the preservation and restoration of the Mauna Kea silversword. In 1972, a 0.9-hectare feral sheep exclosure was built by DOFAW, in cooperation with the U.S. Forest Service and Service, at 2800 meters (9184 feet) elevation on the bank of the Waipāhoehoe Gulch. This exclosure is in the Mauna Kea Forest Reserve on the border of Hawaiian Home Lands. The purpose was to study the recovery of vegetation in the absence of browsing animals (Scowcroft and Giffin 1983). The exclosure was also used to study regeneration of māmane and to plant the Mauna Kea silversword. There were no naturally occurring silverswords within the area at the time the exclosure was built.

Three naturally occurring silversword plants flowered in Waipāhoehoe Gulch in the summer of 1973. Various proportions of achenes were collected from all three individuals and the seeds used to propagate the Mauna Kea silversword. In October 1973, two greenhouse-grown silversword plants were planted within the exclosure. One of these apparently survived. In December of 1973, 46 greenhouse-grown silverswords were planted within the exclosure. All of these outplants died during the winter. The exclosure area was also seeded with achenes gathered in 1973. Only one seedling became established as a result of this first seeding effort (Department of Land and Natural Resources 1974).

Beginning in 1974, Mauna Kea silversword seed was germinated and plants were greenhouse-grown at Hawai'i Volcanoes National Park. In December 1974, 10 individuals were outplanted in the 1972 exclosure. All 10 plants were reportedly surviving in 1976, and one of these individuals flowered in 1976. Two more flowered in 1978 (Department of Land and Natural Resources 1978).

A 20-hectare exclosure was built by DOFAW in 1975 to protect a portion of the remaining natural silversword population in the Waipāhoehoe Gulch proper and to provide a large site for silversword reestablishment. The exclosure straddled both banks of the gulch, extended from 2800 meters (9184 feet) to about 2900 meters (9512 feet) elevation, and included the 0.9-hectare 1972 exclosure. It was estimated that the exclosure protected 15 to 20 naturally occurring silverswords from feral sheep (Wakida 1971). Mouflon sheep, however, were able to enter the exclosure site.

In the spring of 1976, 275 silversword plants were outplanted within the 20-hectare exclosure. Half of these were reportedly destroyed or damaged by mouflon (Wakida 1976). However, many plants may have also suffered from transplant shock. Another 100 plants were outplanted within the 20-hectare exclosure in 1977. In 1978, the DLNR reported that between 150 to 200 silverswords had been reestablished at Waipāhoehoe.

In 1979, a total of 50 silversword plants were planted in two 2-hectare exclosures built in 1978 on the west slope of Mauna Kea. One exclosure is near the cinder cone, Pu'u Nānaha, at 2770 meters (9086 feet) elevation and the other is near Skyline jeep trail at 2970 meters (9742 feet) elevation. Both of these exclosures were also planted with māmane seedlings.

Silversword seedlings were apparently established after several outplanted individuals flowered in 1981, 1982 and 1983 at Waipāhoehoe. A 1982 letter from DLNR to Dan Taylor at Hawai'i Volcanoes National Park indicated that additional Mauna Kea silversword plants were outplanted on Mauna Kea in that year (Wakida 1982). Seed was liberally collected from flowering individuals within the Waipāhoehoe exclosure and used for direct seeding and further propagation.

In December 1987, 138 eighteen-month old greenhouse-grown Mauna Kea silverswords were planted on Mauna Kea. Seventy silverswords were planted within the Skyline exclosure and 68 were planted at Waipāhoehoe. In July 1988, 10 of these outplants were alive at Skyline and 42 outplants were alive at Waipāhoehoe. Overall survival of these outplants within both of the exclosure sites was about 34 percent after 7 months (Powell 1992). Transplant shock or drought or both may have been responsible for most of the outplant deaths.

In February 1989, 12 greenhouse-grown Mauna Kea silversword were planted at Skyline. Of these, 5 individuals were alive in July 1989. In August 1989, 24 greenhouse-grown Mauna Kea silversword were planted at Skyline. Three of these plants were alive in September 1989.

In March 1991, 16 greenhouse-grown Mauna Kea silversword were planted in an exclosure near Halepōhaku at about 2800 meters (9184 feet) elevation. By October 1991, 2 plants had died. In May 1991, 9 greenhouse-grown Mauna Kea silversword were planted at Skyline and 10 were planted at Pu'u Nānaha. By September 1991, 8 plants were alive at Skyline and 4 were alive at Pu'u Nānaha.

The Mauna Kea silversword has been extensively studied by a number of investigators. Most of these studies have been systematic or taxonomic in nature (Meyrat 1982; Witter 1986; Carr 1985). Ongoing biosystematic research is being conducted by Gerald Carr, University of Hawai'i at Manoa; Donald Kyhos and Bruce Baldwin, University of California, Davis; and Bruce Bohm, University of British Columbia, Vancouver. The demography and reproductive biology of the Mauna Kea silversword has been studied by Elizabeth Powell (Powell 1992).

