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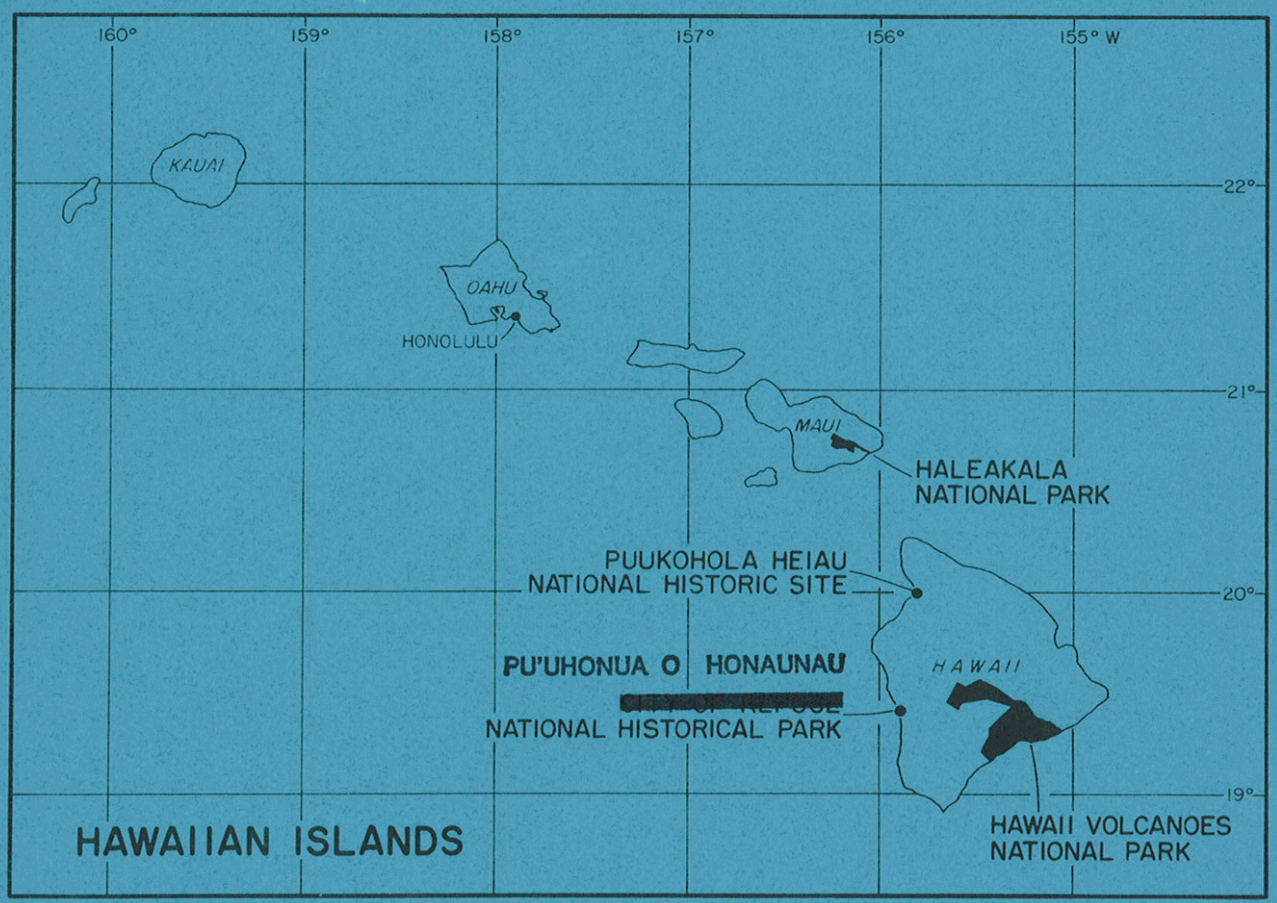
## Hawaii

Technical Report 58

# STATUS OF THE SILVERSWORD IN HALEAKALÄ NATIONAL PARK: PAST AND PRESENT

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# STATUS OF THE SILVERSWORD IN HALEAKALÄ NATIONAL PARK: PAST AND PRESENT

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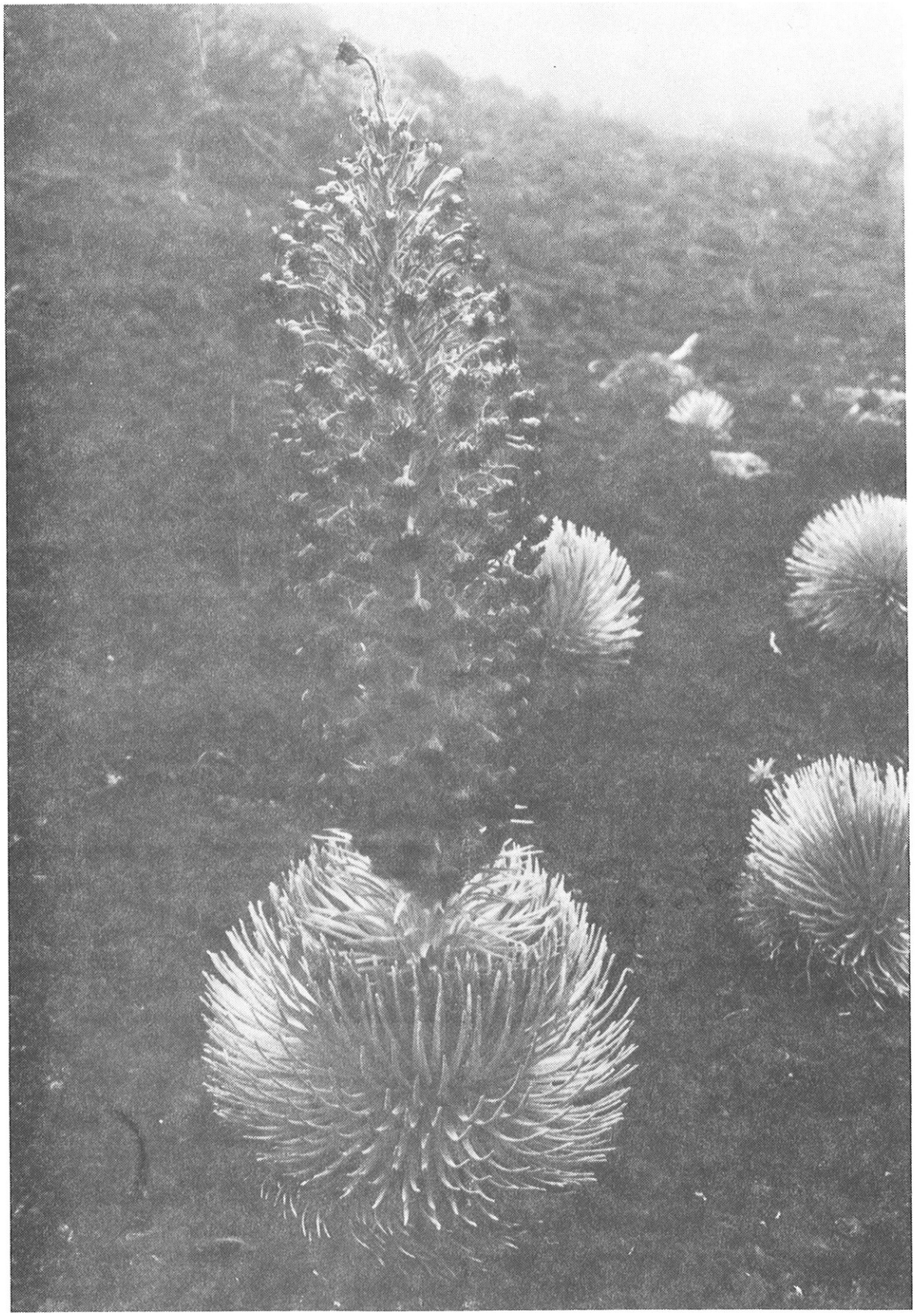


Frontispiece Haleakalā silversword in Haleakalā Crater, Maui, Hawaiian Islands.

## ABSTRACT

The Haleakalā silversword, Argyroxiphium sandwicense DC. ssp. macrocephalum (Gray) Meyrat, declined markedly in the late 1800's and early 1900's due to browsing by goats and cattle and to vandalism by humans. During the 1930's, after protection was provided by the national park, much concern arose over the high level of seed predation by native insects. Nevertheless, following protection, silversword numbers have increased and now total about 50,000 individuals. Although total crater-wide numbers remained stable between censuses in 1971 and 1982, large fluctuations have occurred on individual cinder cones. Plots for long-term study of silversword population dynamics have been established, with data taken annually. Preliminary results after three years suggest that many seedlings establish in some years, few or none in others; that substantial natural mortality occurs in some years; and that wide population fluctuations from year to year are occurring. The greatest threats to the Haleakalā silversword today are thought to be the Argentine ant (Iridomyrmex humilis) and the western yellow-jacket (Vespula pensylvanica), aggressive alien predators (of insects) which could disrupt ecosystem processes, especially pollination. Park managers now recognize the need for preservation of the entire complex of organisms belonging to the silversword ecosystem.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

## INTRODUCTION

The Haleakalā silversword (Argyroxiphium sandwicense DC. ssp. macrocephalum (Gray) Meyrat) receives more attention from visitors to Haleakalā National Park than any other plant species because of its bizarre and beautiful appearance and its limited distribution. This giant rosette plant (Frontispiece) is endemic to the upper slopes of Haleakalā. It has historically received much attention from botanists and park managers for the above reasons and because it has in the past appeared in danger of extinction. Although it has recovered from low populations in the 1920's and currently has stable and increasing populations, long-term survival of the Haleakalā silversword is by no means assured. Its long-lived monocarpic habit, its lack of vegetative reproduction, and other aspects of its life history make it potentially vulnerable to man-induced perturbations. Such perturbations have placed the other subspecies of A. sandwicense, endemic to the island of Hawaii, near the brink of extinction (Degeners and Sunadas 1976; Carr and Meyrat 1982). This report presents data on the current status of the Haleakalā subspecies and reviews relevant aspects of its biology and management history.

