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Technical Report 130

RARE PLANTS OF THE MAUNA LOA SPECIAL ECOLOGICAL AREA, HAWAI`I VOLCANOES NATIONAL PARK

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Acknowledgments

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Summary

The montane and sub-alpine zones of the Mauna Loa Strip in Hawai`i Volcanoes National Park (HAVO) contain some of the most intact native vegetation found within the Park, and most of the study area has been considered a Special Ecological Area (SEA) since the mid 1980s. The Mauna Loa Strip was grazed by cattle prior to its inclusion in Hawai`i National Park. Feral goats and pigs were removed in the 1970s and 1980s, when two units of the SEA were completely fenced. The area above the upper unit, enclosed as the alpine unit in 1999, still supports an unknown number of feral goats and mouflon sheep, but feral animal removal is planned. The present survey was initiated to provide information to managers on the distribution and status of the endangered, threatened, and rare plant species of the Mauna Loa SEA. Population monitoring of selected species was conducted to determine how rare plants were responding to management practices, largely the removal and interdiction of feral animals.

In 1992-93, existing systematic transects at 1,000-m intervals were surveyed in the upper unit, which extends from the Powerline near 1,525 m (5,000 ft) elevation to a cross fence above the Mauna Loa Road terminus at 2,070 m (6,800 ft) elevation. New transects at 100-m intervals were placed in the two vegetated kīpuka of the alpine unit, just above the cross fence. Fifteen endangered, rare, and uncommon plant species were observed and mapped in the Mauna Loa SEA. These included three endangered species (*Asplenium fragile* var. *insulare, Phyllostegia racemosa* or kīponapona, and *Plantago hawaiensis* or laukāhi kuahiwi); one threatened species (*Silene hawaiiensis* or Hawaiian catchfly); and one species of concern (*Sisyrinchium acre* or mau`u lā`ili). Except for *Silene hawaiiensis*, which occurs also on Kīlauea Crater rim and in the Ka`ū Desert, the endangered plants of the Mauna Loa SEA are not found elsewhere in the Park.

The survey also located populations of six species rare in the Park (*Exocarpos menziesii, Geranium cuneatum* subsp. *hypoleucum, Tetramolopium humile*, *Pittosporum* sp., *Rumex giganteus,* and *Santalum paniculatum*). The first three of these species are high-elevation specialists and are restricted in HAVO to the Mauna Loa SEA. The other three rare species range to lower elevations in the Park. Four additional species were uncommon in the SEA, but are found more frequently elsewhere in HAVO: *Rubus hawaiiensis* (`ākala), *Myoporum sandwicense* (naio), *Pseudognaphalium sandwicensium* (`ena`ena), and *Smilax melastomifolia* (hoi kuahiwi). One species of concern formerly reported from the area (*Rubus macraei*, `ākala) was not found during the survey. Two out-planted populations of the endangered *Argyroxiphium kauense,* Ka`ū or Mauna Loa silversword, were contained within the study area.

The tiny fern *Asplenium fragile* var. *insulare* was found at seven HAVO sites, but was restricted in habitat to large-diameter lava tubes. One sighting was

on transect in the upper unit, one was a historically known lava tube at "Three Trees Kīpuka," and five sightings were within separate openings in two high-elevation lava tubes within the alpine unit in areas not previously searched. This survey added six new sites to the known distribution of this endangered species within HAVO.

The endangered mint *Phyllostegia racemosa* or kīponapona was observed at only one Park site, where one plant persisted at least six years but disappeared by 1997. This sighting was significant, as it extended the known range of this critically endangered species more than 8 km to the west into vegetation considerably drier than that of the nearest population.

Plantago hawaiensis, laukāhi kuahiwi, an endangered rosette-forming herb, was found in two separate populations within the alpine unit in 1994. These populations and a few plants scattered at higher elevation are the only occurrences of the species within HAVO. Both populations were monitored for 3.5 years by counting tagged individuals, measuring height and width, and recording phenology and vigor. The population in Kīpuka Kulalio originally contained 357 plants and had declined markedly to 51 plants by March 1996. This site continued to lose plants until only three remained in 2000. The losses appeared to be natural, resulting from scouring of intermittent stream channels by floodwaters and debris torrents that buried *Plantago* plants. The Kīpuka Maunai`u population fared better during the period of monitoring. Originally 277 plants were counted on the eastern edge of this kīpuka near 2,135 m (7,000 ft) elevation. The population increased to 294 plants by 1997, lost a few individuals in 1998, and increased slightly in 1999. By the end of the study in 2000, there were 291 plants in Kīpuka Maunai`u.

When *Plantago* individuals were first measured at Kīpuka Maunai`u in 1997, most were mature plants greater than 11 cm in rosette width. Over the next three years, there was a downward shift in size class distribution due to mortality of large plants, recruitment of new plants, and the partial burying of plants due to winter and spring floods. The mean width of plants decreased by almost 2 cm between 1998 and 1999. By 2000, the number of large plants >20 cm in diameter was less than a quarter of the number present in 1997. Flowering and fruiting was primarily a function of plant size; the largest three size classes consistently carried most of the reproductive spikes. Fruiting capsules were present on some plants at each monitoring session, but appeared to be most abundant during the winter months. Recruitment of seedlings only slightly outpaced plant mortality over the 3.5-year study. Very small germinants were very difficult to monitor, as they were ephemeral and often indistinguishable from seedlings of the alien *Hypochoeris radicata* or gosmore. While *Plantago hawaiensis* appears to be temporarily secure its the Kīpuka Maunai`u site, the precipitous loss of most of the Kīpuka Kulalio population indicates that further monitoring and establishment at additional sites is warranted within the Park.

Silene hawaiiensis or Hawaiian catchfly was found at six sites along three transects in the upper unit of the SEA. One additional large concentration of plants was noted on the Ke`āmoku Flow near the Mauna Loa Road at 1,710 m elevation. Other groups of *S. hawaiiensis* were incidentally observed between transects; the flow channel near the "Three Trees Kīpuka" supported several hundred *Silene* plants. No *S. hawaiiensis* were found along transects in the alpine unit of the SEA, but a few plants were noted on the western edge of Kīpuka Kulalio near 2,195 m (7,200 ft) elevation. Two concentrations of *S. hawaiiensis* plants were selected for intensive monitoring; these were in a flow channel of the Central Lava Flow at 1,830 m (6,000) elevation near transect 16 and on the Ke`āmoku Lava Flow at 1,710 m (5,600 ft) near the Mauna Loa Road.

In 1992, the *S. hawaiiensis* population at the Central Lava Flow site had supported 548 relatively scattered plants and a concentrated group of 614 individuals. When the population was re-visited in 1997, *S. hawaiiensis* had been severely browsed by mouflon sheep, and the 614 clumped plants (group 73) had been decimated and reduced to a few small individuals. The remainder of the population was monitored using a sub-sample of 206 randomly selected plants. Sixty-two percent of sampled *S. hawaiiensis* displayed browsing damage in 1998; browsing pressure decreased over the next two years and by 2000, only 4% of plants showed evidence of recent browsing. Browsing by mouflon changed the size class distribution of the population and reduced the mean height and width of plants by approximately 70% between 1992 and 1998. The average height of plants in the monitored sub-sample was 27.6 cm in 1992 and only 9.1 in 1998. Plants recovered over the next two years, and mean height was 18.1 cm in 2000. While 40% of *S. hawaiienis* had been >30 cm in height (size class 4) in 1992, only 2% of plants were in this tallest class in 2000. Seventy percent of the sub-sampled population comprised the smallest height class of 1-10 cm in 1998, at the peak of mouflon browsing pressure.

Mortality in the *S. hawaiienis* population was 25% between 1992 and 1998. Greater losses were observed in 1999, when 42% of monitored plants had died since 1998. The annual mortality rate was 20% in 2000. Seedling recruitment was observed in 1998, but not in 1999-2000. Mortality of seedlings was high, but approximately a third of observed seedlings persisted for three years. While 49% of *S. hawaiiensis* plants bore flowers or capsules in 1992 (fall and winter), none were fertile in 1998 and 1999, when mouflon browsing was intense. While mouflon were implicated in the loss of many plants due to severe browsing and trampling, a more significant impact of browsing was the suppression of reproduction. If repeated browsing events continue, the *S. hawaiiensis* population of Mauna Loa may be severely reduced or even extirpated.

Twenty randomly selected *S. hawaiiensis* plants were enclosed in wire-mesh cages in 1998, and their mortality, growth, and phenology was compared with that of 20 nearby, unprotected plants. Mortality over two years was slightly higher among unprotected plants; losses were attributed to drought conditions. Mean growth was slightly greater in caged plants, but differences were not significant. Phenology of the two groups differed greatly throughout the two-year study; 77% of caged plants were observed bearing flowers or fruits, while only 7% of unprotected plants were fertile. A second set of six *Silene* plants was selected for an exclosure experiment at a site of intense and repeated browsing (group 73). In this group, caged plants grew an average of 19.4 cm in height over a year, while unprotected control plants stayed the same height (9.3 cm). Fifty percent of caged plants were fertile after a year, while all unprotected plants were sterile.

A second *S. hawaiiensis* population on the Ke`āmoku Lava Flow at 1,710 m elevation was also monitored in 1994 and 1999. No browsing damage was detected at this site, but mortality was very high over the five-year period with the loss of 71% of tagged plants. Losses were distributed over all four of the measured height classes. Mean height and width decreased over the five years, but the decline was not extreme. Thirty-three percent of plants were fertile in 1994, and only 15% bore flowers or fruits in 1999.

Sisyrinchium acre or mau`u lā`ili, a species of concern, was found on the edge of the Central Lava Flow of the upper unit and was also distributed in Kīpuka Mauna`iu of the alpine unit. *Geranium cuneatum* subsp. *hypoleucum* (nohoanu) plants were abundant along transects in Kīpuka Kulalio of the alpine unit, but were restricted to a narrow elevational band near 2,135 m elevation. Few *Geranium* plants were found in Kīpuka Maunai`u. *Exocarpos menziesii* (heau) was restricted to higher elevations in Kīpuka Kulalio, where it was extremely rare and widely scattered. *Santalum paniculatum* var. *paniculatum* (`iliahi), *Pittosporum* sp. (hō`awa), *Rumex giganteus* (pāwale), and *Smilax melastomifolia* (hoi kuahiwi) were each represented within the alpine unit by one to three individuals. These species appear to be high-elevation remnants of populations formerly more abundant in the SEA.

Myoporum sandwicense (naio) trees were encountered in only a few sites within *Acacia koa* (koa) groves of Kīpuka Mauna`iu of the upper unit; the paucity in the Mauna Loa SEA of this usually common species is not understood. Three other common Hawaiian species had very low numbers within the SEA. *Rubus hawaiensis* (`ākala) was noted only near the Mauna Loa Road in the upper unit and at one site near a rock wall in Kīpuka Maunai`u of the alpine unit. The rarity of this species as well as that of the palatable herb *Pseudognaphalium sandwicensium* (`ena`ena) and the dwarf shrub *Tetramolopium humile* may indicate the impact of browsing by mouflon sheep in the SEA.