II. RECOVERY

OBJECTIVE

The objective of this recovery plan is to delineate all actions necessary to achieve downlisting of the Mauna Kea silversword to threatened status. To be considered for downlisting, the silversword will need to occur in at least three large sites on Mauna Kea, have an expanding population structure with ample evidence of consistent and high regeneration, be genetically diverse, have all known extant populations protected, and have no immediate threats.

To achieve delisting of the species, the subspecies will need to be reestablished in areas of historic abundance or other areas of maximal potential. Active genetic management may also be needed to assure long-term survival of the subspecies.

NARRATIVE

1. Protect existing populations of Mauna Kea silversword.

The most immediate need in assuring the survival of Mauna Kea silversword is the protection of the existing plants and their habitat on the four exclosure sites known at this time. In addition, searches should be made on Mauna Kea to determine if any previously undiscovered populations remain and steps taken to protect such populations. Until feral ungulates are removed from the Mauna Kea Forest Reserve, the sites need to be adequately fenced and managed to prevent entrance by feral sheep, mouflon, goats and feral pigs. Signs need to be posted and educational programs initiated to prevent possible human disturbance, as well.

11. Search for unknown silversword populations on Mauna Kea.

The Waipāhoehoe and Wailuku Gulches, and all gulches and steep cliffs above 2600 meters (8528 feet) or where silverswords were historically abundant on Mauna Kea need to be explored for remnant naturally occurring individuals. Any individuals that are encountered should be mapped and described.

12. Protect populations from feral ungulates.

Feral ungulates are one of the greatest immediate threats to the Mauna Kea silversword. All populations should be protected from feral ungulates by fencing if necessary or possible.

121. Remove feral ungulates from Mauna Kea Forest Reserve.

The presence of feral sheep, mouflon, goats, and feral pigs on Mauna Kea will always present a threat to the continued survival of the Mauna Kea silversword. These animals should be completely removed from the Mauna Kea Forest Reserve. Every effort should be made to coordinate ungulate removal from Mauna Kea with DLNR-DOFAW.

122. Fence newly discovered individuals or populations.

Lone individuals or small remnant populations of the Mauna Kea silversword have a very small chance of regenerating. However, these individuals may be a critical addition to a program of genetic management. They should be protected from feral ungulates by fencing. Exclosures should be large enough for future regeneration.

123. Enhance and extend fencing at Waipāhoehoe Gulch.

The fencing of exclosure sites at Waipāhoehoe may be inadequate to prevent the entry of mouflon. As long as mouflon, feral sheep, and hybrid sheep remain on Mauna Kea, fences may need to be augmented in height to at least 2.0 meters (6.5 feet) to prevent these animals from entering silversword sites.

1231. Enhance fencing of exclosure site.

The fence surrounding the Waipāhoehoe Gulch site has gaps that allow the entry of feral pigs. This fence may need to be strengthened at the base as well as increased in height.

1232. Extend fence to protect naturally occurring population.

The remaining naturally occurring individuals that occur above the fence line at Waipāhoehoe Gulch also need to be protected.

1233. Maintain fence lines.

All fences need to be regularly inspected and maintained as long as feral ungulates occur on Mauna Kea.

1234. Remove ungulates that gain entry to exclosure.

Animals that gain entrance to exclosures need to be removed immediately. Hunters in the Kahinahina game management area should be encouraged to report sightings of animals within the Waipāhoehoe Gulch exclosure and these sightings should be acted on promptly.

124. Enhance and maintain fencing at Pu'u Nānaha.

The fencing of exclosure sites at Pu'u Nanaha may need to be enhanced to prevent the entry of mouflon and pig and maintained on a regular basis.

1241. Enhance fencing of exclosure site.

See narrative for Task #1231.

1242. Maintain fence lines.

See narrative for Task #1233.

1243. Remove ungulates that gain entry to exclosure.

See narrative for Task #1234.

125. Enhance and maintain fences at Skyline exclosure.

See narrative for Task #124.

1251. Enhance fencing of exclosure site.

See narrative for Task #1231.

1252. Maintain fence lines.

See narrative for Task #1233.

1253. Remove ungulates that gain entry to exclosure.

See narrative for Task #1234.

126. Enhance and maintain fences at Halepohaku.

See narrative for Task #124.

1261. Enhance fencing of exclosure site.

See narrative for Task #1231.

1262. Maintain fence lines.

See narrative for Task #1233.

1263. Remove ungulates that gain entry to exclosure.

See narrative for Task #1234.

13. Protect populations against human-related disturbance.

Although human disturbance of Mauna Kea silversword plants is rare, removal of even a single plant by humans presents a serious threat to the subspecies. The remnant Mauna Kea silversword populations probably have very limited genetic diversity and the loss of any individual may reduce the ability of the entire population to survive.

131. Inform persons using the Mauna Kea Forest Reserve of regulations and penalties regarding disturbance to vegetation and to the Mauna Kea silversword.