## SOME ASPECTS OF SILVERSWORD ENVIRONMENT AND BIOLOGY

Haleakalā silverswords grow primarily on otherwise barren slopes of cinder cones and to a lesser extent on lava flows within Haleakalā Crater at elevations of 2200-3000m (Fig. 1). All 21 lava flows on the floor of Haleakalā Crater, mapped by Macdonald (1978), are believed by Crandell (1983) to be younger than 2500 years old. Abundant cinder and ash deposits 2500 years old and younger on Haleakalā's upper west slope (Crandell 1983 pers. comm.) suggest that cinder cone activity in the crater is also very recent.

Climate of silversword habitat is characterized by heavy precipitation in sporadic winter storms, dry summers, typically low relative humidities, usually clear skies with high solar radiation, and warm days with high soil surface temperatures and cool nights with the possibility of freezing temperatures during any month of the year (Kobayashi 1973a). Whereas mean monthly temperatures vary less than 4°C between January and July, fluctuations of 20°C can occur within a single day (U.S. Dept. of Commerce 1969-84). Median annual precipitation in silversword habitat is in the neighborhood of 1250mm (State of Hawaii 1982), probably ranging from about 1000mm to 1500mm, with 75% of it falling in the November-April period and with large annual fluctuations (Fig. 2, U.S. Dept. of Commerce 1969-1984). Trade wind clouds move into upper Ko'olau Gap when the trade wind inversion (Blumenstock and Price 1967) is high, creating opportunity for fog drip. Kobayashi (1973a), using

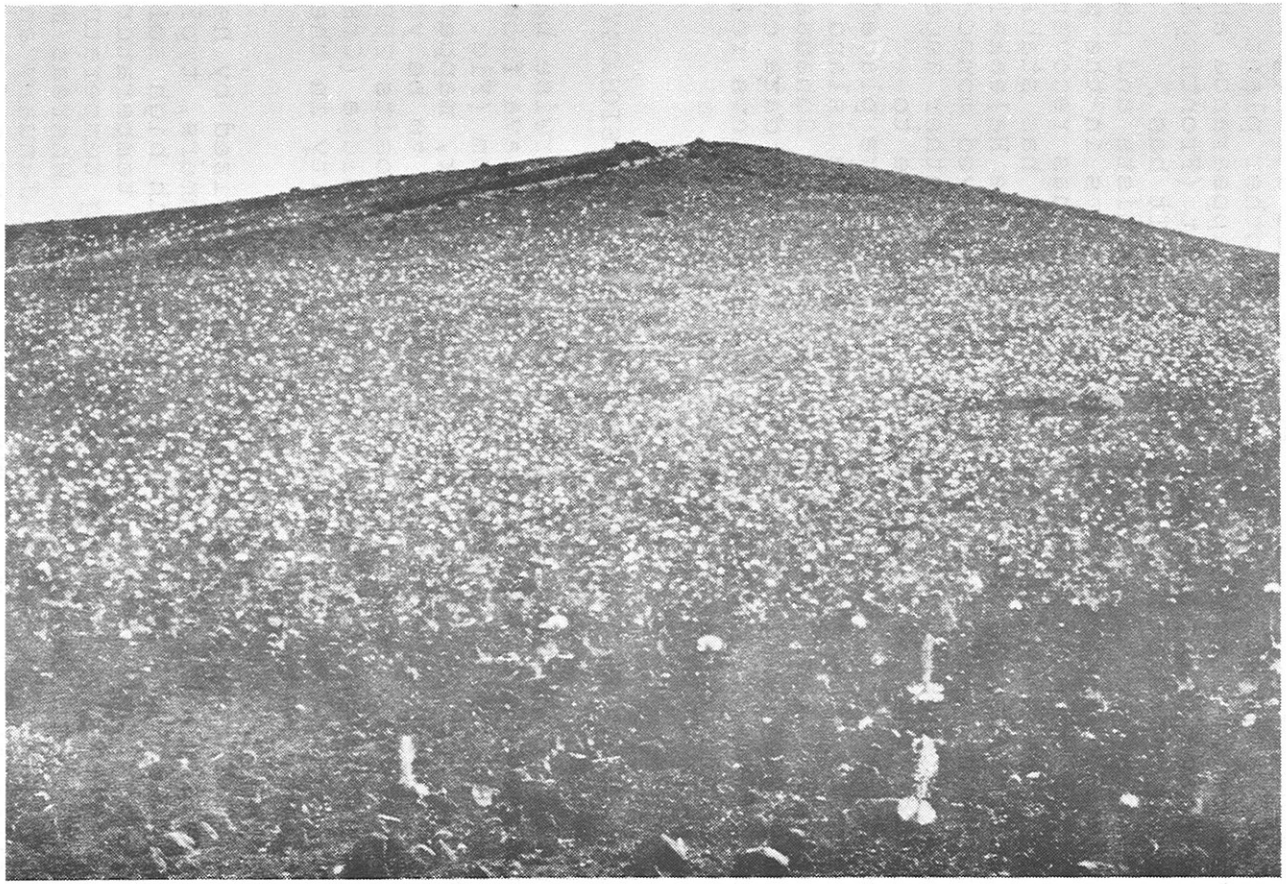


Figure 1. High density of silverswords on north slope of Pu'uomaui, Haleakala National Park, Maui, Hawaiian Islands.

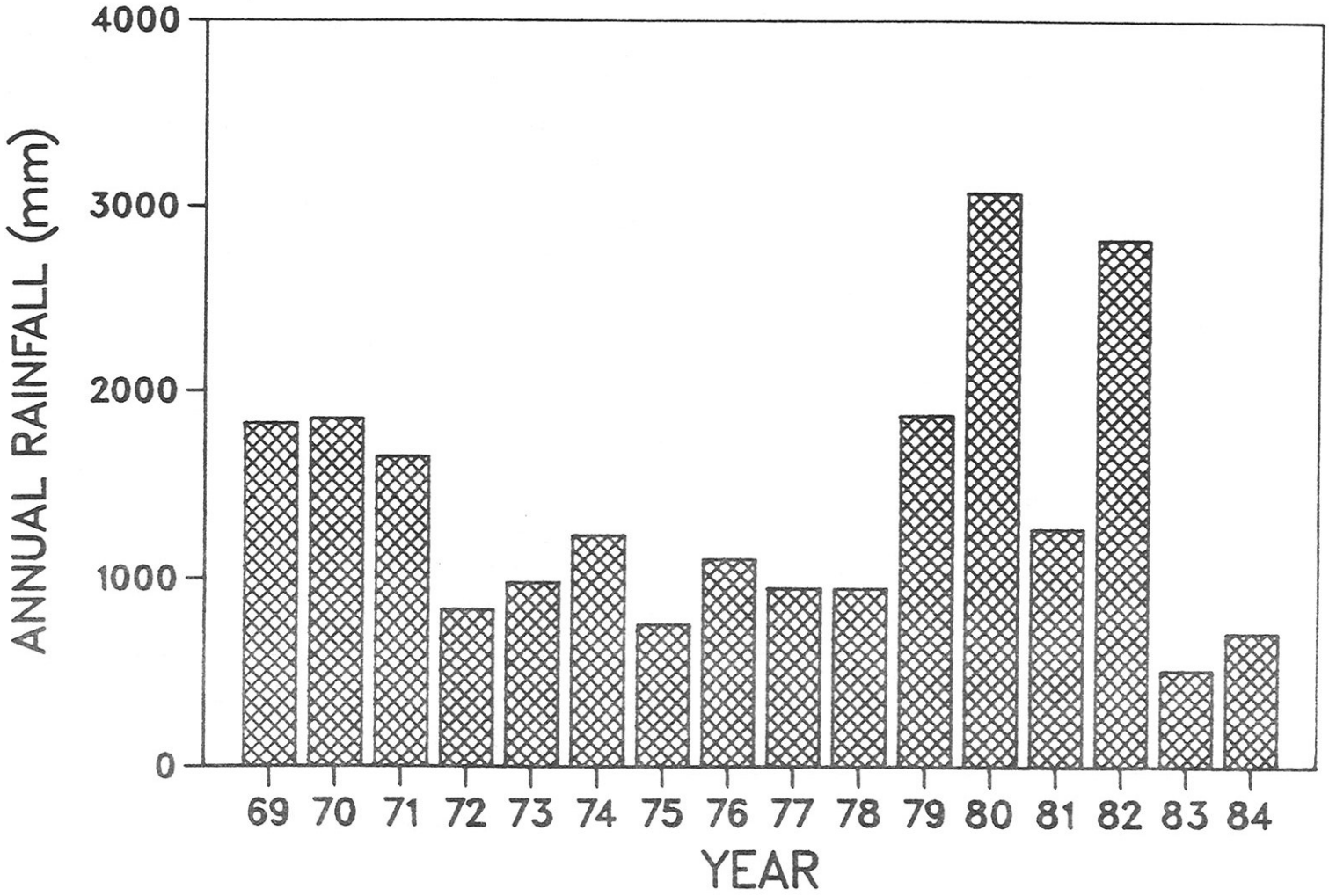



Figure 2. Variation in annual precipitation at Haleakalā Ranger Station (2147m), Maui, Hawaiian Islands, 1969-84.

fog-interception gages designed to simulate silversword plants, found that fog drip may be an important source of moisture in silversword habitats in central Haleakalā Crater, especially in periods without rainfall. Over an 8-month period, fog drip averaged 8-10mm/week and was comparable in amount to precipitation.