Among the threatened and endangered plant species found during this survey of the Mauna Loa SEA, only *Asplenium fragile* appears to be maintaining itself in its specialized habitat and likely needs no human intervention to persist within the Park. However, it is clear from our monitoring data that mouflon sheep must be controlled to ensure the continued existence of *Silene hawaiiensis* in the area. While *Plantago hawaiensis* continues to exhibit a robust population at one site, its virtual extirpation from a second site indicates that Park managers would be prudent to establish population nodes at additional sites within the SEA. The mint *Phyllostegia racemosa* was known from only one Park site and appears to have been lost from the Park; its reintroduction to the Mauna Loa SEA is highly desirable. Low observed numbers of the terrestrial herb *Sisyrinchium acre* suggest that this species of concern could benefit from management, perhaps removal of alien grasses or propagation and out-planting at additional Mauna Loa sites.

The endangered Ka`ū or Mauna Loa silversword, *Argyroxiphium kauense,* has been successfully out-planted within the Mauna Loa SEA, and both upper and alpine units contain suitable sites for continued re-introduction of silverswords, as well as other endangered, rare, and depleted native plants documented from the Park. Five of the six rare plant species of Mauna Loa SEA may require management, including propagation and out-planting, if they are to remain self-sustaining components of the natural communities of the region. Only *Geranium cuneatum* subsp. *hypoleucum* displayed a large population of individuals varied in size, including both mature plants and seedlings. The four uncommon native plants of the SEA will likely increase naturally if mouflon sheep and feral goats are completely removed from the alpine unit of the SEA. These shrub and herb species may be useful elements in future plant community restoration projects in the area.

Rare Plants of the Mauna Loa Special Ecological Area, Hawai`i Volcanoes National Park

Introduction

The Special Ecological Area (SEA) concept was adopted by Hawaii Volcanoes National Park (HAVO) in 1985 as a strategy for focusing feral animal and alien plant control on the most intact ecosystems remaining in the Park (Tunison *et al.* 1986). Areas were selected on the basis of the rarity and exemplary nature of the vegetation type, vegetation intactness, plant species diversity and richness, manageability of alien plants and animals, presence of rare and endangered species, preserve design considerations, immediacy of threats from alien plants, research potential, and interpretive values (Tunison and Stone 1992).

The Mauna Loa SEA includes most of the Mauna Loa Strip above Kīpuka Kī; the SEA has three fenced units. The upper and alpine sections above 1,525 m (5,000 ft) elevation were the focus of this study. Vegetation of these units is primarily native and includes montane dry to mesic forests, sparse vegetation on lava flows, and sub-alpine shrubland ecosystems. The rare plants of the montane mesic forests of Kīpuka Puaulu and Kīpuka Kī will be discussed in a future report. The SEA supports four federally listed endangered (including one species currently being out-planted), one threatened, two to four "species of concern," and at least ten rare or uncommon plant species. Two species not native to the Park (one endangered and one threatened) have also been introduced to the SEA (Pratt, unpublished). Though the naturally-occurring endangered and threatened species are also found outside HAVO, their Park habitat is the only federally protected part of the eastern slope of Mauna Loa, which is otherwise dominated by private and state-leased ranches and State Forest Reserves managed under a multiple use mandate. Because of the existing land use and management pattern on Mauna Loa, the habitat of rare plants in the Park is important for the sustainability of their populations.

The primary objective of this study was to provide Park managers with a report on the current distribution and status of the endangered, threatened, rare, and uncommon plant species in the Mauna Loa SEA. Other objectives were to evaluate potential and observed threats from alien plants and animals; to determine population structure and reproductive success of endangered species; and to assess needs for monitoring or research. The discovery of mouflon sheep (*Ovis musimon*) within the Mauna Loa SEA in 1990 led to one element of the present study, when severe browsing was detected on plants in one population of the threatened species *Silene hawaiiensis*. This damage to a rare plant caused us to focus monitoring on that species, as well as on the endangered *Plantago hawaiensis*, which grew in a section of the SEA then unprotected by boundary fencing.

The Study Area

The Mauna Loa SEA encloses a total area of 8,291 ha (20,479 acres) within the Park's Mauna Loa Strip. The SEA shares boundaries with Keauhou Ranch (Kamehameha Schools/Bishop Estate) on the east and Kapāpala Ranch and Forest Reserve (State lands) on the west. The lower unit of the SEA starts just above Kīpuka Kī at 1,400 m (4,600 ft) elevation and extends to the Powerline Road and fenceline near 1,525 m (5,000 ft). This lower unit was grazed by cattle for many years; lands now within the Park were formerly included within adjacent ranches, which were established between 1860 and 1900 (Henke 1929). Sturdy ungulate-proof boundary fences were constructed after 1970 (Baker and Reeser 1972). Much of the lower section of the Mauna Loa Strip was burned in a 1975 wildfire. Although *Acacia koa,* or koa, is recovering here, alien grasses have invaded and native plant diversity is low. Because of the low probability of finding rare plants, the lower unit was not included in the rare plant study.

The upper unit of the SEA stretches from the Powerline to a fenceline near 2,070 m (6,800 ft) elevation above the terminus of the Mauna Loa Road. This unit encloses 2,260 ha (5,583 acres). The upper fence of this unit was replaced, and the lower fence along the Powerline was built in 1983-85 (Katahira *et al.* 1993). Above the upper unit is the newest of the three enclosed sections of the SEA, called the alpine unit, but including both sub-alpine and alpine ecosystems. The alpine unit extends from the upper unit to a fence near 2,745m (9,000 ft) and contains 5,361 ha (13,241 acres); this exclosure was completed in August 1998. The upper unit and the well-vegetated lower portion of the alpine unit were the focus of this rare plant survey and monitoring project (Fig. 1).

Vegetation

Except for the occurrence of a few alien plant species, it is likely that the present vegetation of the upper Mauna Loa SEA is similar to that of pre-European contact times. Archibald Menzies, surgeon and naturalist of the Vancouver voyages (1792-1794 in Hawai`i) and the first European to climb Mauna Loa, described the vegetation as clumps of trees and grassy spots (Menzies 1920). In 1834, the botanist David Douglas characterized the slopes of Mauna Loa as grassy plains with *Sophora chrysophylla* (māmane) trees above koa forests and below "brushwood" (Wilson 1919).

The vegetation within the upper unit of the Mauna Loa SEA has been variously described as the upper forest zone (Hillebrand 1888; Rock 1913), parkland zone (Robyns and Lamb 1939), and montane seasonal zone consisting of a "mosaic" of several plant community types dominated by grasses, shrubs, or koa trees (Mueller-Dombois 1967). Sub-alpine vegetation consists of largely intact, open forests and scattered trees of *Acacia koa*, *Metrosideros polymorpha*

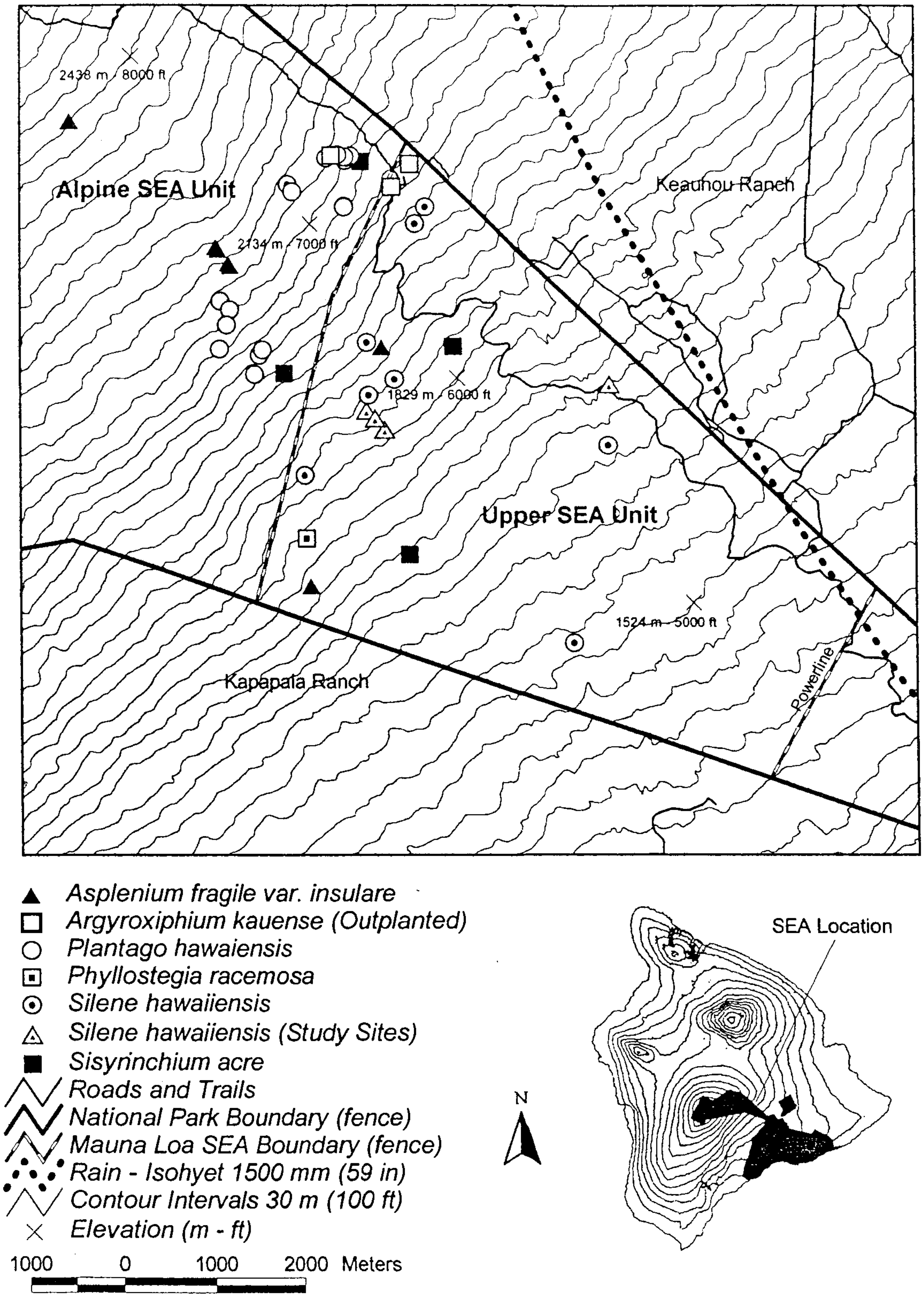


Figure 1. Endangered, Threatened, and Plant Species of Concern of the Mauna Loa Special Ecological Area, Hawaii Volcanoes National Park.

(`ōhi`a) and *Sophora chrysophylla*, mixed with shrublands dominated by *Dodonaea viscosa* (`a`ali`i), *Vaccinium reticulatum* (`ōhelo), and *Leptecophylla tameiameiae* (pūkiawe). These forests and shrublands extend from the top of the Mauna Loa Strip Road upslope to tree line near 2,500 m (8,200 ft) elevation, where vegetation becomes low and sparse (Mueller-Dombois and Fosberg 1998).

Alien plants growing in the study area are primarily grasses associated with past use of the area for grazing cattle, as well as a few well-established temperate broadleaf weeds. *Ehrharta stipoides* (meadow rice grass), *Anthoxanthum odoratum* (sweet vernal), and *Holcus lanatus* (velvet grass) are the most abundant alien grasses, while *Hypochoeris radicata* (gosmore or hairy cat's ear) is the most widespread broadleaf alien. *Verbascum thapsus* (common mullein) and *Rubus argutus* (prickly blackberrry) are potentially the most invasive and ecosystem-altering alien plants in the area, but neither is currently abundant in the surveyed part of the Mauna Loa Strip.