The vegetation of the Mauna Kea Forest Reserve, including Mauna Kea silversword, is protected by Hawai'i State Law. DLNR-DOFAW should ensure that State laws and regulations are enforced on the Mauna Kea Forest Reserve. Persons using the Mauna Kea Forest Reserve need to be informed of these laws. Signs with statements regarding laws affecting the Mauna Kea silversword and exclosure entry can be posted at exclosures.

132. Restrict unnecessary entry into exclosure sites.

Entry to exclosure sites should be limited to authorized persons and persons hunting ungulates within the exclosures.

133. Include information on the distribution of Mauna Kea silversword in existing federal and state fire management plans for Mauna Kea.

Fire is a possible threat to the Mauna Kea silversword in the Waipāhoehoe Gulch and Pu'u Nānaha exclosures. The Skyline population occurs in an area of very scarce vegetation and is probably not threatened by fire. Information on the distribution of the Mauna Kea silversword needs to be included in existing Federal and State fire management plans for the Mauna Kea area.

2. **Monitor and research existing populations.**

A yearly assessment of the size class structure of the existing populations, growth rates, mortality, flowering patterns, and other aspects of reproduction and regeneration provides important baseline information as well as being useful in determining if a population is stable, increasing, or declining at a point in time. A chronically declining population can be identified and management intensified. Sensitive stages of the life cycle can also be identified (Huenneke and Marks 1987). Simulations and models can be used to assess the possible effects of various management methods on the population (Starfield and Bleloch 1986) before such methods are carried out.

21. Monitor existing population.

To determine whether a population is stable, increasing or declining, records must be kept on population structure, growth rates, flowering patterns, seed set, seed parasitism, mortality, and regeneration in existing populations. Such records should be used to monitor each population.

22. Develop and implement a research program on the ecology of the Mauna Kea silversword.

Little is currently known about the ecology of the Mauna Kea silversword. A research program including the ecology of the Mauna Kea silversword needs to be designed and implemented. This information is necessary to make sound management decisions (Bradshaw and Doody 1978).

221. Determine causes of premature mortality in established individuals.

Mortality is highest in the seedling stage, but is low once plants are established (Powell 1992). Plants are particularly susceptible to browsing and drought from the juvenile stage until flowering. Reduced seedling vigor may be a consequence of inbreeding. All causes of mortality of pre-flowering established plants should be researched so that these causes of mortality can be reduced as much as possible.

222. Determine and assess factors limiting regeneration.

The effects of elevation, climatic factors (precipitation, temperature, and light), and soil factors (temperature, moisture, nutrient availability, and texture) on Mauna Kea silversword growth and regeneration need to be studied. The biological interaction of the Mauna Kea silversword with other organisms (competition, parasitism, pollination) and its own physiological constraints (water relations, nutrient and light requirements) also need to be researched.

2221. Determine physical and biological factors which limit growth, germination, and seedling establishment.

Reproduction is a critical event in the life history of the Mauna Kea silversword. Factors limiting reproduction may prevent the population from regenerating or increasing. Seed set in current populations is apparently lower than in the past (see Table 2). The reasons for this low seed set should be investigated.

2222. Determine and assess environmental and genetic factors limiting seed set.

The relative importance of factors such as pollinator activity and seed parasitism to population structure needs to be assessed. The factors limiting the distribution, abundance, and effectiveness of pollinating insects also need to be understood. Genetic relatedness of outplanted populations may be responsible for reduced vitality and survivability of seedlings or outplants. This may be especially important as the population becomes progressively inbred with time.

Although some individuals of the Mauna Kea silversword appear to be partially self-compatible, many appear to be strongly self-incompatible. An understanding of self-incompatibility mechanisms of the Mauna Kea silversword and the relationship of these mechanisms to breeding in the naturally occurring and closely related outplanted populations is important.

3. <u>Develop and implement a program to enhance regeneration within existing populations</u>.

None of the currently existing populations may be large enough to survive over a long period of time. All populations may need to be enhanced to prevent their extinction. The total population of Mauna Kea silversword has increased during the 19 years (1972-1991) of management and protection by DLNR-DOFAW, but the remnant naturally occurring population has declined. It appears that the existing populations are not increasing fast enough naturally to bring Mauna Kea silversword out of endangered species status in the near future, if ever, without active interference and management. A program to enhance regeneration within existing population sites should be designed and implemented.

31. <u>Design program to enhance regeneration within existing populations</u>.

Data from research on regeneration ecology should be used to determine the sites of optimal regeneration potential within existing populations and the need to increase seed set, outplant, and enhance genetic diversity. The need for artificial cross-pollinations should be explored, as well as the need to disperse seeds artificially into optimal regeneration sites, and the need to grow plants under controlled conditions and outplant them within the exclosure sites to increase population size and future out-crossing potential of existing populations.

32. <u>Implement regeneration program, as necessary (see Task 31), and reduce causes of premature mortality in Mauna Kea silversword</u>.