The Haleakalā silversword is generally considered to have a vegetative growth phase of 7-20 years (Ruhle 1959) before flowering and death, although insufficient data exists to give the actual range. (Plants started under greenhouse conditions and planted at Haleakalā National Park headquarters have flowered less than three years after germination.) Initiation of flowering stalks starts in late May to early June, with peak flowering in July-August. Flowering continues into September. The single flower stalk reaches 0.7-1.5m in height and bears 150-600 flower heads (Meyrat, Carr and Smith 1983). Tremendous annual variation occurs in numbers of flowering silverswords (Table 4). Seeds ripen in September-November followed shortly thereafter by wind-dispersal.

Silversword seeds germinate best at 25°C and they lose viability when exposed to 35°C for 8 hours (Siegel et al. 1970). Soil surface temperatures in Haleakalā Crater commonly exceed 35°C (Kobayashi 1973a). Kobayashi (1973a) described in detail the exacting and dynamic substrate conditions necessary for highly successful silversword seedling establishment--a layer of coarse, slowly sliding cinder fragments no thicker than 5cm overlying a substratum of sand-sized cinder particles with a high moisture retaining capacity. Such substrate occurs only on cinder cone slopes of approximately 35 degrees. According to Kobayashi's hypothesis, silversword seeds sift through the coarse surface fragments (thus avoiding lethal soil surface temperatures). Following germination, root growth and survival are sustained by the moisture of the underlying sandy layer. Such sites with optimal reproduction are obviously ephemeral since maintenance of proper depth and particle size of the veneer layer requires the presence of a parent material source in just the right amount. Over a period of centuries, optimal sites of silversword habitat will probably shift considerably. Maintenance of optimal conditions through time probably depends on continual cinder cone activity.

Hybrids between Argyroxiphium sandwicense and Dubautia menziesii were first reported by Kobayashi (1973b). Carr and Kyhos (1981) verified their hybrid status through experimental crossing and cytological analysis. These hybrids occur at the base of cinder cones where the habitats of the two species (A. sandwicense on cinder cones, D. menziesii on adjacent lava flows) overlap. Peak flowering times of the two species differ, but flowering times overlap slightly in September. Two dozen such hybrids were reported by Kobayashi (1973b). Our 1982 silversword census located only seven hybrids.

Several endemic insect species are associated with the silversword ecosystem--including flies (Trupanea), bees (Nesoprosopis), moths (Agrotis, Rhynchephestia), planthoppers (Nesosydne), and a cerambycid beetle (Plagithmysis, Fig. 3).

## PAST POPULATION STATUS: DECLINE AND RESURGENCE

Accounts of the East Maui silversword prior to 1900 (Missionary Herald 1829; Wilkes 1845; Bird 1890; Alexander 1870; Pickering 1876) give little specific information on silversword distribution and abundance. Several of them give descriptions which can be and have traditionally been interpreted as indicating that the plants were very abundant (e.g., reference to a "field of silverswords" by Alexander in an area where few exist now; descriptive passage by Bird of "thousands of silverswords...making the hillside look like winter or moonlight" in 1873). There is no firm evidence that silverswords ever occurred extensively on East Maui outside Haleakalā Crater. They were observed by Wilkes (1845) who noted them on Haleakalā's west slope in 1841 "commencing at an elevation of 9000 ft [2744m], and extending to within 30 feet of the summit." However, Rock (1913) stated that "in earlier days this interesting plant was also found plentifully on the slopes of the mountain, but it has now vanished.." Rock wrote that "the steep slopes in the upper part of Kaupō gap are covered with this most beautiful plant. Wild goats are doing great damage to it, as they devour it eagerly, and so also do cattle.."

There is firm evidence that feral goats and cattle were present up to Haleakalā's summit as early as 1841, based on a report of "a few goats" and "bullock tracks" by Wilkes (1845). Domestic cattle were pastured in Haleakalā Crater and on Kalapawili Ridge during summers until many years after the park was established in 1916 (von Tempsky 1944:258-259). It is likely that the range of the silversword was reduced substantially at its periphery by browsing and trampling by these introduced animals. Whereas silversword is not particularly preferred as a browse plant, there is no doubt that goats, cattle, and horses will browse it when available (Fig. 4). Within a few years after Rock (1913) wrote of its decline in upper Kaupō gap, it had disappeared from there and has not since reestablished. Browsing may have had less impact on silverswords on cinder cones in the central portion of Haleakalā Crater because the vegetation there may have always been too sparse to attract more than occasional browsing animals.

Newspaper reports and other accounts from the early 1900's strongly suggest that direct impact on silversword plants by humans may have been the primary cause of whatever decline occurred in that area. Lyon (1896) mentions the practice of rolling "huge blocks of lava rock down into the crater" for

Figure 3. Cerambycid beetle (Plagithmysus terryi Perkins) in silversword root, Haleakala National Park, Maui, Hawaiian Islands (photograph by B. H. Gagné).

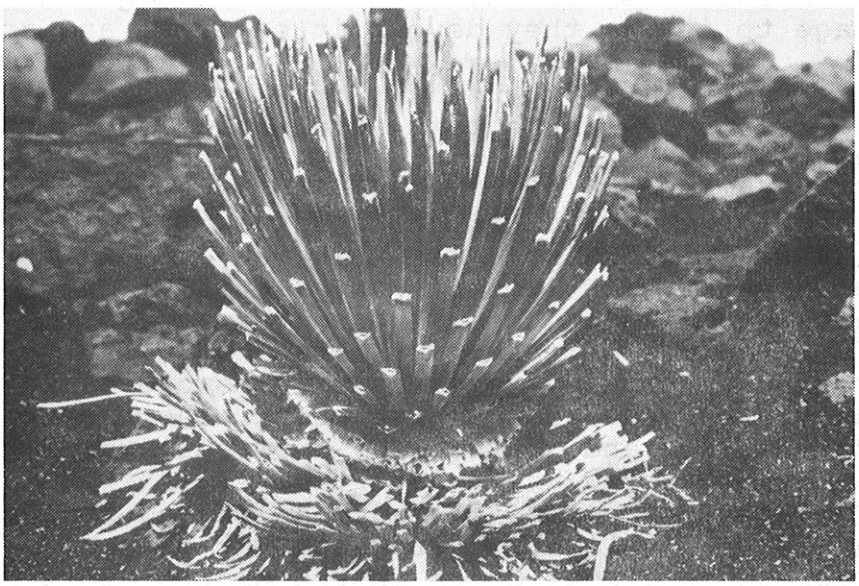


Figure 4. Browsed silversword, Haleakala National Park, Maui, Hawaiian Islands (photograph by R. J. Nagata).

entertainment. Richards, reportedly the first Caucasian to ascend Haleakalā, stated that "our guide and servants made ornaments of it for their hats, to demonstrate to those below that they had been to the top of the mountain" (Missionary Herald 1829). This possibly harmless practice of the indigenous Hawaiians was escalated considerably within the next 100 years, with removal of whole plants becoming commonplace (Fig. 5).

In 1911, Dr. Aiken, a physician from Kahului, Maui, established a tradition of gathering silverswords for the purpose of decorating floats for the annual Washington's Birthday parade in Honolulu. In 1911, his group found that "wild cattle had eaten most of the plants in places of easy access," but "after much hard work.. obtained seven gunny sacks full of them" (Maui News 1911a). In the parade, Aiken's car "was one immense silversword" (Maui News 1911b). In 1913 it took two days and several persons to obtain "nine gunny sacks" (Maui News 1913a). This tradition was continued at least until 1914 (Maui News 1914; Fig. 6). As their fame spread, silverswords began to take on commercial value. The October 1921 issue of Popular Science Monthly (p.8, classified ads) contained an advertisement for the sale of silverswords--"a specimen at fifty cents or a whole plant for One Hundred Dollars" (Maui News 1921b).