Climate

The montane forests and savannahs of the Park's Mauna Loa Strip have a seasonal climate with dry periods during the summer (Mueller-Dombois 1966). Mean annual rainfall ranges from 2,000 mm (79 in) to 1,500 mm (59 in) at the lower-elevation limit of the upper unit of the SEA (Giambelluca *et al.* 1986). Annual rainfall over a 12-year period (1988-99) collected at two rain gauges near the Mauna Loa Strip Road averaged 1,300 mm (51 in) at 1,710 m (5,600 ft) elevation and 1,023 mm (40 in) at 2,040 m (6,700 ft) elevation (National Park Service, unpublished data). Mean annual temperature in this region ranges from 10 ° C (50 ° F) to 16 ° C (60 ° F) (State of Hawai`i, DLNR 1970).

The climate of the sub-alpine zone (that includes the lower part of the alpine unit of the SEA) is characterized by low annual temperature ranging from 4.5 ° C (40 ° F) to 10 ° C (50 ° F), and frost is common at night, especially in the winter months. Rainfall averages 762 mm (30 in) to 1,016 mm (40 in) annually and is decidedly seasonal with dry summers and wet winters (State of Hawai`i, DLNR 1970). Mean annual rainfall is approximately 1,000 mm (39 in) near the interface of the sub-alpine and alpine zones (Giambelluca *et al.* 1986). Fog drip from low clouds is an important source of moisture for plants in this zone (Juvik and Perreira 1973; Juvik and Nullet 1995).

A significant climate feature of the high slopes of Mauna Loa and Mauna Kea is the trade wind inversion zone, which lies between 1,525 and 3,050 m elevation (5,000-10,000 ft) and is regulated by descending tropical air masses that meet the prevailing Northeast trade winds. Descending air masses have a warming and drying effect, and the inversion acts to keep rising, humid marine air from reaching high altitudes. Above the inversion, clear skies, low humidity and minimal precipitation prevail (Giambelluca and Schroeder 1998).

El Niño events, which affect weather patterns over wide areas of the eastern Pacific, also alter Hawaiian weather (Giambelluca and Schroeder 1998). The drought associated with El Niño events can have direct impacts on plant populations and reproduction. The first months of 1998 were the driest recorded for windward Hawai`i Island. Drought conditions returned throughout the winter of 1999, but were of shorter duration than those of 1998. At a rain gauge near 1,710m (5,600 ft) on the Mauna Loa Strip, monthly rainfall totals for January through August 1998 were the lowest for these months in a 12-year period. The summer months of 1999 (May through August) were even drier than those of 1998 (National Park Service, HAVO Fire Management Office, unpublished data).

Geology and Soils

Substrates on the eastern slope of Mauna Loa are weathered `a`ā and pāhoehoe lava from Mauna Loa's Northeast rift zone, and they vary in age from 150 to greater than 4,000 years (Lockwood *et al.* 1988). The most recent activity in the area is the massive, late prehistoric Ke`āmoku lava flow that crosses the Mauna Loa Strip Road at 1,710 m (5,600 ft). Two richly vegetated kīpuka of old pāhoehoe lava (1,500-4,000 years), Kīpuka Kulalio and Kīpuka Mauna`iu, extend upslope into the sub-alpine zone. Recent pāhoehoe substrates are generally impermeable, and seasonally heavy rainfall events have carved an extensive network of intermittent stream channels where ash soil has accumulated in kīpuka of the sub-alpine zone area of the Park. These channels are subject to flash flooding and debris torrents. Heavy runoff results in alluvial deposits of fine ash and organic soils onto rocky open flats, which are often occupied by native shrubs. Lower depressions with deeper soils support *Deschampsia nubigena*, the dominant native bunch grass of the mountain slopes. In general, soils of the upper Mauna Loa SEA are relatively shallow silty or sandy loams derived from volcanic ash; they are classified in the Apakuie and Hanipoe soil series. Sub-alpine soils are even shallower, and were mapped as "rockland" in the last island-wide soil survey (Sato *et al.* 1973).

Fires and Disturbance from Ungulates

Fires have occurred as a natural disturbance in the past within the montane parkland, and some native species show adaptations to fire (Mueller-Dombois 1981). Fires started by lava flows or lightning may have encouraged the development and expansion of grasslands, but such grasslands may not depend on fire (Mueller-Dombois 1967; Vogl 1969). All historical and modern fires in this section of the Park were caused by humans (Smith and Tunison 1992; Tunison *et al.* 2001).

Disturbance from introduced herbivores has altered vegetation in the montane and sub-alpine forests and parklands. Pigs (*Sus scrofa* subsp. *scrofa*), goats (*Capra hircus*), and cattle (*Bos taurus*) were introduced to Hawai`i Island in the late eighteenth century (Tomich 1986). While Polynesians introduced a small pig of Asian ancestry more than 1,500 years ago (Tomich 1986), such animals are unlikely to have had great impact on dry upland regions uninhabited by humans. Though the Mauna Loa Strip was added to the Park in 1927, cattle grazing continued there until 1948 (Apple 1954). Goats were excluded from most of the Mauna Loa Strip in the 1970s, and pigs were removed in the 1980s (Katahira *et al.* 1993). Mouflon sheep (*Ovis musimon*) were introduced to Hawai`i Island on Mauna Kea in 1963, and were subsequently released on a ranch south of the Park, where they now range along the south rift of Mauna Loa (Tomich 1986). Mouflon sheep were first observed within HAVO in 1990 (Larry Katahira, pers. comm.), and represent a recent arrival within the Park.

Wherever they occur in Hawai`i, domestic and feral animals have disrupted natural ecosystems by consuming, trampling, and uprooting native plant species. These disturbances have resulted in displacement of native species and invasion of alien plants (Stone 1985). Several earlier studies of vegetation in the Mauna Loa strip investigated the impacts of cattle (Baldwin and Fagerlund 1943), feral goats (Spatz and Mueller-Dombois 1973), and feral pigs (Spatz and Mueller-Dombois 1975).

Methods

In 1984-85, as part of a joint Resources Management and Research Division project, 19 transects were placed across the Mauna Loa Strip at 500-m intervals starting at Kīpuka Kī and ending above the upper terminus of the Mauna Loa Road. These transects were originally established to collect data on bird populations, vegetation cover, and pig activity. In 1992, even-numbered transects above the Powerline fence (at 1,000-m intervals) were relocated and re-flagged as part of a native forest bird survey (Fig. 2). Subsequently, rare plants were counted and alien plant species were recorded in Braun-Blanquet cover abundance classes as they occurred on these even-numbered transects. Transects were belts 10-m wide for the purpose of searching for rare plants, but some rare species (especially trees) were noted outside the 10-m belt. Rare plant occurrences were mapped to display distribution and abundance throughout the study area (Fig. 1). The upper unit of the Mauna Loa SEA was sampled for rare plants systematically throughout its elevational range, and the searched transects extended from the eastern to the western boundaries of the Mauna Loa Strip. While transect intensity was low at 1,000 m intervals, the search was thorough and included both lava flows and vegetated kīpuka.

Eleven additional monitoring transects were later established in two vegetated kīpuka above the cross fence near 2,070 m (6,800 ft) elevation to search for endangered, threatened, and rare plants not adequately sampled below the fence. Transects in the alpine unit were 1,000- m long and were placed at 100-m intervals measured along the fence line from the Mauna Loa Trail gate in Kīpuka Kulalio and along a rock wall in Kīpuka Mauna`iu. As with transects of the upper unit, the width of the belt transects was 10 m. Transect spacing was closer in the

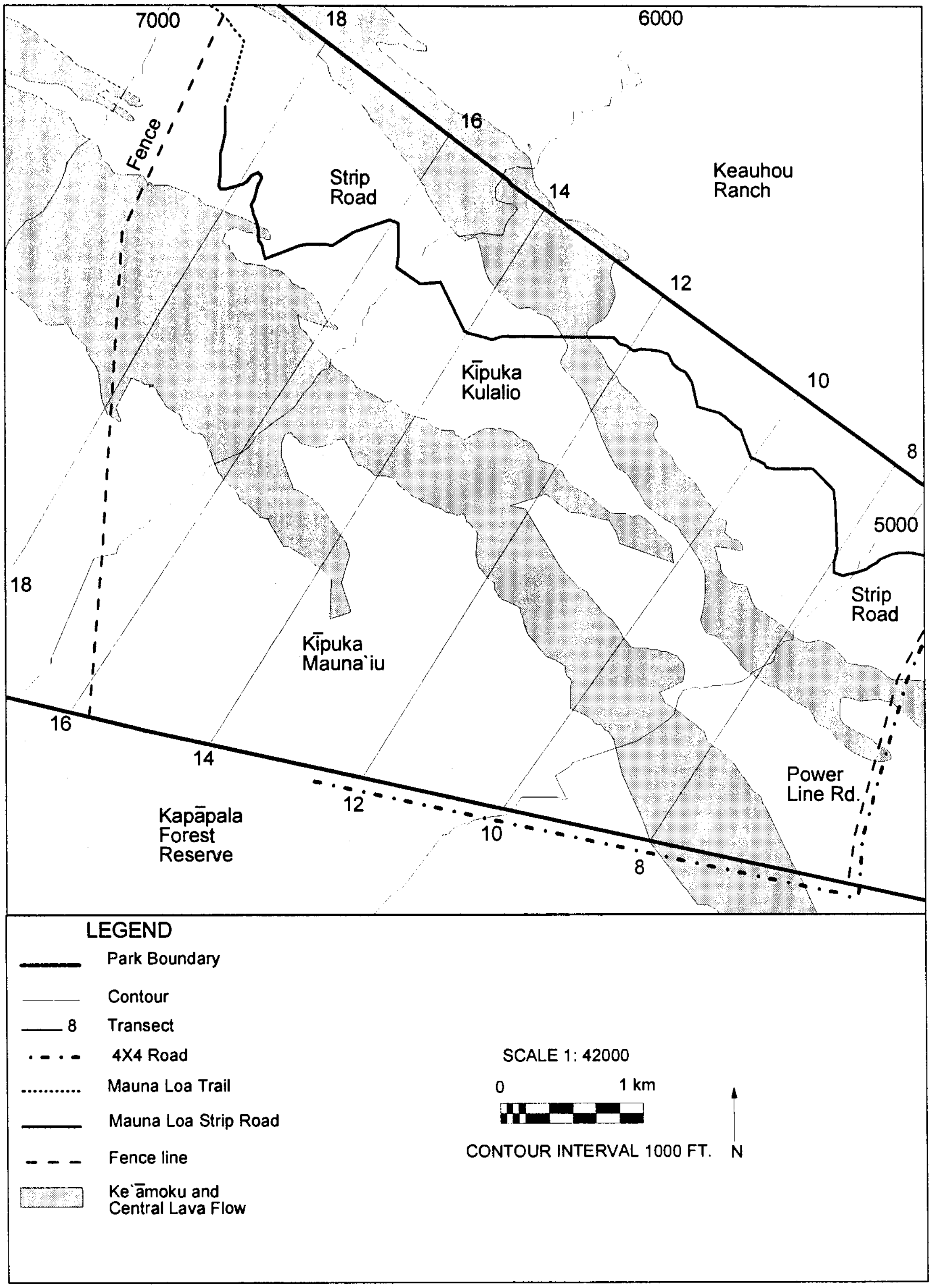


Figure 2. Survey transects in the upper unit of the Mauna Loa SEA, HAVO.

alpine unit (compared to the 1,000-m intervals of the upper unit), because the vegetation of the sub-alpine kīpuka is dense with native shrubs, and visibility for small, terrestrial plants is low. Additional survey work was carried out between transects and above the elevation of the highest sampled transect; this search focused on historical collection sites and areas of recent rare plant observations. Sites previously known to support the endangered fern *Asplenium fragile* and the endangered mint *Phyllostegia racemosa* or kīponapona were also revisited in 1998 and 2000. Only a small portion (perhaps 20%) of the large alpine unit was surveyed for rare plants during this study. Areas selected to survey were the most densely vegetated portions of two kīpuka, adjacent to the upper unit of the SEA. When this project was initiated, the alpine unit was not enclosed by fences and only barrier fences extended above 2,070 (6,800 ft) elevation along the Park boundaries. As the alpine unit has now been enclosed and feral animals are being removed, the remaining unsurveyed area of the unit should be systematically searched for rare plants, at least as high as tree line.