Existing populations that are already in areas of good regeneration potential need to be augmented and the causes of pre-flowering mortality reduced as much as possible.

33. <u>Develop a program of genetic management</u>.

The naturally occurring population is a remnant of a wider-ranging and diverse population and may not be typical or representative of the historic Mauna Kea silversword. Further, the small size of the remnant naturally occurring population suggests that this population has limited genetic diversity and is undergoing a severe genetic bottleneck. The planted populations are of even more limited genetic background derived from the remnant naturally occurring population. The inbreeding that has been occurring in the planted population at Waipāhoehoe may eventually result in individuals that have reduced ability to produce viable offspring. This possibility must be explored. Genetic management may be necessary to prevent eventual extinction of the Mauna Kea silversword.

Genetic management of the Mauna Kea silversword should be undertaken with great care, utilizing current techniques in plant genetics. The distribution of genes in Mauna Kea silversword and their interactions need to be determined. An understanding of the self-incompatibility system and the number of alleles involved is particularly important. The goal of genetic management may be not only to increase diversity, but to enable the population to survive under current conditions and adapt to future changes (Ledig 1986). Experts in rare plant genetic management need to be consulted in development of a program of genetic management.

34. <u>Implement controlled breeding program</u>.

Facilities and personnel must be provided to initiate a controlled breeding program. Records of all enhancement and genetic management activities should be carefully kept and new management goals and techniques developed, as appropriate.

Greenhouse propagation and outplanting of Mauna Kea silversword has been successful in enhancing the Mauna Kea silversword population in the past. However, this approach is expensive and labor intensive. One advantage of this method of population enhancement or reestablishment is that a limited number of seeds can be maximized in terms of production of established plants. Seeds of known genetic history can be promoted or withheld as needed to balance the genetic contribution of certain individuals in the population.

Controlled rearing of silverswords bypasses the stage of high mortality experienced by seedlings under field conditions. Plants grow faster under greenhouse conditions than under current field conditions at Waipāhoehoe (Powell 1992). This means that plants reach the stable juvenile stage of low mortality and fast growth earlier than field established individuals. This may have the advantage of lessening the probability of mortality in these individuals.

One of the major disadvantages of this method in the absence of genetic management is that certain genotypes may be favored by the greenhouse, with the inadvertent effect of altering the genetic structure of the population. Offspring from a few parents may be favored resulting in further limited genetic diversity in future generations. There is the danger that greenhouse rearing of silverswords may become increasingly more difficult with inbred plants.

4. **Reestablish Mauna Kea silversword within areas of historic abundance.**

Several large areas suitable for the reestablishment of the Mauna Kea silversword need to be identified and protected within the historic range of the Mauna Kea silversword. Habitats that historically supported large populations of the Mauna Kea silversword are probably habitats most favorable for silversword growth and reproduction. The current habitat of the naturally occurring population, cliff faces along the Waipāhoehoe Gulch, is probably a refuge from browsing animals and may not have ever supported large silversword populations. Historic evidence suggests that the Mauna Kea silversword was most abundant on open cinder flats above treeline on the south and east slopes of Mauna Kea. These habitats, however, have been denuded of silverswords, and in some cases, other vegetation as well.

41. Design a reestablishment program for Mauna Kea silversword.

Data from research on the ecology of Mauna Kea silversword can be used to explore the possibility of successful reintroduction of Mauna Kea silversword to areas where the Mauna Kea silversword was historically abundant. Factors limiting growth, reproduction, and regeneration in these habitats need to be understood.

It is possible that the severe alteration of the high elevations of Mauna Kea by browsing and grazing animals has rendered some historic habitats unsuitable for reintroduction of Mauna Kea silversword at this time. Habitat restoration may be necessary in the absence of feral ungulates prior to attempting a large-scale reestablishment program. Pollinating insects and their larval food species or necessary habitats may be missing from historic habitats, rendering natural cross-pollination of the Mauna Kea silversword impossible. Areas that appear suitable for reestablishment based on these concerns need to be identified and protected.

The potential reestablishment sites need to be as large and as numerous as possible. Numerous reestablishment sites will give the Mauna Kea silversword a greater probability of surviving stochastic or localized events which may adversely effect silversword populations. The reestablishment program should strive to create as large and as genetically diverse population as possible. Outplanting sites within protected habitats, the density of outplanting, and outplanting schedules need to be carefully determined. Patterns of flowering and seed dispersal, cross-pollination distances, and locations of necessary supportive species or competitors need to be taken into account.

A large population size may be achieved by outplanting a portion of the number of plants desired in the final population every year for a number of years. This will create a population which may be more balanced in size class structure and less vulnerable to chance events which may impact or destroy a particular size class of the population. Flowering in a population of mixed size classes will take place over many years. This may optimize the chance that viable seed will be produced in optimal years for regeneration and minimize the possibility of an overly large portion of the population flowering in a sub-optimal year or in a series of poor regeneration years.