Populations seem to have reached a low point in the 1920's. Rock (1913) reported that "they still occur in thousands in Haleakalā crater.." Haleakalā Ranch manager Louis von Tempsky was reported in a newspaper article to have said that "although the plants have been pretty well cleaned out on one side of the crater [Kaupō gap side], there were plenty more than ever before--in places known to dwellers on the mountain side" (Maui News 1913b). By 1921, however, the Maui Chamber of Commerce sent a petition to Washington requesting action to save the silversword from extinction due to vandalism (Maui News 1921a). Although they were sent a copy of existing legislation protecting the flora and fauna of the national park (which had been established on paper in 1916, but without land acquisition), no steps had been taken to enforce regulations as late as 1925 (Maui News 1921c, 1925). Botanist Otto Degener, after a survey of Ko'olau Gap and adjacent Haleakalā Crater in 1927, reported to the park superintendent that "barely 100 plants were left of the silversword population" (Degener 1930). Responding to a letter from Supt. Wingate in 1935, Degener stated that the reference to 100 individuals in 1927 referred to plants of all ages (Lamb 1936).

Degener's report is difficult to reconcile with that of S.H. Lamb only eight years later. Lamb (1935b) reported counting 1470 silversword plants (of which 88 were blooming and 743 were over 8in in diameter) on a single cinder cone--Kamoaopele. He found that a total of at least 217 plants were flowering in the crater in 1935. Lamb's (1935a)

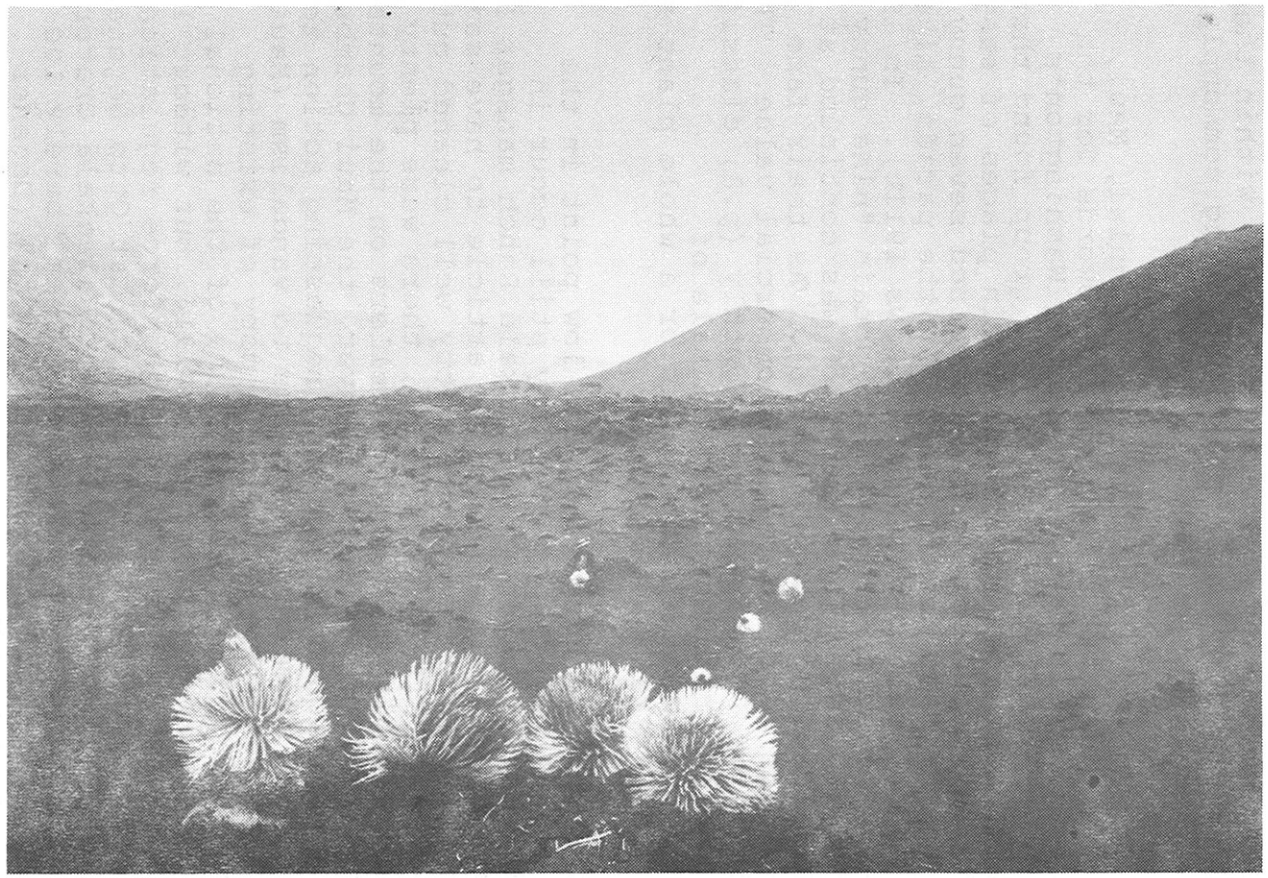


Figure 5. Vandalized silverswords near Kapalaoa, Haleakala National Park, Maui, Hawaiian Islands (photograph from early 1900's--B. P. Bishop Museum).

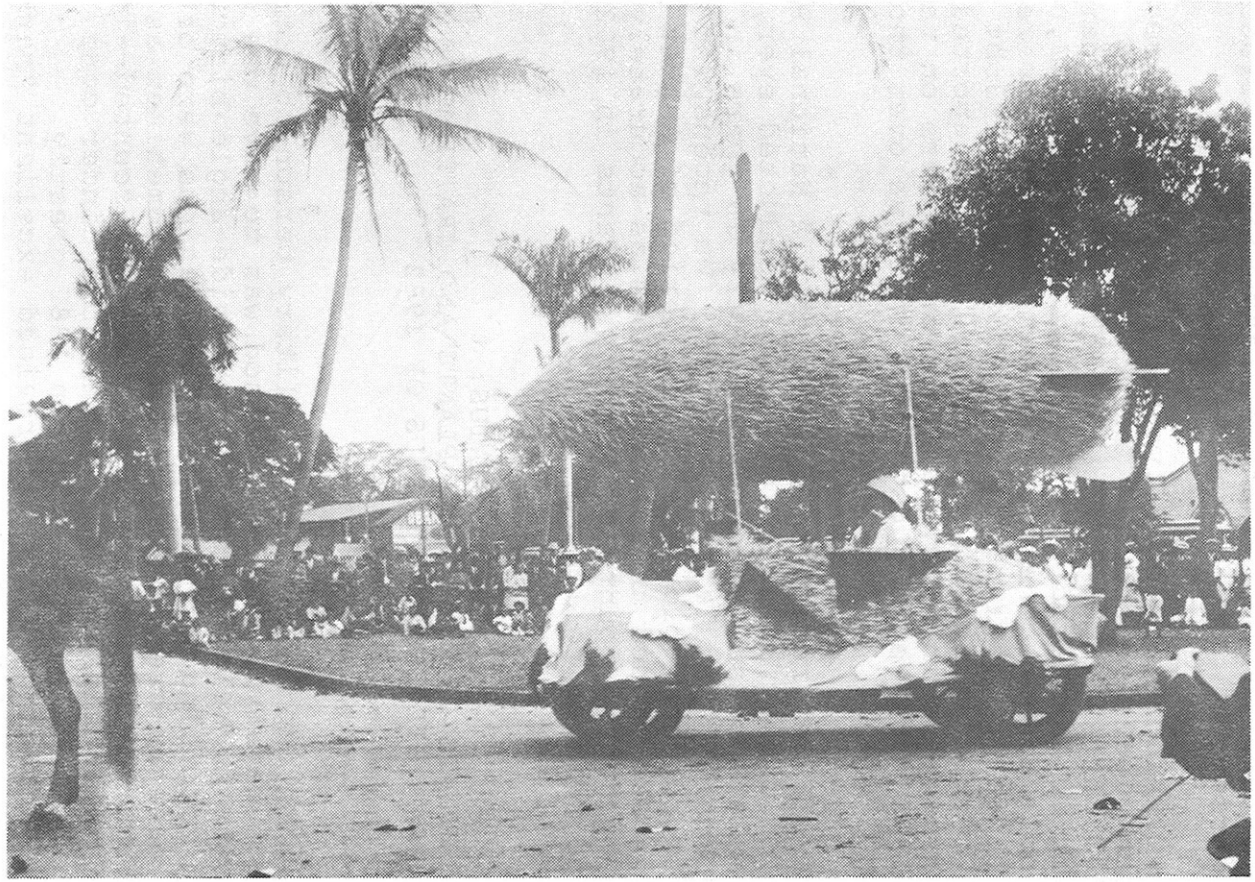


Figure 6. Silversword float in Honolulu parade, February 1914 (photograph--Hawaii State Archives).

conclusion after consulting numerous individuals knowledgeable on the subject was that "the plants are probably as numerous now as they have ever been since 1906, although some areas have been denuded or decimated." Powers (1938) made useful baseline assessments of relative silversword abundance in various parts of Haleakalā Crater. In 1941, Ranger Frank Hjort recorded 815 flowering silverswords.

No further information on silversword numbers was recorded until Badaracco (1962) recensused Kamoaopele. Kobayashi (1973a) carried out an extensive census throughout the park in 1971, recording an estimated total population of over 43,000 plants. The only cinder cone where he was able to compare numbers with those of previous investigators (Lamb 1935b; Badaracco 1962) was Kamoaopele. Kobayashi (1979) reported on a resurvey of Kamoaopele in 1979. Silversword numbers on this cone for the 1970's showed a substantial increase over those of the 1930's and 1960's.