Plantago hawaiensis Monitoring

Because substantial populations of both the endangered *Plantago hawaiensis* (laukāhi kuahiwi) and the threatened *Silene hawaiiensis* (Hawaiian catchfly) were discovered during the surveys along transects, these two species were selected for more intensive monitoring to detect changes in abundance, vigor, population structure, and animal damage. Baseline data were collected for *P. hawaiensis* in 1994 when sites supporting the plants along transects were marked with flagging tape, and plants were counted but not individually tagged.

In March 1996 (Kīpuka Kulalio) and February 1997 (Kīpuka Mauna`iu), *Plantago* individuals were assigned numbers and tagged with plastic plant labels. Height and width (or diameter) of rosette foliage was measured (to the nearest 0.5 cm), and phenology and vigor data were collected at six- to nine-month intervals until March 2000. Phenology data recorded were the presence of flower spikes or fruiting capsules. Plants without spikes were regarded as sterile. Condition or vigor ratings were somewhat subjective. Plants were considered to display good vigor if they were green, unwilted, undamaged by insects, and of normal appearance. Plants were rated as "fair" if they were wilted or damaged but seemed likely to survive. "Poor" vigor was recorded for dry and brown or severely wilted plants that seemed likely to die. Dead plants were rarely observed; they were more often missing from the site supporting the numbered tag. Tiny seedlings near adult plants were counted but not individually tagged; seedlings and small plants were not measurable until they had achieved a diameter of 1 cm or more.

To understand the demography of the *P. hawaiensis* population at both Kīpuka Kulalio and Kīpuka Mauna`iu, we divided plants into five size classes based on width measurements. Size class 1 was 1-5 cm; size class 2 was 6-10 cm; size class 3 was 11-15 cm; size class 4 was 16-20 cm; and size class 5 was >20 cm.

Growth and width data at Kīpuka Mauna`iu showed some anomalous fluctuations in classes from one monitoring period to another, probably caused by the seasonal effects of rainfall and drought. One or more flash floods in intermittent stream channels partially buried some plants in debris resulting in variation of size measurements. Wilting and leaf loss during dry periods may also have caused decrease in rosette width. In some instances, extreme changes in width data indicated new recruitment associated with marked tags where the original plant had died between visits. We adjusted the data by considering the original plant dead, and assigned new numbers to 13 small plants that appeared to be new recruits to the population.

Silene hawaiiensis Monitoring

Baseline data were collected for *Silene hawaiiensis* populations at two sites. One group was discovered along transect at 1,830 m (6,000 ft) elevation in 1992 (Central Lava Flow site), and the second was found near the Mauna Loa Strip Road on a flow channel of the Ke`āmoku Lava Flow at 1,710 m (5,600 ft) in 1994. Additional between-transect surveys were conducted throughout 1998, and several outlying populations of *S. hawaiiensis* were discovered and mapped, but were not monitored as part of this project. Overall, the upper unit of the SEA was thoroughly surveyed at 1,000-m intervals, but *Silene* (and other rare plants) established between transects were found only if they occurred at a historical sighting or if they happened to be incidentally observed during travel to monitoring sites. Only a fraction of the alpine unit of the SEA (perhaps 20%) was surveyed for rare plants during this study; undoubtedly additional *Silene* occur in the alpine unit.

At the Central Lava Flow site, the population was composed of 73 clusters of plants, each marked with a flagged wire stick. Individual plants of groups 1 to 72 were numbered and tagged with a metal label on a nail at ground level. Group 73 plants were counted and measured, but individuals in the dense stand were not tagged. Height and width were measured (to the nearest 0.5 cm); only the live part of the plant was measured. Phenology was recorded, and condition or vigor was assessed for all individuals. Phenology records consisted of noting the presence of flowers, fruit capsules, or old empty fruit. Plants without flowers or fruits were regarded as sterile. Plants were considered in "good" condition if they appeared normal; plants were rated "fair" if leaves were partially dry or wilted and stems were broken; plants were considered in "poor" condition if they seemed likely to die. Dead plants were dry, brittle, and either leafless or bearing only dry, brown leaves. Re-monitoring of a sub-sample of 27 randomly selected plant groups was carried out at this site in 1998, 1999 and 2000. New plants found within each sampled plant group were also tagged and measured. We recorded GPS points of all originally recognized groups.

After observing that all tagged groups had been recently browsed in 1998, we placed wire exclosures or cages over 20 randomly selected plants and compared these with 20 control plants randomly selected from nearby *Silene* groups. Each individual plant had its own exclosure, which was large enough to allow for plant growth. These cylindrical cages were constructed of small-gauge (0.5 inch mesh) fencing material with fencing wire tops. They were held down with guy wires attached to nails driven into the ground to prevent animals from pushing them over. In 1999, we placed an additional set of six cages and controls at plant group 73, a site with consistent, severe mouflon damage that had formerly supported more than 600 *Silene* plants. Plants were monitored once a month from June to August 1998 and at six-month intervals from August 1998 to March 2000. Plant group 73 was monitored every six months between January 1999 and March 2000.

At the Ke`āmoku lava flow site, *Silene hawaiiensis* plants were counted and tagged in 1994-95, soon after their discovery. Height and width were measured, phenology recorded, and vigor assessed in the same way as was done at the Central Lava Flow site. The entire population was remonitored in 1999. To characterize the population structure of *S. hawaiiensis* at both intensive sites, plants were placed into four classes based on height in centimeters: size class 1, 1-10 cm; size class 2, 11-20 cm; size class 3, 21-30 cm; and size class 4, >30 cm.

Results (By Species)

Systematic surveys along transects and later searches of appropriate habitat in the upper and alpine units of the Mauna Loa SEA located fifteen rare native plant species. Populations or individuals of three listed endangered species (*Asplenium fragile* var. *insulare, Phyllostegia racemosa, Plantago hawaiensis*), one threatened species (*Silene hawaiiensis*), and one species of concern (*Sisyrinchium acre*) were mapped in the SEA (Fig. 1). One species of concern reported from the area, *Rubus macraei* (`ākala), was not observed. An additional ten species were found to be rare in the study area. Some of the species considered rare in this survey are upper montane or sub-alpine habitat specialists, including *Exocarpos menziesii* (heau), *Geranium cuneatum* subsp. *hypoleucum* (nohoanu*), and Tetramolopium humile.* Other plants found rarely in the Mauna Loa SEA are uncommon species of lower elevations that are near the top of their range here; these include *Santalum paniculatum* var. *paniculatum* (ili`ahi or sandalwood), *Pittosporum* sp. (hō`awa) and *Rumex giganteus* (pāwale). Four species common elsewhere were sparsely distributed or very localized in the study area; these are *Rubus hawaiiensis* (`ākala), *Myoporum sandwicense* (naio), *Pseudognaphalium sandwicensium* (`ena`ena), and *Smilax melastomifolia* (hoi kuahiwi).

Endangered Plant Species

Asplenium fragile var. **_insulare_**, No common name

Asplenium fragile var. *insulare* was listed as endangered in 1994 and at that time was known from eight populations on Hawai`i Island and one recently reported population on East Maui. Hawai`i Island populations are distributed in the

Pohakuloa Training Area (PTA), Kūlani, Keauhou, Mauna Loa Strip of HAVO, Kapāpala Forest Reserve, Ka`ū Forest Reserve, and Hualālai. The populations closest to HAVO are at Kūlani and Keauhou (U. S. Fish and Wildlife Service 1998). The nomenclature of this fern is currently under review. It has recently been known as *A. rhomboideum*, and it may soon be placed within the species *Asplenium peruvianum* (Palmer, in prep. 2000). The fern was previously considered an endemic Hawaiian variety of a species first described from Peru and the Andes (Morton 1947); it is not known how this nomenclatural and status change may affect official recognition of the fern as an endangered species.

During the 1992-93 survey of transects in the upper unit, *Asplenium fragile* was found at only one site near the Park's western boundary with Kapāpala Ranch at 1,680 m (5,500 ft) elevation (TR-14 at 200m). A previously recorded site at the "Three Trees Kīpuka" within the Central Lava Flow near 1,890 m (6,200 ft) elevation was visited in 1998, 1999, and 2000 and continued to support a large number of ferns (Fig. 1). At least 200 plants were growing on the interior walls of a large lava tube within the kīpuka in January 1999; many of the ferns bore pendent fronds greater than 20 cm long. The first record of the fern at this site was a collection by Fagerlund and Mitchell in 1943 (HAVO Herbarium), so the species has persisted in the same lava tube for almost 60 years. One additional site was reported by W. H. Wagner Jr. in 1992 near the Mauna Loa Trail above the SEA upper unit fence line at 2,070 m elevation. No *Asplenium fragile* was found in 1997 when lava tubes in the area were searched.

Prior to a more focused search of likely habitat within the sub-alpine vegetation of the alpine unit of the Mauna Loa SEA in 2001, two large lava tube systems were identified on aerial photographs. Field examination of numerous skylights or openings in these lava tubes led to the discovery of *Asplenium fragile* at five additional sites (Fig. 1). A series of four openings in a lava tube between Kīpuka Kulalio and Kīpuka Mauna`iu above 2,195 m (7,200 ft) elevation each supported 10 to 30 clumps of the endangered fern. Several of these openings were relatively close to one another, and so they appear as only one mapped location on Figure 1. A second tube system just northwest of upper Kīpuka Kulalio extended downslope from 2,620 to 2,530 m (8,600-8,300 ft) elevation, but *Asplenium fragile* was confirmed in only one opening at 2,590 m (8, 500 ft). Approximately five small ferns were found near the base of a dark and damp wall of this tube, which was the highest elevational sighting of *Asplenium fragile* in HAVO. Other openings of this tube system were examined, but did not support the rare fern. A few skylights had very steep sides and could not be entered, so it is possible that *Asplenium fragile* persists elsewhere in the extensive lava tube.

Phyllostegia racemosa, Kīponapona

A vine in the mint family (Lamiaceae), *Phyllostegia racemosa* or kīponapona is a very rare species endemic to Hawai`i Island. Extant populations are known at Hakalau on Mauna Kea and on Keauhou Ranch, but the species was historically found at several additional sites between Mauna Kea and Mauna Loa (U. S. Fish and Wildlife Service 1997). Fewer than 50 individuals are thought to exist.