The mortality of outplants has been high. Plants may experience transplant shock or be unable to adjust to relatively stressful field conditions after being raised under stable greenhouse conditions. Handling and transporting plants to outplant sites may result in damage. Optimal methods of reducing outplant mortality need to be devised.

42. Implement reestablishment program.

Once the genetic management program is worked out, it should be used to generate genetically desirable seeds, or to collect suitable seeds produced in existing populations. Reestablishment may be possible by reseeding optimal sites within protected habitats, or outplanting may be necessary.

Records need to be kept of all reestablishment activities. Successful methods or reestablishment areas can be identified and augmented. Less successful sites and methods can also be identified and reevaluated.

43. Monitor all reestablished populations.

All newly reestablished populations need to be monitored to assess the success of enhancement and reestablishment programs. The appropriate periodicity and methods of monitoring must be determined. Reestablishment and enhancement schedules and methods should be revised as needed or in response to new ecological or genetic information.

5. **Verify recovery objectives.**

The information gained from monitoring can be compared to a predetermined definition of a viable population. One definition has been offered by Schaffer (1981): "A minimum viable population for any given species in any given habitat is the smallest isolated population having 99% chance of remaining extant for 1000 years despite the foreseeable effects of demographic, environmental, and genetic stochasticity, and natural catastrophes."

Models and computer simulations can be used as tools to predict a population's ability to survive over long periods of time. Enhancement, reestablishment, and genetic management programs can be terminated, continued, intensified, or reinitiated based on information gained from long-term monitoring. The goal of management should be to obtain a population size larger than the minimum viable population size.

Because information on the silversword's historic populations is lacking, it currently may be difficult to estimate the population size, density and genetic diversity that will produce a viable population for the Mauna Kea silversword. It may be necessary to regularly compare the its population size and structure with some predetermined criteria for viability of the population.

It may also be helpful to compare the Mauna Kea silversword population size and structure with that of other silversword species that are not critically endangered by their small population size, such as the Haleakalā silversword and the Eke silversword (*A. caliginis*).

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IMPLEMENTATION SCHEDULE

The implementation schedule that follows outlines actions and estimated costs for the Mauna Kea silversword recovery program. 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, stabilize populations, and hopefully lead to delisting of this subspecies. Monetary needs for all parties involved are identified to reach this point. A complete estimate of the cost of recovery is also provided.

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

FWE -	Fish and Wildlife Service, Pacific Islands Office, Ecological Services, Honolulu, Hawai'i
DLNR -	Hawai'i Department of Land and Natural Resources
UH -	University of Hawai'i, Department of Botany
FWS-RES -	U.S. Fish & Wildlife Service, Research

SILVERSWORD RECOVERY PLAN IMPLEMENTATION SCHEDULE (THRU 1996)

PRIOR-ITY #	TASK #	TASK DESCRIPTION	TASK DURA-TION (YRS)	RESPONSIBLE PARTY	TOTAL COST	COST ESTIMATES ($1,000) FY 1992	FY 1993	FY 1994	FY 1995	FY 1996	Comments
		Waipahoehoe Gulch:									
1	1231	Enhance fencing of exclosure site.	1	DLNR* FWE	15 10		15 10				
1	1232	Extend fence to protect naturally occurring population.	2	DLNR* FWE	30 20		15 10	15 10			
1	1233	Maintain fence lines.	C	DLNR	15	3	3	3	3	3	
1	1234	Remove ungulates that gain entry.	C	DLNR	5	1	1	1	1	1	
		Pu'u Nanaha:									
1	1241	Enhance fencing of exclosure site.	1	DLNR* FWE	15 10		15 10				
1	1242	Maintain fence lines.	C	DLNR	15	3	3	3	3	3	
1	1243	Remove ungulates that gain entry.	C	DLNR	5	1	1	1	1	1	
		Skyline:									
1	1251	Enhance fencing of exclosure site.	1	DLNR* FWE	15 10		15 10				
1	1252	Maintain fence lines.	C	DLNR	15	3	3	3	3	3	
1	1253	Remove ungulates that gain entry.	C	DLNR	5	1	1	1	1	1	
		Halepohaku:									
1	1261	Enhance fencing of exclosure site.	1	DLNR* FWE	15 10		15 10				
1	1262	Maintain fence lines.	C	DLNR	15	3	3	3	3	3	
1	1263	Remove ungulates that gain entry.	C	DLNR	5	1	1	1	1	1	

SILVERSWORD RECOVERY PLAN IMPLEMENTATION SCHEDULE (THRU 1996)