Kobayashi (1973a) recommended to Haleakalā National Park that a census of flowering silverswords be conducted every year and that a complete census be conducted every 10 years in order to adequately monitor population dynamics. We recensused the entire silversword population during the period of August 24 to September 18, 1982, mapped these populations as accurately as we could, and conducted counts of flowering plants in 1982-85. Our methods and results follow.

## CURRENT STATUS: ANNUAL COUNTS OF FLOWERING PLANTS AND CRATER-WIDE SILVERSWORD CENSUS OF 1982

### Methods

It was almost impossible for a solitary person to count silverswords accurately. The best method was to have one or two persons counting using a good pair of wide-angle binoculars and one person recording the numbers. Evaluations were often made from the base or crest of a cinder cone--sometimes as much as 200m away from the most distant plants being counted--in order to avoid serious damage to the unstable cinder cone slopes. The high level of flowering in 1982 greatly facilitated the counting, since it provided excellent "markers" to divide the populations into manageable segments for counting. In addition to flowering plants, other vegetation, rock outcroppings, and contrasting colors of cinder were used for this purpose.

Plants were recorded in one of three categories used by Kobayashi (1973a) and earlier investigators--flowering plants, plants greater than 20cm in diameter, and plants less than 20cm in diameter. Differentiating the two latter classes was done visually, by comparing observed plants with a mental image of

measured plants 20cm in diameter. We feel that accuracy within 5cm or less is obtained with this method. A more serious problem is that many small plants are inevitably missed. The count for plants less than 20cm in diameter should be regarded as a minimum number in this size class. In spite of obvious inadequacies of the method for obtaining precise counts, we feel fairly confident regarding the method and the data for all counts except those on the north slope of Pu'uomaui where the plants are very closely spaced and seem virtually impossible to count accurately without unacceptable disturbance.

We recorded population data so as to correspond as closely as possible to the data of Kobayashi (1973a). In many instances, however, interpretation of boundaries of individual populations (listed and mapped in Appendix III and IV of Kobayashi 1973a) was not possible so that comparisons could only be done for entire cinder cones. Like Kobayashi, we generally recorded populations only if they had at least 25 individuals. Populations were mapped as accurately as possible in the field using topographic base maps at a scale of 1:12,000.

Results and Discussion

The 1982 silversword census data is tabulated and compared with the 1971 data of Kobayashi (1973a) in Table 1. Comparison of 1982 data for Kamoaopele with his (Kobayashi 1979) data and data of previous investigators is given in Tables 2a and 2b. Table 3 gives comparisons of total populations of individual cinder cones in the format of Powers (1938). The silversword populations based on Kobayashi's (1973a) interpretations in 1971 were mapped and our delineations from 1982 field work added (Figure 7).

Any serious comparison of data sets of this sort must recognize that the potential for counting error is great. We cannot discard the possibility of counting or tabulating errors in earlier censuses, or for that matter, during the 1982 census. We made the most accurate count we could and assume that previous workers did the same.

The total population shows a modest increase of 10% from 1971 to 1982. However, when individual areas or populations are compared, the fluctuations in numbers appear to have been great. The following increases were recorded for major cinder cones: Pu'uopele, 34% increase; Kama'oli'i, 40% increase; Kamoaopele, 70% increase; and Pu'unaue, 75% increase. The increase on Halāli'i from 44 to 1079 is presumably artificial--the result of failure of previous investigators to examine the craters of this cinder cone. On the other hand, spectacular decreases were recorded for Pu'u nole (50% decrease) and Pu'uomaui (44% decrease). The latter is particularly noteworthy since it involves a decrease of over 9000 plants. Since we found the silverswords on the north

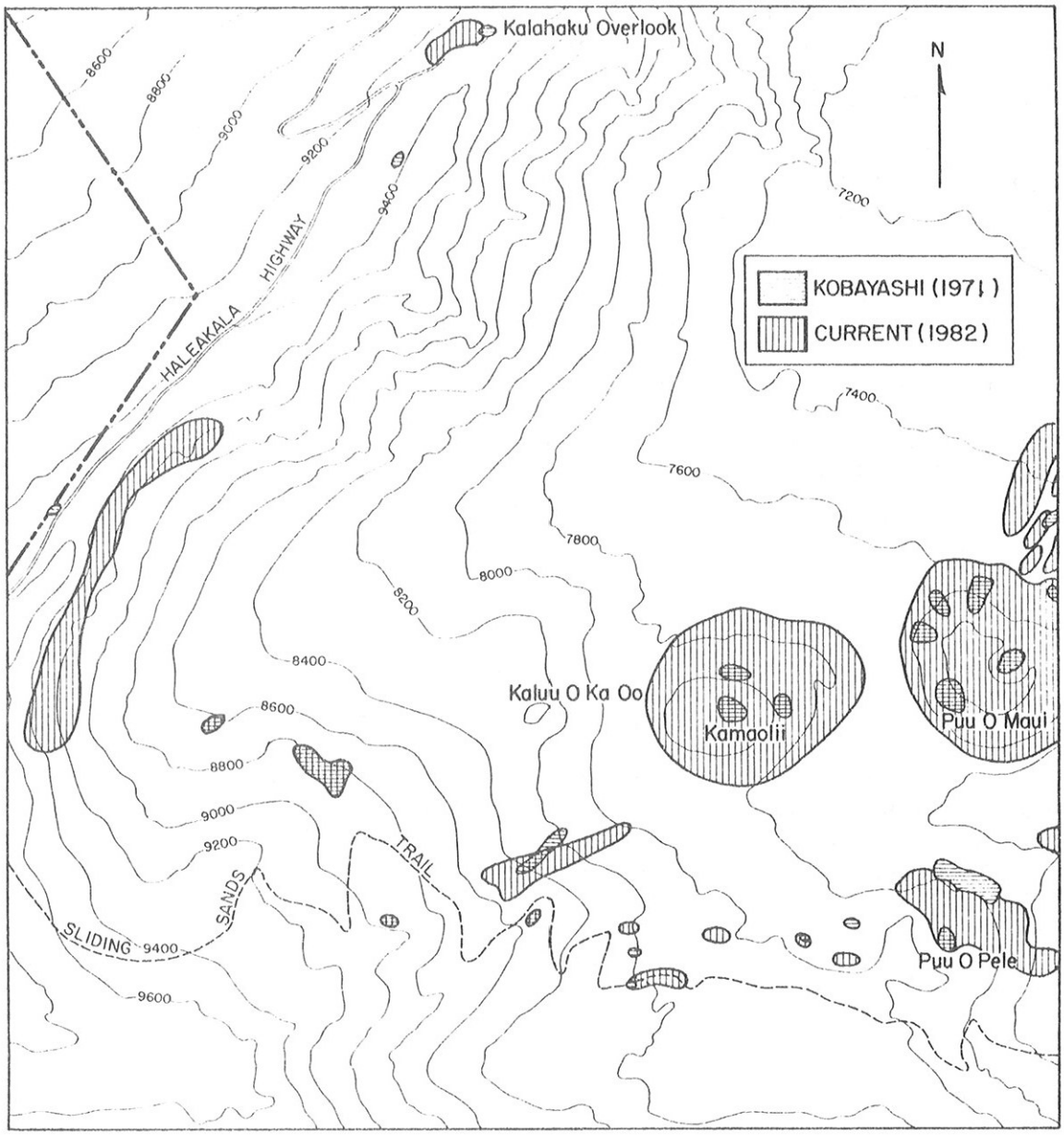
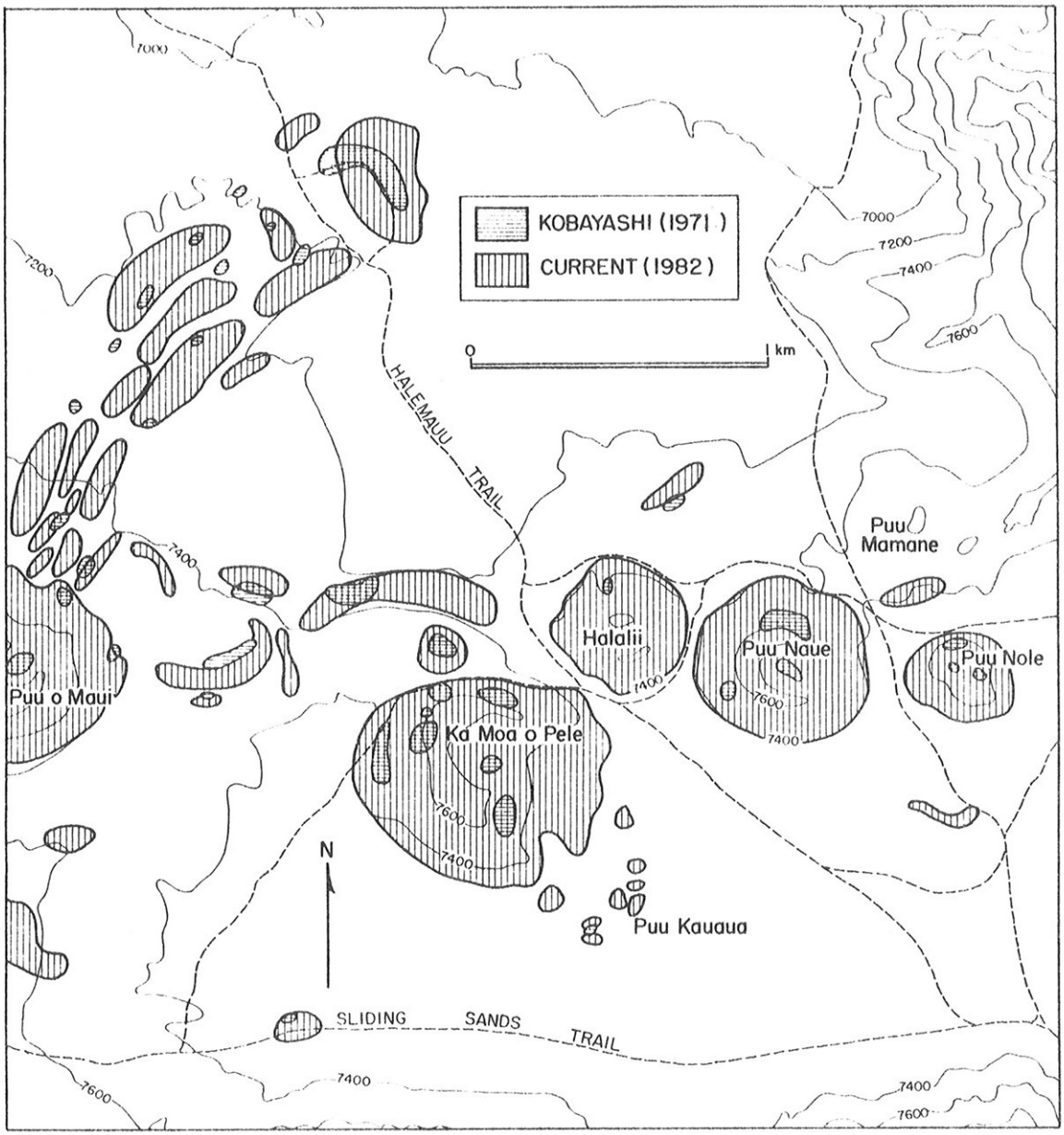