Phyllostegia racemosa was not known from HAVO until one plant was found along a Mauna Loa SEA transect (transect 16) during a 1987 forest bird census. The plant was sighted again in 1991 and persisted through 1993, when it was noted on transect during the SEA rare plant survey. The site is within Kīpuka Mauna`iu near 1,800 m (5,900 ft) elevation in an *Acacia koa* grove with a ground cover of alien *Ehrharta stipoides* or meadow ricegrass (Fig. 1). Subsequent searches of the area in 1997 and 1998 failed to find the known individual or any additional plants, and the species may have been lost from the Park. Between 1997 and 2000, mouflon sheep were present within the upper Mauna Loa SEA, and they may have browsed or killed any remaining *Phyllostegia* plants. Mouflon are known to browse on herbaceous native plants, and the animals are recognized as a potential threat to this and other endangered plant species (U. S. Fish and Wildlife Service 1996).

Plantago hawaiensis, Laukāhi kuahiwi

Plantago hawaiensis or laukāhi kuahiwi, a Hawai`i Island endemic, was listed as endangered in 1994. Populations of *P. hawaiensis* on Hawai`i Island have a wide distribution on the southern slopes of Mauna Kea; northeastern, slopes of Mauna Loa, and the western slopes of Hualālai. The U.S. Fish and Wildlife Service (1996) cites five historic and eight current populations in montane forests of *Acacia koa* and *Metrosideros polymorpha* at elevations between 1,800 m (5,900 ft) and 2,450 m (8,040 ft). Most populations are reported to have few plants, but no monitoring data are currently available for sites outside the Park. The largest known population of *P. hawaiensis*, an estimated 5,000 plants, is on Mauna Loa near 2,440 m (8,000 ft) elevation within Kapāpala Forest Reserve west of the Park (U.S. Fish and Wildlife Service1996). Kapāpala and Kūlani, which is east of HAVO, are the known sites nearest to the Mauna Loa SEA.

No *Plantago hawaiensis* plants were found along transects that crossed the Mauna Loa Strip in the upper unit of the SEA, with the possible exception of one unconfirmed sighting in Kīpuka Mauna`iu near 1,710 m (5,600 ft) elevation. Subsequently in 1994, more than 600 plants were found along four transects in the sub-alpine zone of the alpine unit of the SEA (Fig. 3). At this time, similar numbers of individuals were counted in both Kīpuka Kulalio and Kīpuka Mauna`iu. Apart from the concentrations of plants found within the two kīpuka during the 1994 survey, there have been additional sightings by Resources Management botanists at sites just above or below the 2,070 m fenceline in Kīpuka Kulalio. An unknown but small number of plants persisted for several years within a silversword introduction exclosure below the fence and east of the Mauna Loa trail. An additional cluster of fewer than 25 *Plantago hawaiensis* individuals was recently (2001) sighted on a narrow finger of vegetation on the western edge of Kīpuka

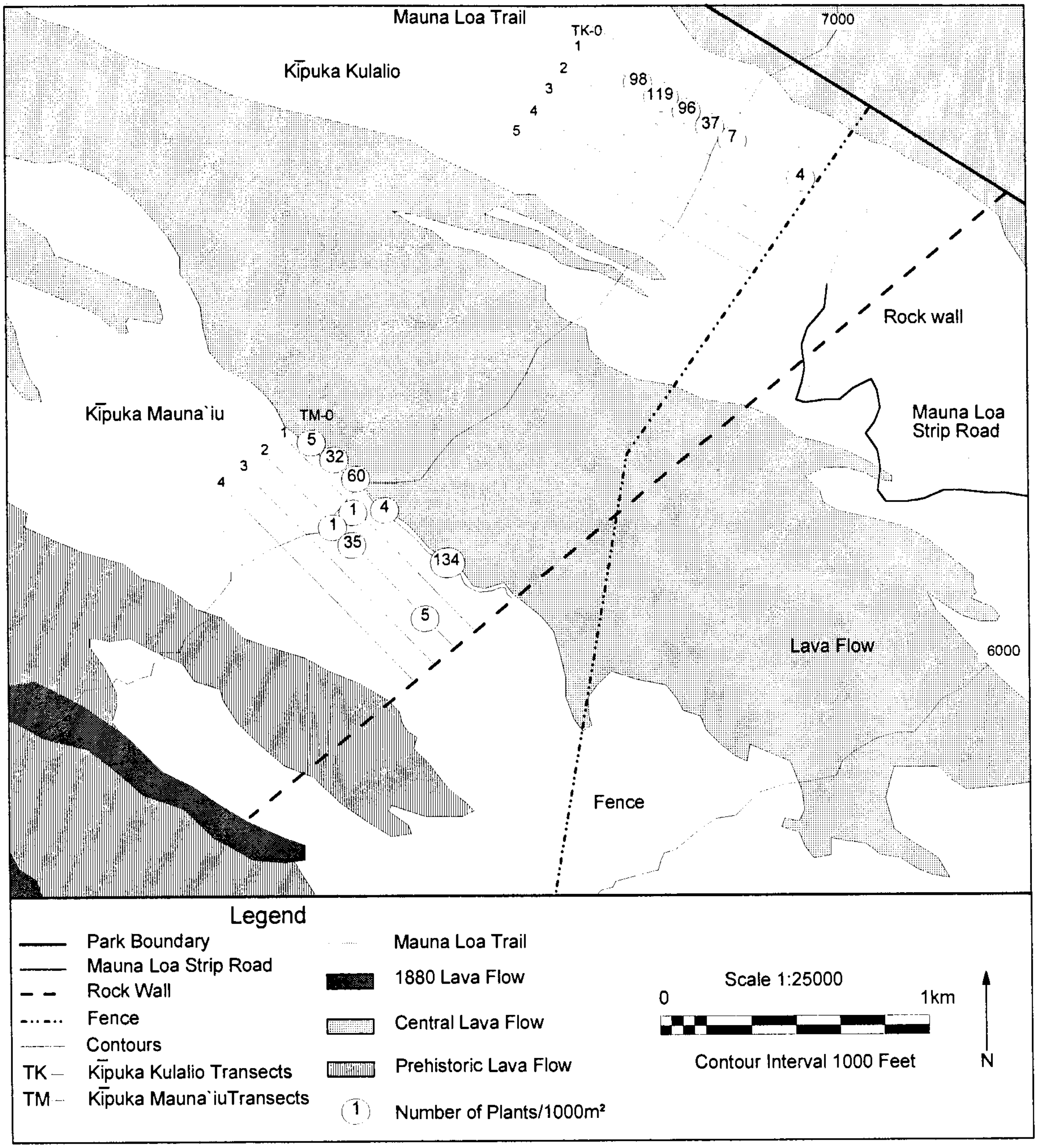


Figure 3. Distribution of *Plantago hawaiensis* (laukāhi kuahiwi) on transects in the alpine unit of the Mauna Loa SEA, HAVO.

Kulalio near 2,180 m (7,160 ft) elevation. Only the two concentrations of *Plantago hawaiensis* found on systematic transects in the alpine unit of the SEA were revisited and monitored for several years.

Plantago hawaiensis at Kīpuka Kulalio

In March 1994 a total of 357 *P. hawaiensis* was counted along one of six 1,000-m long belt transects in Kīpuka Kulalio. This population of *P. hawaiensis* was scattered along a 400-m length of a braided intermittent stream course with a few individuals (maximum of 24) at any one site (Fig. 3). (Note that numbers of plants on the figure represent totals for 100 m lengths of the transect.) The plants were found in leaf litter beneath low-growing shrubs of *Leptecophylla tameiameiae* and *Vaccinium reticulatum* and in moss mats within the stream channels. Plants were never more than five meters from these channels. In March 1996 when we resumed monitoring, only 51 plants remained. The number of plants increased to 64 in November 1996 and fell to 50 in September 1997. After September 1997 the number of plants continued to decline to a low of three individuals in March 2000 (Fig. 4).

Size Class Distribution - By the March 1996 census, when plants were assigned an individual number and tagged, the *P. hawaiensis* population at Kīpuka Kulalio had dropped to critically low numbers. The marked sites of 1994 were relocated using transect distances and site flagging, yet at many sites no plants were extant. In a two-year period, the recorded population of *P. hawaiensis* at Kīpuka Kulalio had declined by 85%; it is not precisely known when the losses occurred. In March 1996, all size classes were present but most plants were small. Twenty-three plants (45%) were of size class1 (1-5 cm), and only two plants (4%) were in the largest size class 5 (>20 cm).

After a nine-month interval, in November 1996, 41 of the tagged plants were relocated and re-measured. Ten plants were missing; this represented a 20% decline from March. Twenty-three new plants were observed near tagged plants and at sites where plants had been present in 1994 (but not in March 1996), resulting in a net gain of 25% of the March population. The total number of plants in the population was 64. The number of individuals in the five size classes was relatively stable between March and November; only size class 3 (11-15 cm) showed much change, increasing by eight plants (Fig. 5).

The 23 new plants observed in November 1996 were almost equally distributed in the first three size classes (8 plants in class 1, 6 in class 2, and 7 in class 3). While it is possible that the smallest plants represent new seedlings, it is unlikely that plants in the larger size classes reflect new recruitment to the population between March and November 1996. These new plants either were missed on our monitoring in March or they later emerged from debris deposited in winter floods.

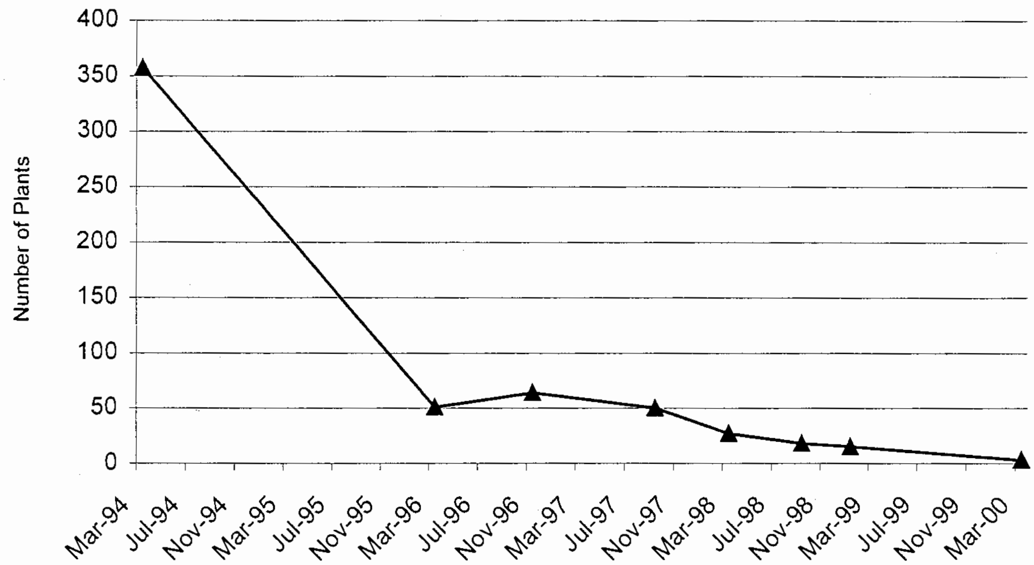


Figure 4. Population size of *P. hawaiensis* at Kīpuka Kulalio, March 1994 to March 2000 (No data collected between March 1994 and March 1996).