PRIOR-ITY #	TASK #	TASK DESCRIPTION	TASK DURA-TION (YRS)	RESPONSIBLE PARTY	COST ESTIMATES ($1,000) TOTAL COST	FY 1992	FY 1993	FY 1994	FY 1995	FY 1996	Comments
1	121	Remove feral ungulates from Mauna Kea Forest Reserve.	15	DLNR* FWE	50 10	10 2	10 2	10 2	10 2	10 2	
1	11	Search for unknown silversword populations on Mauna Kea.	5	FWE* UH DLNR	32 8 8		8 2 2	8 2 2	8 2 2	8 2 2	
1	122	Fence newly discovered individuals or populations.	6	DLNR* FWE	60 40		15 10	15 10	15 10	15 10	
2	131	Inform persons using Mauna Kea Forest Reserve of regulations & penalties.	O	DLNR	5	1	1	1	1	1	
2	132	Restrict unnecessary entry into exclosure sites.	O	DLNR	5	1	1	1	1	1	
2	133	Include information on distribution of MKSS in existing federal & state fire management plans for Mauna Kea.	5	DLNR* FWE	2 2		0.5 0.5	0.5 0.5	0.5 0.5	0.5 0.5	
		NEED 1 (PROTECT PLANTS)			452	30	193	93	68	68	
2	21	Monitor existing population.	O	DLNR* FWE UH	25 25 15	5 5 3	5 5 3	5 5 3	5 5 3	5 5 3	
2	221	Determine causes of premature mortality in established individuals.	10	FWS-RES* DLNR UH	12 8 8		3 2 2	3 2 2	3 2 2	3 2 2	
2	2221	Determine physical & biological factors which limit growth, germination & seedling establishment.	10	FWS-RES* DLNR UH	12 8 8		3 2 2	3 2 2	3 2 2	3 2 2	

SILVERSWORD RECOVERY PLAN IMPLEMENTATION SCHEDULE (THRU 1996)

PRIORITY #	TASK #	TASK DESCRIPTION	TASK DURATION (YRS)	RESPONSIBLE PARTY	TOTAL COST	COST ESTIMATES ($1,000) FY 1992	FY 1993	FY 1994	FY 1995	FY 1996	Comments
2	2222	Determine & assess environmental & genetic factors limiting seed set.	10	FWS-RES*	12		3	3	3	3	
				DLNR	8		2	2	2	2	
				UH	8		2	2	2	2	
		NEED 2 (MONITOR/RESEARCH)			149	13	34	34	34	34	
2	31	Design program to enhance regeneration within existing populations.	4	FWE*	12		3	3	3	3	
				DLNR	8		2	2	2	2	
				UH	8		2	2	2	2	
2	33	Develop a program of genetic mgmt.	5	DLNR*	8		2	2	2	2	
				FWE	32		8	8	8	8	
2	34	Implement controlled breeding program.	15	DLNR*	20		5	5	5	5	
				FWE	8		2	2	2	2	
2	32	Implement regeneration program, as necessary & reduce causes of premature mortality.	10	DLNR*	20		5	5	5	5	
				FWE	8		2	2	2	2	
		NEED 3 (ENHANCE REGENERATION)			124	0	31	31	31	31	
3	41	Design a reestablishment program for the silversword.	4	DLNR*	0						
				FWS-RES	0						
				UH	0						
3	42	Implement reestablishment program.	10	DLNR*	0						
				FWE	0						
3	43	Monitor all reestablished populations.	C	DLNR*	0						
				FWE	0						
3	5	Verify recovery objectives.	1	FWE*	0						
				DLNR	0						
		NEED 4 (REESTABLISH/VERIFY RECOVERY OBJECTIVES)			0	0	0	0	0	0	
		TOTAL COST			725	43	258	158	133	133	

APPENDIX 1: Historical sightings and collections of the Mauna Kea silversword.

DATE	LOCATION	ELEVATION	REFERENCE
1264-1657	Waikahalulu	me	Allen, 1981

Note: Waikahalulu Gulch at the Mauna Kea adze quarry complex. "A cluster of dead silverswords on the vicinity of the 'Ahinahina Rockshelter at 11,400 ft suggests a former colony in that area...Fragments of silverswords were collected from all four excavated shelters, ranging from 10,000 to 12,000 ft. This evidence also suggests that the genus was once more widespread."

DATE	LOCATION	ELEVATION	REFERENCE
1825	South slope?	unknown	Wilson, 1922.

Note: Macrae's diary, as extracted by Wilson states, "...we had travelled 3 miles over sandy pulverized lava...The last mile was destitute of vegetation except one plant of the Syginesia Tribe, in growth much like a Yucca, with sharp pointed silver colored leaves and green upright spike of three or four feet producing pendulous branches with brown flowers, truly superb, and almost worth the journey of coming here to see it on purpose...As we advanced, every step became steeper and more difficult. All vegetation had ceased, even the yucca-looking plant, but we got up the mountain...Here we collected enough stumps and leaves to light a fire..." The lectotype specimen designated by Carr of material collected by Macrae is in the Cambridge University Botany School Herbarium, Lindley Collection, Cambridge, England. An isolectotype is in the De Candolle Herbarium at Conservatorie et Jardin Botaniques, Geneve.

DATE	LOCATION	ELEVATION	REFERENCE
1834	South slope?	unknown	Hooker, 1837.