Figure 7. Map showing distribution Haleakalä silversword in Haleakalä National Park, Maui, Hawaiian Islands.


KOBAYASHI (1971)
CURRENT (1982)
0
km
HALEMAUU TRAIL
Puu Mamane
Halalii
Puu Naue
Puu Nole
Puu o Maui
Ka Moa o Pele
Puu Kauaua
N
SLIDING SANDS TRAIL
7000
7200
7400
7600

slope to be by far the most difficult to count and since Kobayashi (1973a) rounded his counts for this area to the nearest thousand, we doubt that the decrease on Pu'uomaui is as significant as the numbers indicate.

The comparisons in Tables 2 and 3 provide revealing results. Not only has the total population on Kamoaopele increased by 70% since 1971, but it has increased by 84% since 1979! The number of plants less than 20cm in diameter has more than doubled in the three years since 1979. In area IV (north slope), one of the easiest areas in the Crater to count because of its proximity to the trail, the increase in plants less than 20cm in diameter has been over 400% since 1979. Counting is quite easy for Kamoaopele in general. That the numbers are up substantially in all parts of this cinder cone with more than a few plants suggests strongly that excellent reproduction of silverswords took place in the years preceding 1982, perhaps following the relatively good flowering years of 1978 (with 284 recorded flowering plants, Table 4) and 1979 (with 436 flowering). The possibility that delayed germination and slow growth following the excellent flowering year of 1974 (with 797 flowering plants recorded) is now showing results also exsists. The combination of large numbers of seeds in the soil and optimal environmental conditions for germination and growth may result in rapid increases. A comparison of precipitation for the past 15 years at Haleakalā Ranger Station (at 2147m on the NW slope of Haleakalā) shows that the mid-1978 to mid-1982 period was much wetter (mean annual precipitation = 2184mm) than any comparable period since before 1967. (Mean annual precipitation during the 35-year period of record at Haleakalā Ranger Station is 1350mm).

The number of flowering silverswords in 1982 (2262) far surpasses any year for which data are available (Table 4). Counts in subsequent years found 903 plants in 1983, 84 plants in 1984, and 163 plants in 1985. The previous high count, which took place in 1941 (Kobayashi 1973a, and Haleakalā National Park files), was 815. The possibility exists that greater numbers of flowering plants were present in some years but were not recorded, and certain locations such as the craters of cinder cones may have been missed in such years as 1941 and 1974.

What environmental factor triggers heavy silversword flowering? A parameter that obviously varies substantially from year to year is precipitation. When precipitation for the 6, 12, and 24-month periods preceeding flowering (arbitrarily chosen as occurring on July 1) is compared with the number of recorded flowering plants for a 15-year period, no correlation is evident (Table 5).

The ecology of the silversword population on Pu'uomaui could be a profitable subject for future investigations. Certain areas on the north slope of this cinder cone have an

almost continuous cover of silverswords. Kobayashi (1973a) found that approximately half the entire Haleakalā silversword population occurred on this one cinder cone, yet only 12.8% of the flowering plants occurred there in 1969 and 2.4% in 1971. In 1982, 17.7% of the plants flowering were on Pu'uomaui, whereas 25.1% of the total population was recorded there. In 1971, 90.9% of the Pu'uomaui plants were under 20 cm in diameter. In 1982, 83.9% of the Pu'uomaui plants were still under 20 cm in diameter, even though the population appeared to have declined by over 9000 plants.

## SILVERSWORD MANAGEMENT AND RESEARCH IN HALEAKALĀ NATIONAL PARK: HISTORY AND FUTURE NEEDS

Management of Haleakalā National Park (status as Haleakalā section of Hawaii N.P., 1916-1961) began in the late-1920's and strict protection of flora and fauna was instituted. A permanent ranger was assigned there in 1936. That protection of the silversword was considered a very high priority in the early days of the park is not surprising in view of the local concern for and interest in the plant. With limited personnel, strict protection was emphasized above all else through the 1940's. The main park entrance was either manned or locked, primarily to prevent illegal removal of silverswords and other park resources (C. McCall pers. comm.).

No sooner had vandalism been effectively brought under control than concern arose regarding the impact of insects on silversword seeds. During his trip in the crater in August 1927, Degener collected insects associated with silversword and took them to O.H. Swezey, entomologist with the Hawaii Sugar Planters Association, resulting in a report by Swezey and Degener (1928) which provided identifications for most of the species. Degener (1930) reported that predation on seeds by two insect species, a phycitid moth [Rhynchephestia rhabdotis Hampson] and a tephritid fly [Tephritis (Trupanea) cratericola Grimshaw], was "so enormous that only a few could be gathered for propagation." Hillebrand (1854) had called attention to this same phenomenon nearly 80 years earlier.

Substantial pressure was brought to bear upon the National Park Service by the local press to deal with this emergency situation and evidence of action was forthcoming. A Maui News article (1930) titled "PESTS DESTROY BEAUTIFUL SILVER SWORDS IN CRATER," stated the situation dramatically: "The silver sword in the crater of Haleakalā is threatened with extermination. Five different kinds of pest are feeding on the plant, famed the world over, and sapping from it every vestige of vitality. There is a large worm eating into the roots, another worm that is feeding on the stem, a beetle that is eating the leaves and a fly... No one is able to give any explanations of how the pests got into the crater and attacked the sword. One thing is

certain, the national park authorities are going to take every measure possible to prevent further ravages..."

Degener's (1930) analysis of the situation seems to reflect the thinking of that time: "From its former abundance and its present scarcity, the Haleakalã silversword appears to be on the road to extinction unless action is taken. Two main factors are responsible, namely man and insects.... The most praticable way to increase the number of silverswords in Haleakalã is to spray the plants judicially with insecticides from the time the flowering cluster develops until the seeds are mature. This work should be supplemented by placing fine-meshed cages over a few clumps of sprayed plants just before these are ready to reproduce, and insuring cross-pollination at the correct time later on. This would enable the ripening of many thousands of good seed. These could be scattered or raked into the cinders in favorable places for growth."

A program of insecticide spraying was apparently initiated by the National Park Service in 1931 (Maui News 1931). No further manipulation of this type was done after 1935, however, when Ranger S.H. Lamb (assisted by Civilian Conservation Corps personnel) carried out a project designed to gather pertinent information and formulate recommendations for silversword management. Lamb made observations on the life histories of and damage by the silversword insect fauna and consulted extensively with Dr. Swezey and other experts. Dr. Swezey pointed out the ineffectiveness of widespread spraying and advised that "each insect be treated separately" and its life cycle studied to determine the most effective means of control. Burning of plants after completion of flowering and seed dispersal, a technique suggested by Swezey to destroy insect larvae, was tried. It was discontinued after it was found that even dead plants would not burn readily and that burying the dead plants was too time consuming. Experiments with tenting of plants with cheese cloth and bamboo were inconclusive due to weather and vandalism, and were abandoned after Lamb found that abundant viable seed was being produced by unprotected plants. He also noted good seedling establishment. Lamb's (1936) conclusion was that the insects in question are not recent introductions and have been living in association with silverswords for a long period of time. His report advocates a "wait and see" attitude.

Concern regarding insect impacts resurfaced in the 1960's, after destruction of silversword seed by insects was estimated at 80-100% by entomologist J.W. Beardsley in 1962 and at 90-95% in 1968 by Park Naturalist R. Harris. Nevertheless, Larson (1969) considered that the silversword in Haleakalã "has begun the slow process of regaining its former range."