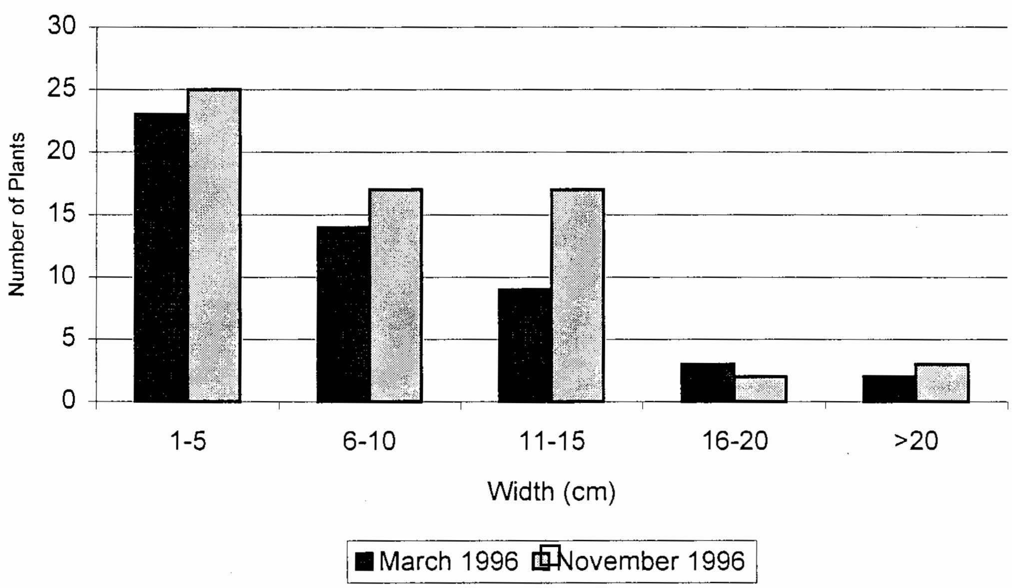


Figure 5. Size class distribution of *P. hawaiensis* at Kīpuka Kulalio in March and November 1996.

In September 1997, 50 of the tagged plants were located and re-measured. Fourteen plants were missing, representing a 22% decline from November 1996. No new plants or seedlings were observed. All size classes were still present. There were decreases in the smallest size class (1-5 cm) and that of 11-15 cm width and small increases (one to two plants) in width classes 6-10 cm and 16-20 cm.

By March 1998, the *P. hawaiensis* population of Kīpuka Kulalio had severely declined, and only 26 of 50 plants present in September 1997 were relocated. This represented a loss of nearly half the plants in a six-month period and a 93% decrease since March 1994. All size classes were present, but numbers in each class were reduced from the previous year. The smallest two size classes comprised 73% of the population (Fig. 6).

Further losses were noted six months later in September 1998, when only 16 plants were found, a 38% decline in the population since March. Five months later, in January 1999, 14 plants were counted. The population collapsed over a 19-month period from September 1998 to March 2000. The two largest size classes disappeared by January 1999, and by March 2000 only three sterile plants of the smallest class remained.

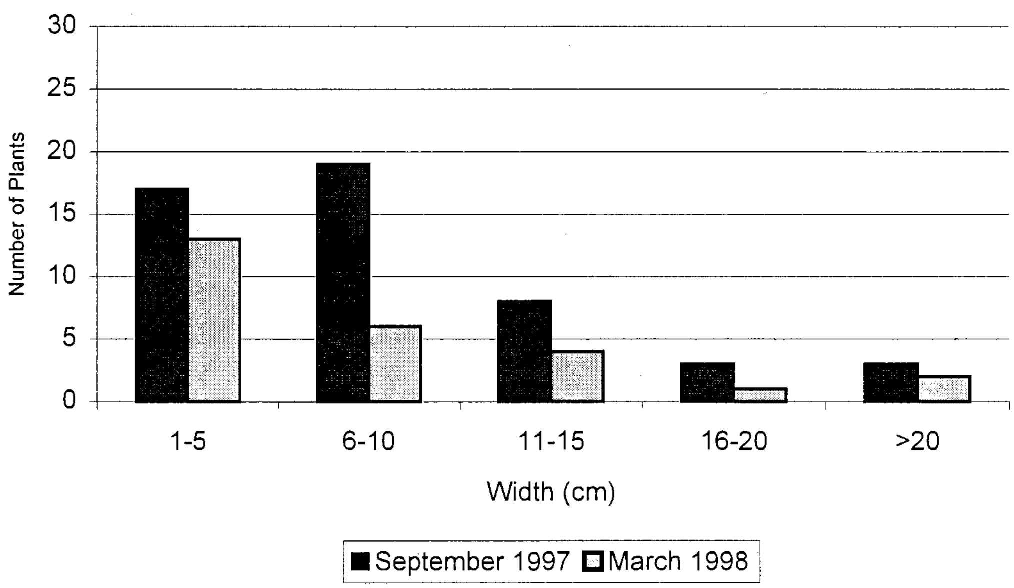


Figure 6. Size class distribution of *P. hawaiensis* at Kīpuka Kulalio in September 1997 and March 1998.

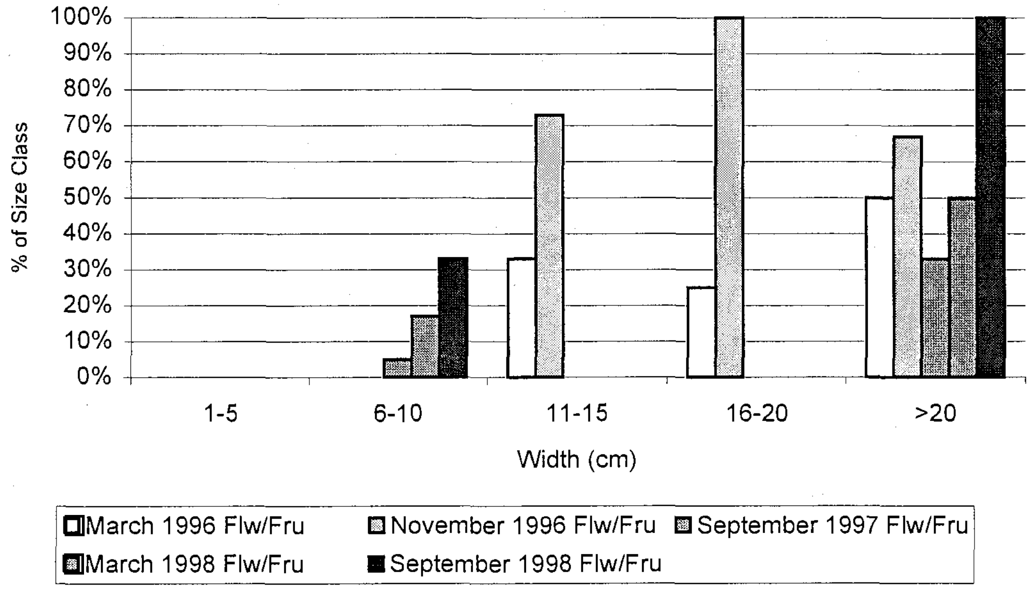


Figure 7. Percentage of *P. hawaiensis* flowering and fruiting by size class at Kīpuka Kulalio, 1996-1998.

Phenology - Small plants in size class 1 (1-5 cm), comprising almost half the population in 1996, were sterile throughout the duration of our monitoring. Most flowering and fruiting plants observed were in the three largest size classes (11-15, 16-20, and >20 cm) (Fig. 7). In 1996, a third (33%) of plants 11-15 cm in width were fertile in March, and 73% bore flowers or fruit in November. Size class 4 (16-20 cm) showed phenology similar to the smaller class with 25% of plants bearing flowers and fruit in March and 100% of plants fertile in November 1996. Flowering in the largest size class varied from 50% of plants in March to 67% in November 1996. From September 1997 to September 1998, only plants in size classes 2 (6-10 cm) and 5 (>20 cm) bore flowers or fruits, with the highest percentages of flowering seen in the largest size class. In January 1999, 50% of the few remaining plants between 11 and 20 cm in width had flowers or fruit, and in March 2000 all three surviving plants were small and sterile. No clear seasonal pattern of flowering was seen, although there was consistently a greater percentage of fertile plants in fall and winter than was noted in the spring (March). Fruits seem to persist on the stalks for more than a year.

Plantago hawaiensis at Kīpuka Mauna`iu

In March 1994, 277 *Plantago hawaiensis* were counted along three of five transects in Kīpuka Mauna`iu. The population was scattered, patchy, and distributed in an area 300 x 800 m with few individuals at most sites. A maximum of 134 plants was clustered at one site. Plants were growing in leaf litter beneath low-stature shrubs of *Leptecophylla* and *Vaccinium*, in moss mats along intermittent stream channels, and along the eastern kīpuka edge near its interface with an `a`ā lava flow. When we resumed monitoring in February 1997 the population had increased to 294. The number of *Plantago* plants continued to slowly rise between 1997 and 1999 except for a small drop in July 1998. The total number of plants decreased slightly between 1999 and 2000 (Fig. 8).

Size Class Distribution - In February 1997, 83% of the 294 plants observed were distributed evenly throughout the largest three size classes. The population consisted primarily of mature plants. The smallest size class 1 contained only 4% of the population. *Plantago hawaiensis* population and size class distribution remained stable from February to December 1997 with small shifts in numbers toward the two largest classes and corresponding decreases in the 6-10 and 11-15 cm width classes (Fig. 9).

From December 1997 to May 1998 the total population showed little change with a net increase of only three measurable plants. Between these monitoring periods there was a large increase in size class 2, size class 3 remained stable, and size classes 4 and 5 lost plants. The increase in plants 6-10 cm wide came from the higher size classes rather than from growth of smaller plants. From May to November 1998 there was a continued shift of individuals to smaller classes, resulting in losses from the largest size classes 4 and 5 (Fig. 10). Shifts in size class were related to recruitment, mortality, and most importantly, the partial burying of plants due to floods between May and November 1998. Mean height of plants dropped almost 2 cm, and mean width decreased more than 3 cm (Table 1).

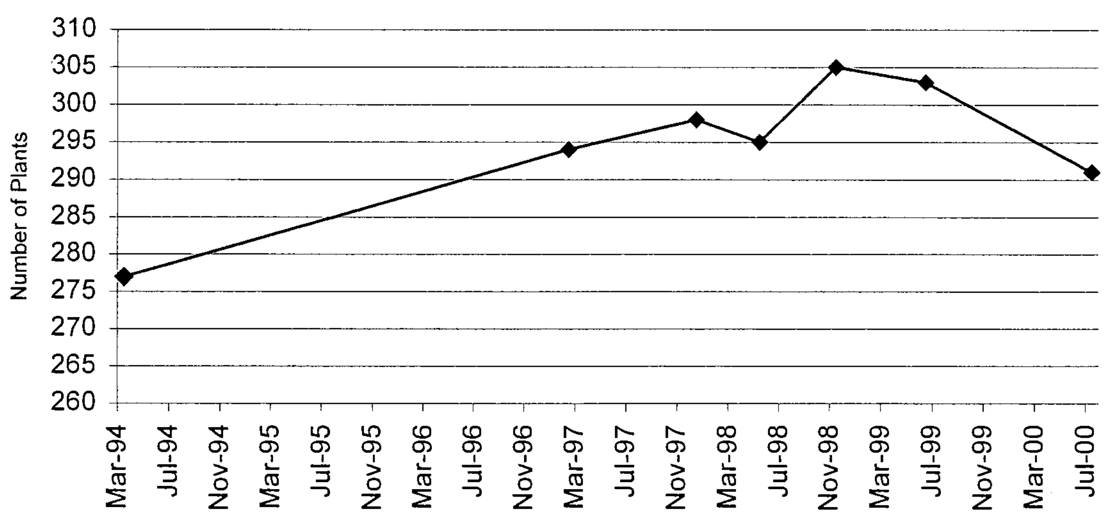


Figure 8. Population size of *P. hawaiensis* at Kīpuka Mauna`iu, March 1994 to July 2000.