Note: David Douglas' memoirs as collected and extracted by W. J. Hooker state, "The last plant that I saw upon the mountain was a gigantic species of the Compositae...with a column of imbricated, sharp-pointed leaves, densely covered with a silky clothing...we had to make a fire of the leaves and dead stems of the species of Compositae mentioned before, and which, together with a small Juncus, grows higher up the mountain than any other plant." Douglas' specimen is in Cambridge Botany School Herbarium, University of Cambridge, England.

DATE	LOCATION	ELEVATION	REFERENCE
1841	Wailuku Gulch	3050-3660m	Pickering, 1854.

Note: A specimen collected by the U.S. Exploring Expedition is in the Gray Herbarium of Harvard University, Cambridge, Massachusetts. Pickering wrote, "Argyroxiphium (No. 1). Having something of the habit of Yucca, but leaves shorter, closely imbricate, and silvery...Growing on Mauna Kea from the elevation of 10,000 to 12,000 feet." Also, he wrote, "In regard to vegetable growth...plants extend much higher up the mountain [on Mauna Kea]; and only at the elevation of 12,000 feet did the ground become fairly bare. Even here plants did not entirely cease, but a few scattered stocks continued in sheltered situations to within...the elevation of 13,000 feet."

1892	South slope	~3200m	Alexander, 1892.

Note:"...the party halted for lunch at an elevation of 10,500 feet. The upper limit of the māmane tree is not far from 10,000 feet...The beautiful silversword once so abundant, is nearly extinct except in the most rugged and inaccessible places."

1910	near Puu Lehu	3081m	Rock 8434 BISH

Note: This specimen is in the Herbarium Pacificum, Department of Botany, Bernice P. Bishop Museum Herbarium, Honolulu, Hawai'i. Label states "above Horner's ranch near Puu Lehu."

1915	Wailuku Gulch?	3050m?	Forbes 880 BISH

Note: This specimen is in the Bishop Museum Herbarium. Label states, "Source of the Wailuku river." This could have been at about 10,000 ft.

1916	Kukaiau	2440-3355m	Hitchcock 14280 BISH

Note: This specimen is in the Bishop Museum Herbarium. Hitchcock was probably using the Umikoa trail. In a 1917 publication of his botanical explorations, Hitchcock wrote, "...the silversword ...grows only on the slopes of cinder cones in the crater of Haleakalā and in a few very limited localities on Hawai'i."

DATE	LOCATION	ELEVATION	REFERENCE
1921	Wailuku Gulch?	unknown	K. Sunada, pers. comm.

Note: Mr. Sunada gave me a copy of a 1921 picture of his father in the company of a number of men posing with 9 silverswords collected on Mauna Kea. In the text of a 1974 speech Mr. Sunada made on his silversword experiences, he states, "As I recollect the past, his [Mr. Sunada's father] description was that his eyes glared at the reflection of the morning sun as they went up the northern or right hand side of the river head...Now, this proves to me that the Silversword were so abundant that the ground where one steps on was rather vegetated. To this, I would estimate that there were a good ten thousand plants of all sizes growing there."

DATE	LOCATION	ELEVATION	REFERENCE
1921	South slope	2750m?	E. Ide, pers. comm.

Note: In 1987, Mr. Ide said that he found only a few plants in a rocky area on his trek to the summit. Mr. Ide did not know the elevation or the location, but based on his path and the timing of the find, he may have been in the area of Halepōhaku at about 9,000ft. Mr. Ide has a photograph of himself and a companion with about 7 silversword plants.

DATE	LOCATION	ELEVATION	REFERENCE
1921	Wailuku Gulch?	Unknown	Anonymous, 1971

Note: In a 1971 Hawai'i Tribune-Herald article, Kaichi Nishimoto remembered his 1921 trip to the Wailuku Gulch (or perhaps the Waipāhoehoe Gulch) to gather silverswords. Article states, "Nishimoto has recalled that silverswords were very plentiful during those early days as they grew on flats and steep banks. 'There must have been thousands of plants, ' Nishimoto told Pung."

DATE	LOCATION	ELEVATION	REFERENCE
1921	Northeast slope	3050m	
	South slope	unknown	Bryan, 1922

Note: About his ascent on the Umikoa trail, Bryan wrote, "At about 10,00 feet the mamani becomes scattered and shortly ends. Here we find very little growth. A few bunches of grass, silversword, a silver leaf geranium and a few other plants...On the way down [from Lake Waiau] we stop to see a few patches of silversword...There are only a few remaining of this strange looking plant on Mauna Kea."

DATE	LOCATION	ELEVATION	REFERENCE
1922	West slope	3000-32000m	Skottsberg, 1926.

Note: "...only dead plants observed."

DATE	LOCATION	ELEVATION	REFERENCE
1923	Northwest slope	3200m	Hartt and Neal, 1940

Note: "Neal descended on the northwestern slope. Before any other plants, many dead stalks of silverswords were seen..." and in plant list of 1940 publication, "10,500 [feet] (dead)".