Kobayashi (a Ph.D. candidate in the University of Hawaii Botany Department) began his important study on silversword

ecology with financial support of the Hawaii Natural History Association in 1969. His findings (Kobayashi 1973a; 1974) strongly supported and updated the earlier findings of Lamb (1935a,b; 1936). He found that silversword populations had expanded substantially since the 1900's and that insect predation on seeds, while quite significant (average of 40% of the seeds destroyed in the 10 populations sampled in 1971), was not jeopardizing abundant seedling establishment (Kobayashi 1974). He identified human trampling of young silverswords and soil compaction and disturbance as a major potential threat, but found that it was affecting only than 1% of the population that occurs along park trails (Kobayashi 1973a).

Increased and sustained concern by the Haleakalã National Park administration for the park's magnificent but rapidly deteriorating biological resources in the mid-1970's led to an increased research effort--at first largely through the University of Hawaii (e.g., Beardsley 1980; Stemmermann et al. 1981) and later (after 1980) with research personnel stationed at Haleakalã. Efforts at resource management also increased; by 1985, fencing of Haleakalã's Crater District to allow feral goat control was approaching completion.

Carr (University of Hawaii Botany Department) undertook long-term studies on the systematics and biology of the Argyroxiphium-Dubautia alliance, beginning in the mid-1970's (e.g., Carr and Kyhos 1981; Carr and Meyrat 1982; Meyrat, Carr and Smith 1983, Carr 1985). In 1982-84, Elizabeth Powell, one of Carr's students, carried out a study to determine the pollination biology of the Haleakalã silversword. Although her findings on pollinators are not complete, she did establish early in the study that silverswords are self-incompatible, requiring pollinators for viable seed set (Powell pers. comm.; Carr, Powell and Kyhos 1986). Although the introduced predatory wasp Vespula pensylvanica is not currently abundant in silversword habitat, Powell and others have observed the wasps apparently probing silversword plants for insects. This wasp has become a concern for managers due to rapid buildup of populations following its establishment in 1978 and its possible negative impact on vulnerable endemic Hawaiian insects. In addition, as of 1985, predacious Argentine ants (Iridomyrmex humilis) were established as high as 9300ft (2835m) elevation on Haleakalã (Medeiros and Loope unpublished). Although these ants have not yet established populations in Haleakalã Crater, they may have the potential to do so. This situation has lead to the realization that loss of associated pollinators may be the greatest long-term threat to the silversword. Ironically, whereas endemic insects were believed at one time to threaten the silversword's survival, it is now clear that the species is dependent on its pollinators, which may or may not play a role in seed predation.

The park research program is now carrying out silversword population monitoring along lines suggested in Kobayashi's

(1973a) recommendations, including counts in permanently marked plots. Although recensus of the total Haleakalā silversword population at 10-year intervals is a useful tool for monitoring long-term population trends, it obviously has its limitations. A more precise and quicker supplementary method for determining population trends over short- and long-term is needed. Kobayashi recommended that additional marked long-term plots be established. He established and analyzed four marked plots on Kamoaopele in 1972 and resampled them in 1979. We established 11 new plots in October, 1982, in the following localities, chosen to represent a wide range of silversword habitats: Pu'u nole (2), Pu'unaue (3), Pu'uopele (3), Kamoaopele (2), and K27, E of Pu'uomaui (1). These plots are 5m x 20m, subdivided into four 5m x 5m subplots, and marked with PVC pipe and wooden stakes. Silverswords are assigned to four categories (<5cm in diameter, 5-20cm in diameter, >20cm in diameter, and flowering) and counted. Size classification is estimated from the edge of the plot so that no walking in the plot is necessary. These plots average 35-40 plants per $100m^2$ plot and collectively contain nearly 1% of total silversword population. Data are recorded annually. Preliminary results after three years suggest that many seedlings establish in some years, few or none in others; that substantial mortality of silverswords occurs in some years; and that wide fluctuations in populations from year to year are occurring. Silversword numbers in the 11 plots declined by 11% the first year, increased by 18% the second year (abundant seedling establishment), and declined by 22% the third year. About 70% of the seedlings established in 1984 died or disappeared in 1985. In the three years since 1982, an overall 14% population reduction has occurred in the plots. One or more heavy precipitation events appeared to be a primary cause of high mortality in 1985.

Other cooperating researchers are investigating the physiological ecology of the silversword and its relatives (R. Robichaux), growth and dynamics of tagged silversword populations (M. S. Witter and P. W. Rundel), and life histories of silversword-associated insects (B. H. and W. C. Gagné).

Continued work on the pollination biology of the silversword and initiation of studies on biology and impact of Vespula pensylvanica and Iridomyrmex humilis in Haleakalā National Park are clearly needed. The philosophy of the current park administration includes concern for the long-term survival of the park's native insects as well as its native plants, and recognizes the desirability and practicality of aiming for preservation of the entire complex of organisms belonging to the silversword ecosystem. Public education regarding the silversword offers an outstanding opportunity for National Park Service personnel to introduce park visitors to the beauty and complexity of the endemic Hawaiian biota and the need for improving our understanding and management of it.

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Table 1. 1982 silversword census data compared with 1971 data of Kobayashi.

| | Flowering | Diam. >20cm | Diam. <20cm | Total 1982 | Total 1971 | % Increase or Decrease |
|---|---|---|---|---|---|---|
| Near Sliding Sands Trail | | | | | | |
| K1 | 3 | 30 | 24 | 57 | 26 | 119 |
| K2 | 8 | 108 | 275 | 391 | 314 | 25 |
| K3 | 1 | 16 | 24 | 41 | 35 | 17 |
| K4 | 3 | 228 | 227 | 458 | 453 | 1 |
| K5 | 3 | 6 | 17 | 26 | 43 | -40 |
| K6 | 8 | 63 | 159 | 230 | 244 | -6 |
| K7 | 3 | 41 | 99 | 143 | 38 | 276 |
| Pu'uopele (K8-12) | | | | | | |
| I (E slope) | 59 | 220 | 293 | | | |
| II (N slope) | 145 | 720 | 1317 | | | |
| III (Crater) | 69 | 617 | 1073 | | | |
| IV ("Side Crater"-K8&9) | 3 | 39 | 75 | | | |
| Subtotal | | | | 4630 | 3443 | 34 |
| K13 | 9 | 22 | 55 | 86 | 29 | 197 |
| Kama'oli'i | | | | | | |
| K14 (Center of cone) | 14 | 227 | 1024 | | | |
| K15 (N side) | 3 | 34 | 95 | | | |
| K16 (E side) | 23 | 75 | 217 | | | |
| W side | 6 | 68 | 293 | | | |
| S side | 2 | 25 | 17 | | | |
| Subtotal | | | | 2123 | 1521 | 40 |

Table 1. (Continued)

| | Flowering | Diam. >20cm | Diam. <20cm | Total 1982 | Total 1971 | % Increase or Decrease |
|---|---|---|---|---|---|---|
| Pu'uomaui (K17-21,23-25) | | | | | | |
| N slope "A" (K20?) | 52 | 355 | 847 | | | |
| N slope "B" (K19?) | 74 | 296 | 5401 | | | |
| Inside cone (K21) | 71 | 370 | 654 | | | |
| NE section (K23+24?) | 48 | 247 | 924 | | | |
| E side | 41 | 66 | 234 | | | |
| SE side | 18 | 12 | 26 | | | |
| S side | 0 | 1 | 0 | | | |
| SW side "A" | 2 | 42 | 126 | | | |
| SW side "B" | 5 | 21 | 94 | | | |
| W side | 21 | 54 | 762 | | | |
| NW side | 18 | 111 | 930 | | | |
| Subtotals | | | | 11923 | 21190 | -44 |
| NE outlier of Pu'uomaui | 5 | 25 | 98 | 128 | | |
| Group E of Pu'uomaui | | | | | | |
| K26 | 7 | 238 | 41 | 286 | 89 | 221 |
| K27 | 101 | 2126 | 599 | 2826 | 362 | 681 |
| K28 | 46 | 398 | 84 | 528 | 181 | 192 |
| E of K27 | 7 | 77 | 37 | 121 | | |
| K29 (N side of cone of K30) | 222 | 1710 | 697 | 2629 | 1773 | 48 |
| K30 (NNW of Kamoaopele) | 17 | 87 | 72 | 176 | 369 | 57 |

Table 1. (Continued)

| | Flowering | Diam. >20cm | Diam. <20cm | Total 1982 | Total 1971 | % Increase or Decrease |
|---|---|---|---|---|---|---|
| Kamoaopele | | | | | | |
| I (K36) | 102 | 472 | 1268 | | | |
| II (K37) | 191 | 589 | 857 | | | |
| III | 3 | 2 | 6 | | | |
| IV (K35) | 79 | 442 | 922 | | | |
| V (K31,33,35,part of 32) | 112 | 581 | 1090 | | | |
| VI (part of K32) | 12 | 54 | 81 | | | |
| Subtotal | | | | 6863 | 4029 | 70 |
| Outliers of Kamoaopele | | | | | | |
| #1 | 3 | 56 | 61 | | | |
| #2 | 2 | 20 | 30 | | | |
| #3 | 2 | 24 | 10 | | | |
| #4 | 1 | 11 | 15 | | | |
| #5 | 3 | 14 | 7 | | | |
| #6 | 2 | 25 | 59 | | | |
| #7 | 0 | 22 | 51 | | | |
| #8 | 0 | 5 | 0 | | | |
| Subtotal | | | | 423 | 52 | 813 |
| Haläli'i (incl. K39) | | | | | | |
| N slope (K39?) | 5 | 40 | 98 | | | |
| E slope | 1 | 0 | 4 | | | |
| S slope | 0 | 4 | 0 | | | |
| W slope | 0 | 1 | 0 | | | |