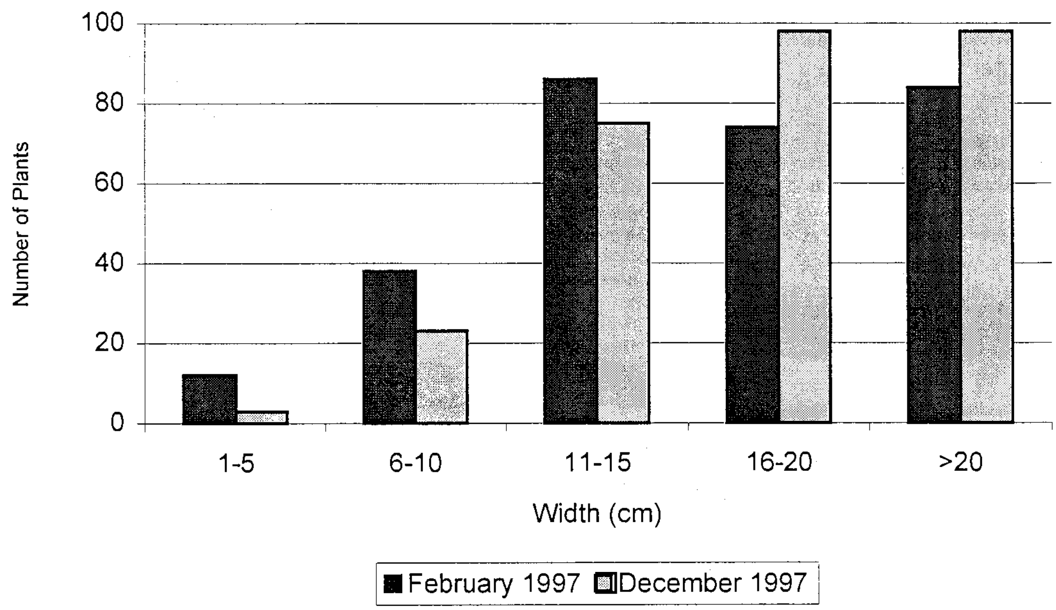


Figure 9. Size class distribution of *P. hawaiensis* at Kīpuka Mauna`iu in February and December 1997.

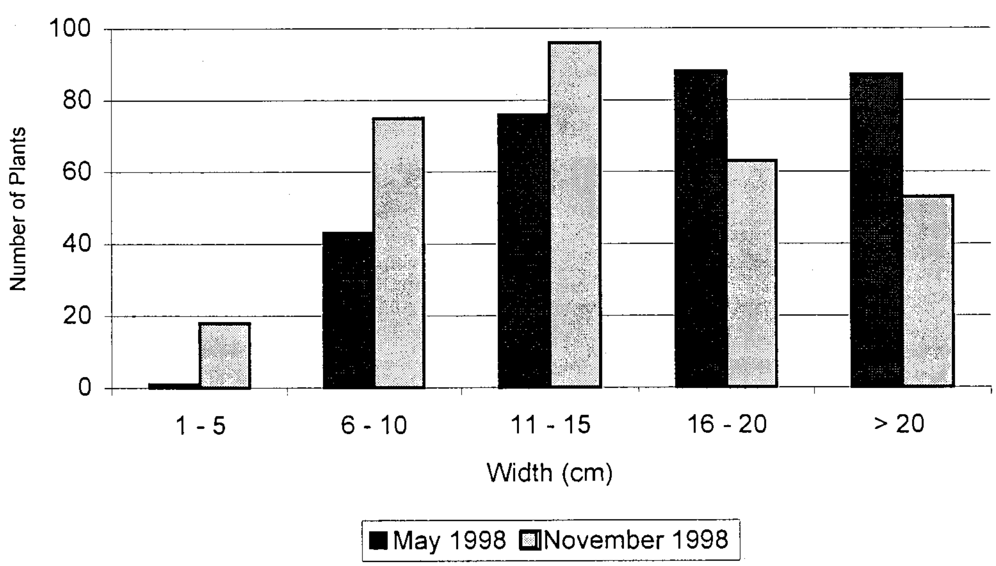


Figure 10. Size class distribution of *P. hawaiensis* at Kīpuka Mauna`iu in May and November 1998.

Table 1. Mean height and width of *Plantago hawaiensis* at Kīpuka Mauna`iu from 1997 to 2000.

Date	Number of Plants	Mean Height (cm)	SD	Mean Width (cm)	SD
Feb. 1997	294	11.0	5.7	16.9	7.0
Dec. 1997	297	11.8	6.3	19.0	7.1
May 1998	295	11.5	6.0	17.8	7.4
Nov. 1998	305	9.7	5.4	14.5	7.0
June 1999	303	9.9	5.6	13.6	6.1
July 2000	291	9.1	5.0	11.5	5.3

In June 1999, *Plantago* size class distribution was similar to that of November 1998. Over half a year, the three smallest size classes showed slight increases, but the largest two classes lost plants (Fig. 10 and 11). From June 1999 to July 2000, plants were added to size classes 1 and 2. This gain was pronounced for the 6-10 cm size class, which increased by 31 plants due to the growth of a few of the previous year's small plants, as well as shrinkage of plants formerly placed in the largest two size classes. More than half of the plants >20 cm in width were lost between 1999 and 2000 (Fig.11). This was largely due to decrease in plant size rather than attrition from mortality.

The number of large individuals seen in 2000 was less than a quarter of those present in February 1997. Most plants that had been large (>20 cm) in 1997 had been reduced in rosette width; only 15 plants (19%) remained in the largest size class throughout the three-year monitoring period. Seven large plants were confirmed dead. Most plants shrank into the 16-20 cm (25%) or the 11-15 cm width class (31%). Nineteen percent of plants that were large in 1997 were reduced to the smallest two size classes by 2000.

Phenology and Recruitment - Over the 3.5-year monitoring period of February 1997 to July 2000, flowering and fruiting was primarily a function of plant size; the largest three size classes consistently carried most of the reproductive spikes. Size class 5 was most productive in terms of flowers and capsules though there were fewer plants in the class (Fig.12). Regardless of time of year, the percentage of fertile plants in the >20 cm class ranged from 68 to 87%. Throughout the study, the percentage of plants bearing flowers or fruits varied from 48 to 72% in the 16-20 cm width class and from 37 to 55% in the 11-15 cm group.

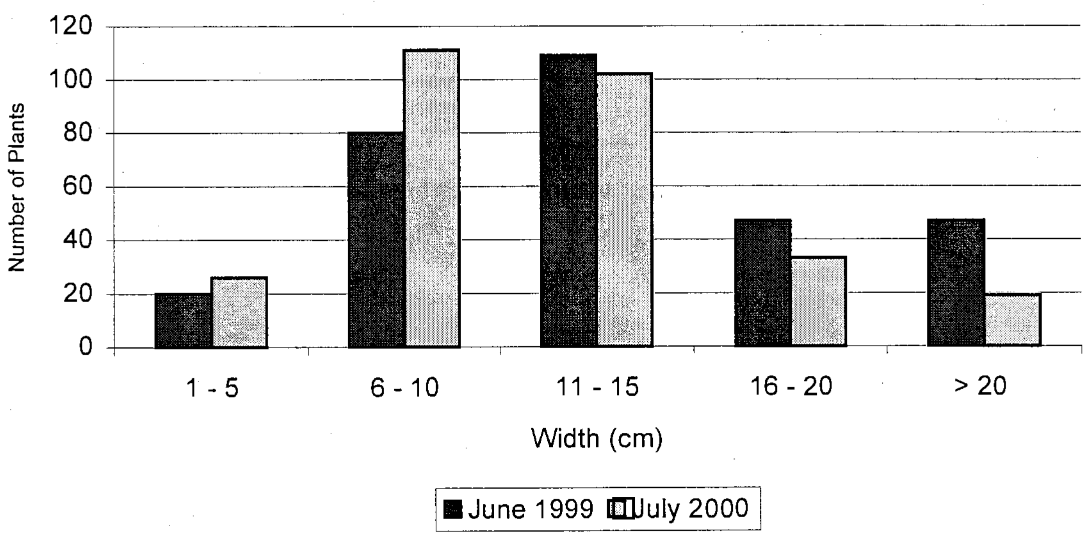


Figure 11. Size class distribution of *P. hawaiensis* at Kīpuka Mauna`iu in June 1999 and July 2000.

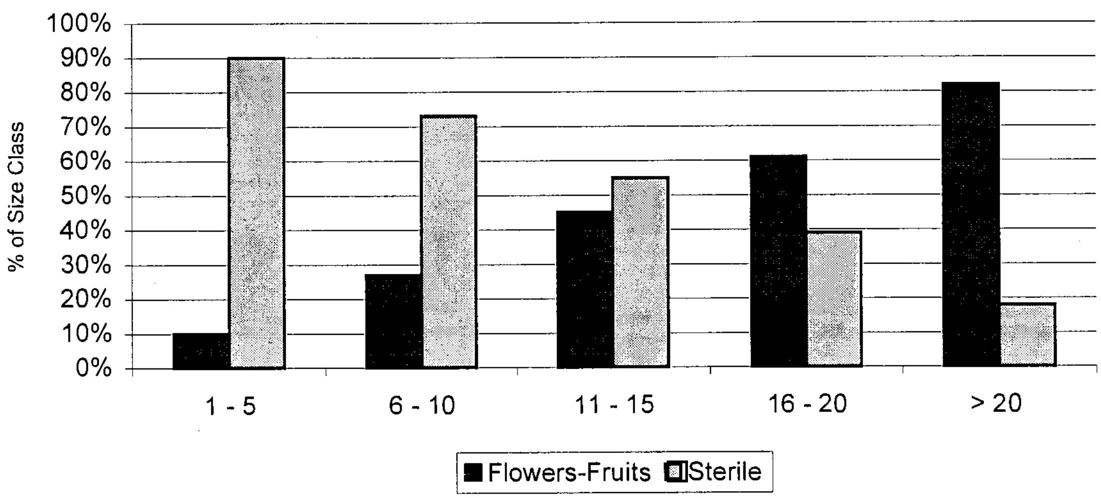


Figure 12. Percentage of sterile and fertile plants within each size class of *P. hawaiensis* at Kīpuka Mauna`iu averaged over the monitoring period of February 1997 to July 2000.

From 1997 to 2000, almost 2,000 flowering and fruiting spikes were counted at Kīpuka Mauna`iu with an average height of 33 cm. Each spike may have over 100 capsules containing as many as four to six seeds each. February 1997, December 1997, and May 1998 were the only monitoring periods where flowers were recorded. Of these monitoring periods, February 1997 had the highest percentage flowering with 92 of 294 plants (31%) fertile. Only one plant was flowering in December 1997, and 45 of 295 plants (15%) bore flowers in May 1998. No flowering was noted in the summer or fall. While few flower-bearing stalks were observed, capsule-bearing stalks were present at each monitoring session. The percentage of plants bearing fruits ranged from a low of 35% in July 2000 to a high of 58% in December 1997.