1925-6	Pahakuloa Gulch	3550m	
	Wailuku Gulch?	3200m	Kilmartin, 1975.

Note: "I found several silversword plants growing in the Wailuku river water course. They were growing at an altitude of 10,500 feet above sea level and .7 of a mile north of Puu Kaupakuhale...While mapping on the west slope I found several plants growing in Pōhakuloa gulch at an elevation of 11,650 feet above sea level and 1.7 miles downstream from lake Waiau."

1928	Pahakuloa Gulch	3350m?	S. Higashi. pers. comm.

Note: Mr. Higashi said that he saw a dozen silverswords in the gulch near the adze quarry. The quarry extends from 10,000 to 12,400 ft in elevation. He pulled one plant with multiple rosettes off the cliff wall. He also has a photograph of himself and companions with a silversword plant.

1935	South slope	3736m	Hart and Neal, 1940

Note: "The only plant of _Argyroxiphium sandwicense_ was growing upon a rocky shelf in a position well protected from grazing animals, and with it _Vaccinium peleanum_, at 12,250 feet altitude, the highest position at which any shrub was found." A specimen collected from this expedition is in the Bishop Museum Herbarium, Neal 1019, and is labeled,"below adze quarries at 3,736m alt."

1930's?	Puu Makanaka	~3660m	Bryan, 1971.

Note: Byran notes that he took a photograph of a silversword at this location.

1950	Puu Kanakaleonui	~2750m	Bryan, 1971.

Note: "I might add that my notes show one plant above Kanakaleonui on July 20, 1950."

1951	Waipāhoehoe Gulch	3050-3350m	Bryan, 1971.

Note: "...on the side of the North fork of the Wailuku River =Waipāhoehoe Branch at 10 to 11,000 ft. in elv. At that time, 1951, I counted 27 plants growing there on the Pali side where sheep could not get them."

DATE	LOCATION	ELEVATION	REFERENCE
1955	Waipāhoehoe Gulch	~2500m	Bryan, 1971.

Note: "...a plant on a side of the same gulch just above the forest fence mauka of the Kahinahina Cabin. I took Dr. J. F. Rock to see this plant on Dec. 6, 1955."

1971	Waipāhoehoe Gulch	2500-3200m	Anonymous, 1971

Note: "State Forester Ernest Pung of Hilo says there are about 100 plants on Mauna Kea...between the 8,000 and 10,500 foot level...about 30 or 40 of them are full-sized. Others are younger and smaller."

1971	Waipāhoehoe Gulch	3050-3200m	K. Sunada, pers. comm.

Note: Mr. Sunada recalled his 1971 trip to Mauna Kea with Ernest Pung. He recalled seeing 60 to 80 plants in the Waipāhoehoe Gulch between 10,000 and 10,500 feet in elevation.

1971	Waipāhoehoe Gulch	2750-3050m	Wakida, 1971.

Note: "In all, just casually observing as we walked down, we saw about 15-20 plants...Best group of about 10 plants was on a ledge just about at 9,400 feet where a couple other gullies meet the Wailuku." (However, this gulch was actually the Waipāhoehoe.)

1970-1972	Waikahalulu	~3600m?	S. Porter, pers. comm.

Note: Stephen Porter wrote: " I made several sightings of silverswords during my work on Mauna Kea in 1970-1972,. . . I found these plants in and near upper Waikahalulu Gulch on the south side of the mountain, mainly on ledges of cliff faces where feral goats and sheep could not reach them. If my memory is correct, I probably saw half a dozen plants, at least, as well as dead ones. Those growing on open slopes or accessible cliffs were extremely vulnerable to destruction by browsing animals, which were plentiful at that time on the intermediate and upper slopes of the mountain. I was surprised to see these plants, as I had been led to believe that they grew only on Haleakalā."

1973	Waipāhoehoe Gulch	2750-3050m	Landgraf, 1973.

Note: He notes "In the Wailuku River Canyon, between 9,000 and 10,000 feet...The Division has initiated a program to protect existing plants (approximately 150 on 75 acres)..."

DATE	LOCATION	ELEVATION	REFERENCE
1977	Waipāhoehoe Gulch	2800-2866m	Meyrat MK-25 HAW.

Note: Meyrat collections MK-10, MK-21, MK-22, and MK-24, from 1977 are also in the University of Hawai'i Herbarium. Note that collections and population estimates after 1973 reflect primarily plants that were planted on Mauna Kea within exclosures.

1978	Waipāhoehoe Gulch	2800-2866m	Meyrat MK-55A HAW.

Note: Meyrat collections Mk-55B, MK-56B, MK-57A, MK-57B, and MK-58A are in the University of Hawai'i Herbarium. Meyrat collections MK-56A, MK-58B, and MK-58C are in the Bishop Museum Herbarium.

1978	Waipāhoehoe Gulch	2,850m	Meyrat, 1982.

Note: "...only 35 plants were counted in 1978."

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