Table 1. (Continued)

| | Flowering | Diam. >20cm | Diam. <20cm | Total 1982 | Total 1971 | % Increase or Decrease |
|---|---|---|---|---|---|---|
| Halăli'i (incl. K39) continued | | | | | | |
| Crater #1 | 49 | 84 | 284 | | | |
| Crater #2 | 26 | 86 | 282 | | | |
| #3 | 0 | 11 | 36 | | | 2452 |
| #4 | 1 | 2 | 27 | | | |
| #5 | 2 | 4 | 12 | | | |
| Wash #6 | 4 | 3 | 13 | | | |
| Subtotal | | | | 1079 | 44 | |
| K40 (N of Halăli'i) | 14 | 64 | 138 | 216 | 367 | -41 |
| Pu'unaue (K41-43) | | | | | | |
| I (N slope) | 110 | 708 | 1815 | | | |
| II (Crater) | 98 | 691 | 1937 | | | |
| III (W slope) | 34 | 215 | 311 | | | |
| IV (S slope) | 6 | 41 | 66 | | | |
| Subtotal | | | | 6032 | 3440 | 75 |
| Pu'unole (K44-46) | 65 | 602 | 856 | 1523 | 3054 | -50 |
| Pu'ukauaua | 2 | 6 | 76 | 84 | | |
| *Red flow from* Pu'uomaui (K47-56) | | | | | | |
| # 1 | 7 | 9 | 8 | | | |
| # 2 | 2 | 30 | 108 | | | |
| # 3 | 5 | 19 | 61 | | | |
| # 4 | 7 | 37 | 81 | | | |

Table 1. (Continued)

| | Flowering | Diam. >20cm | Diam. <20cm | Total 1982 | Total 1971 | % Increase or Decrease |
|---|---|---|---|---|---|---|
| Red flow from Pu'uomaui (K47-56) continued | | | | | | |
| # 5 | 3 | 5 | 28 | | | |
| # 6 | 1 | 1 | 23 | | | |
| # 7 | 4 | 21 | 113 | | | |
| # 8 | 15 | 31 | 92 | | | |
| # 9 | 2 | 14 | 10 | | | |
| #10 | 15 | 115 | 336 | | | |
| #11 | 8 | 13 | 48 | | | |
| #12 | 14 | 36 | 111 | | | |
| #13 | 3 | 15 | 41 | | | |
| #14 | 48 | 260 | 838 | | | |
| #15 | 1 | 8 | 16 | | | |
| #16 | 1 | 2 | 57 | | | |
| Subtotal | | | | 2723 | 1574 | 73 |
| K57 (Silversword Loop) | 61 | 305 | 777 | 1143 | 455 | 151 |
| South Rim | 2 | 77 | 257 | 336 | | |
| Kalahaku (K58) | 9 | 46 | 176 | 231 | 160 | 44 |
| Observatory-Kilohana, below rim | 3 | 77 | 64 | 144 | | |

Table 1. (Continued)

| | Flowering | Diam. >20cm | Diam. <20cm | Total 1982 | Total 1971 | % Increase or Decrease |
|---|---|---|---|---|---|---|
| Miscellaneous populations | | | | | | |
| Kaluaokao'o (SE side) | 1 | 0 | 0 | | | |
| NE of Pu'uopele | 2 | 6 | 4 | | | |
| E of K6,past K7, N of trail | 0 | 6 | 0 | | | |
| Pu'umämane, S slope | 2 | 2 | 18 | 22 | | |
| K59 (not counted in 1982) | | | | | 12 | |
| K60 (not counted in 1982) | | | | | 13 | |
| TOTAL | 2262 | 14789 | 30589 | 47640 | 43262 | 10 |

Table 2a. Silversword numbers (all sizes) on Kamoaopele cinder cone in Haleakalã National Park, Hawai'i, from census data taken in five different years from 1935-1982. Data from Lamb (1935b), Badaracco (1962), Kobayashi (1973a, 1979), and our 1982 census. Counting units were established by Lamb (1935b) and used by all other investigators.

| Counting Unit | 1935 | 1962 | 1971 | 1979 | 1982 |
|---|---|---|---|---|---|
| I | 319 | 550 | 1200 | 1259 | 1842 |
| II | 440 | 550 | 1230 | 1068 | 1637 |
| III | 35 | 50 | 6 | 16 | 11 |
| IV | 243 | 250 | 500 | 323 | 1443 |
| V | 318 | 798 | 764 | 1008 | 1783 |
| VI | 115 | 50 | 290 | 63 | 147 |
| Total | 1470 | 1248 | 3990 | 3737 | 6863 |

Table 2b. Silversword numbers (plants <20cm in diameter only) on Kamoaopele, Haleakalā National Park, Hawai'i, in four different years, based on data from Lamb (1935b), Kobayashi (1973b; 1979) and our 1982 census data. As in Table 2a, counting units were established by Lamb (1935b) and used by all subsequent investigators.

| Counting Unit | 1935 | 1971 | 1979 | 1982 |
|---|---|---|---|---|
| I | 89 | 1020 | 750 | 1268 |
| II | 170 | 1100 | 640 | 857 |
| III | 17 | 2 | 3 | 6 |
| IV | 89 | 470 | 160 | 922 |
| V | 212 | 663 | 496 | 1090 |
| VI | 62 | 230 | 26 | 81 |
| Total | 639 | 3485 | 2075 | 4224 |

Table 3. Comparison of Haleakalâ silversword numbers for major population areas of Haleakalâ National Park, Hawai'i, in 1982 census with earlier data from Kobayashi (1973a) and a subjective evaluation by Powers (1938). Table is adapted from Table 1 of Kobayashi (1973a).

| Powers' Locations | Excerpts from Powers | Census total 1971 | Census total 1982 |
|---|---|---|---|
| 1. Pu'uomaui cone | A good many plants; with location 3, 2nd most abundant. | 22,000 | 12,000 |
| 2. Kamoaopele cone | Greatest number in any locality. | 3,900 | 6,900 |
| 3. Red 'a'â flow from Pu'uomaui to Silversword Loop | A good many plants; with location 1, 2nd most abundant. | 1,900 | 2,700 |
| 4. Pu'uopele cone | A few good plants. | 3,400 | 4,600 |
| 5. Kama'oli'i cone | None. | 1,500 | 2,100 |
| 6. Pu'unaue cone | A few plants. | 3,400 | 6,000 |
| 7. Pu'unole cone | A few plants. | 3,000 | 1,500 |
| 8. Halâli'i cone | Relatively abundant. | 44 | 1,100 |
| 9. Upper palis of west rim | 3rd most abundant. | 180 | --- |

Table 4. Numbers of flowering silverswords in Haleakalā National Park for years since 1969, based on records in park files, Kobayashi (1973a), and our census data in 1982-85.

| Year | Plants Flowering | Year | Plants Flowering |
|---|---|---|---|
| 1969 | 195 | 1978 | 284 |
| 1970 | 0 | 1979 | 436 |
| 1971 | 206 | 1980 | few |
| 1972 | 1 | 1981 | few |
| 1973 | 72 | 1982 | 2262 |
| 1974 | 797 | 1983 | 903 |
| 1975 | 17 | 1984 | 84 |
| 1976 | 24 | 1985 | 163 |
| 1977 | ? | | |

Table 5. Relationship between number of flowering Haleakalā silverswords and various precipitation totals for Haleakalā Ranger Station, Hawai'i (elevation 2147m). Weather data are from U. S. Department of Commerce, 1981-85.

| Year | # flowering | Precipitation for preceding (mm) 6 mo. | 12 mo. | 24 mo. |
|---|---|---|---|---|
| 1969 | 195 | 1039 | -- | -- |
| 1970 | 0 | 782 | 1576 | -- |
| 1971 | 206 | 1376 | 2440 | 4016 |
| 1972 | 1 | 518 | 774 | 3214 |
| 1973 | 72 | 388 | 435 | 1209 |
| 1974 | 797 | 785 | 1376 | 1811 |
| 1975 | 17 | 453 | 901 | 2277 |
| 1976 | 24 | 958 | 1244 | 2145 |
| 1977 | ? | 584 | 733 | 1977 |
| 1978 | 284 | 393 | 762 | 1495 |
| 1979 | 436 | 1477 | 2036 | 2798 |
| 1980 | few | 2751 | 3147 | 5183 |
| 1981 | few | 542 | 868 | 4015 |
| 1982 | 2262 | 1955 | 2687 | 3555 |
| 1983 | 903 | 83 | 955 | 3642 |
| 1984 | 84 | 417 | 851 | 1806 |
| 1985 | 163 | 1167 | 1461 | 2312 |