Compared with the baseline total from 1994, 20 plants had been gained in the population by the end of 1997. In the following three years, small losses due to mortality were noted, particularly in summer and fall, followed by gains due to recruitment in the fall. Of note are the gains made in November 1998, when we recorded the highest level of recruitment of measurable plants (20) and the second highest mortality with 10 dead. July 2000 had the second highest recruitment with 13 new plants and the greatest number of dead plants (25). Overall new plant recruitment and establishment slightly outpaced plant mortality with 47 dead and 61 new plants established (>1 cm width) over the entire monitoring study (Fig. 13). In 2000, the *Plantago hawaiensis* population at Kīpuka Mauna`iu was 291 plants, 14 above the baseline count of 277 in 1994, representing a 5% net increase over a five-year period.

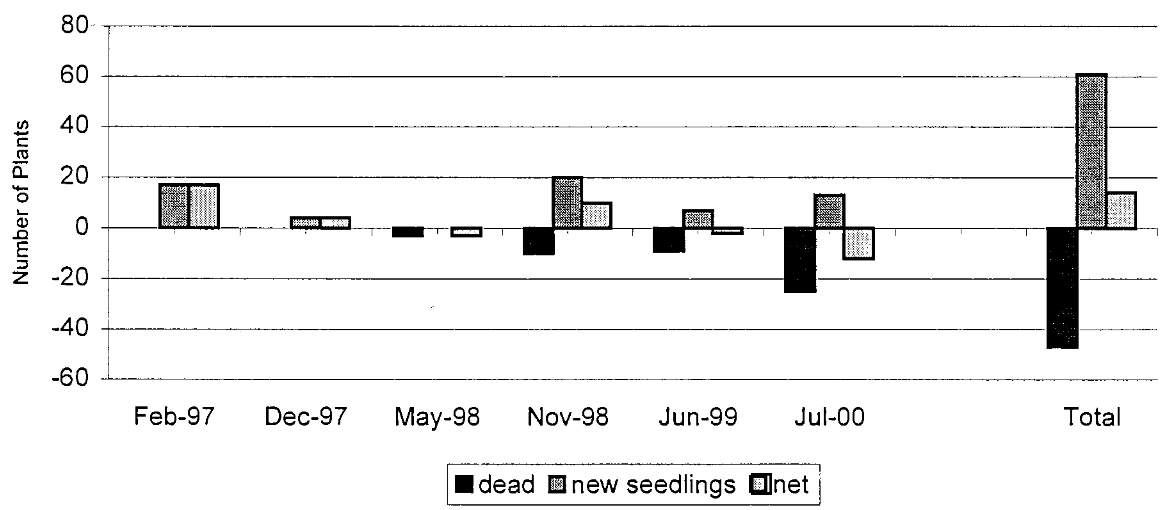


Figure 13. Seedling establishment and mortality of *P. hawaiensis* at Kīpuka Mauna`iu from February 1997 to July 2000.

Very small seedlings or germinants were very difficult to monitor, as they were ephemeral and often indistinguishable from seedlings of the alien, rosette-forming *Hypochoeris radicata* (gosmore or hairy cat's-ear). Tiny seedlings were observed near adult plants in February 1997, May 1998, November 1998, and June 1999. Seedlings were particularly abundant in November, when more than 100 tiny plants, <1 cm in width, were marked with toothpicks. Their species was not determined until June 1999, and by then most of the marked seedlings had died unidentified. Of those remaining, 10 were identified as *Hypochoeris*, and 20 were confirmed as *Plantago.* Because most died before they were completely identifiable, the true mortality rate is not known. Of approximately 250 potential *P. hawaiensis* seedlings noted during three years, only 27 survived and were confirmed as *Plantago* plants. This represents a worst-case survival rate of only 11% (assuming all were *P. hawaiensis*). Since it is clear that many of the tiny plants were actually *Hypochoeris*, the real survival rate of *Plantago* is unknown.

Threatened Plant Species

Silene hawaiiensis, Hawaiian catchfly

Silene hawaiiensis, a small shrub in the carnation family (Caryophyllaceae), is endemic to Hawai`i Island, where it is widely distributed on the western slopes of Mauna Kea, Hualālai summit, Humu`ula saddle, slopes of Mauna Loa, and Kīlauea. *Silene hawaiiensis* was proposed as an endangered species in 1992 and listed as threatened in 1994, when only 3,000 plants were thought to exist on the island (U. S. Fish and Wildlife Service 1992, 1994). In the Big Island recovery plan (U. S. Fish and Wildlife Service 1996), eleven populations were recognized and reported to contain more than 11,000 plants. At Hawaii Volcanoes National Park, populations of *S. hawaiiensis* are concentrated south of Kīlauea Crater and in the Mauna Loa SEA. Throughout the range of the plant on Hawai`i Island, browsing by goats, sheep, and mouflon, as well as rooting by feral pigs, are present or potential threats *to S. hawaiiensis.*

Distribution in the Mauna Loa SEA

In 1992-93, *Silene hawaiiensis* was found at six sites along three transects between 1,520 m (5,000 ft) and 1,980 m (6,500 ft) elevation (Fig. 14). At one of these sites near 1,830 m (6,000 ft) elevation, plants were very numerous northwest of the transect along a channel in the lava flow separating Kīpuka Kulalio from Kīpuka Mauna`iu; this concentration of *Silene* was selected for more intensive monitoring. An additional concentration of plants was found between transects on an arm of the Ke`āmoku lava flow that crosses the Mauna Loa Strip Road near 1,710 m (5,600 ft) elevation. This was chosen as a second monitoring site, because of its accessibility and the presence of a large number of *Silene* plants.

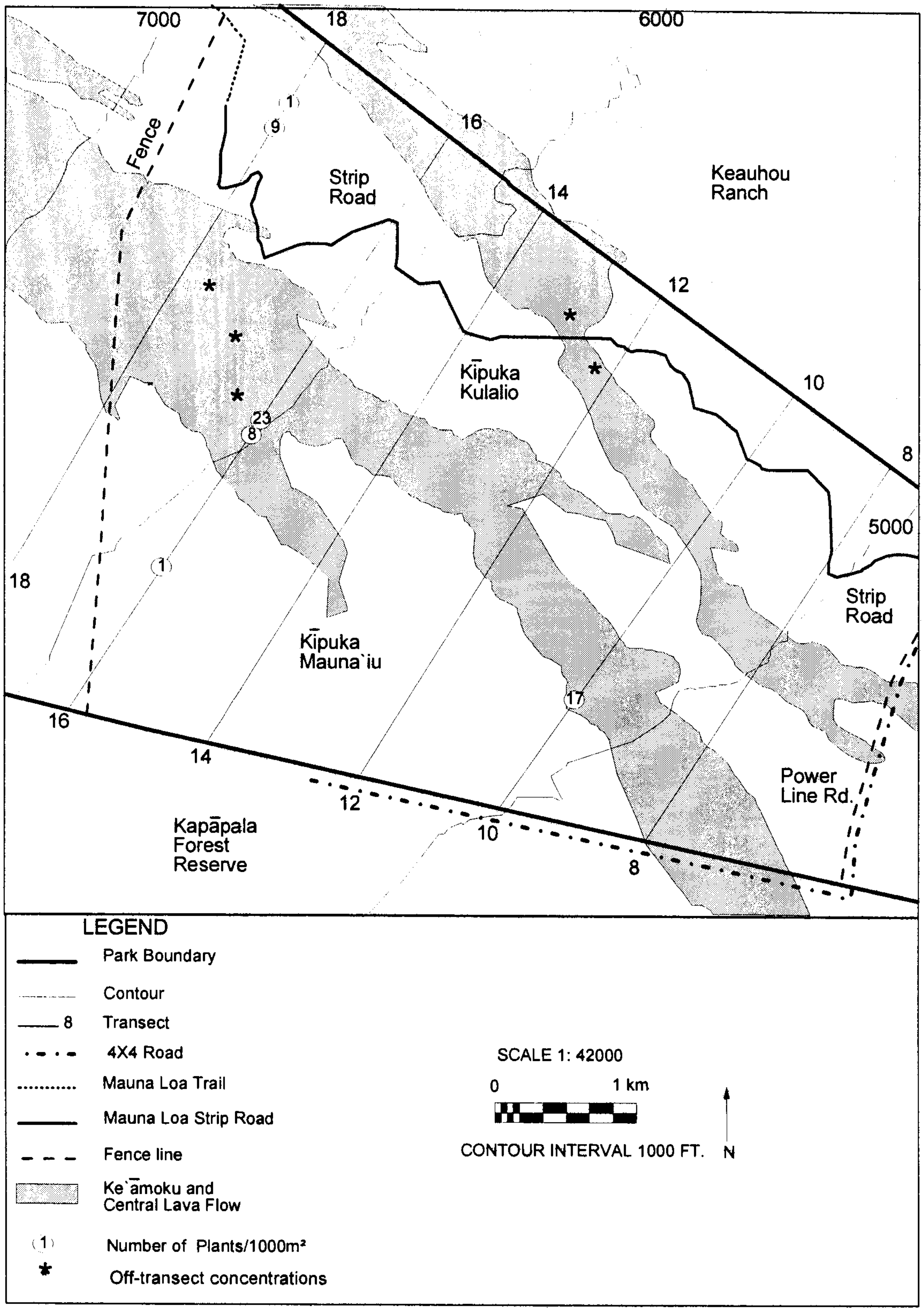


Figure 14. Distribution of *Silene hawaiiensis* on transects in the upper unit of the Mauna Loa SEA, HAVO.

During travel to monitoring sites in 1997-2001, additional individuals and groups of *S. hawaiiensis* were observed between surveyed transects of the upper unit; plants seemed to be particularly numerous along a flow channel between the "Three Trees Kīpuka" near 1,890 m (6,200 ft) elevation and the monitored population at 1,830 m (Fig. 14). No *Silene hawaiiensis* was seen along transects in the two kīpuka of the alpine unit, although a few plants were noted on the western edge of Kīpuka Kulalio just below 2,195 m (7,200 ft) elevation. These plants were associated with several other rare and uncommon species (*Plantago hawaiensis, Exocarpos menziesii*, and *Rumex giganteus*).

Silene hawaiiensis at the Central Lava Flow Site

In December 1997, we returned to re-monitor this population. On the way to the site, we observed three mouflon sheep (one ewe and two rams) approximately 1,000 m from the Mauna Loa Strip Road and 800 m from the *Silene* study site. On arriving at the study area, it was evident that the *Silene hawaiiensis* population had been severely browsed. Population group 73 had been greatly reduced by browsing and had few remaining plants of the original 614. It is estimated that three to six mouflon sheep were present in the upper Mauna Loa SEA during the course of the study from 1997 to 2000 (Howard Hoshide, pers. comm. 2000).

The randomly selected sub-sample groups in 1998 included 206 individuals or 37% of the 1992 baseline of plant groups 1-72. In the 1998 monitoring, 52 plants or 26% of the original sub-sample were dead. Ninety-five new plants were associated with the randomly selected plant groups in 1998. These young plants were primarily 1-10 or 11-20 cm in height and represented a net increase of 43 plants or 21% of the sub-sample. Recruitment was almost double mortality in the 1998 monitoring. After 1998, no additional recruitment was observed in our sub-sample, and annual losses of *Silene* were noted in both 1999 and 2000.

Browsing and Size Class Distribution - Initial mouflon sheep browsing occurred prior to December 1997, but the length of time plants were exposed to the animals is uncertain. Mean height and width of the monitored sub-sample of the *Silene* populations decreased substantially between 1992 and 2000 (Table 2). A decrease of 18.5 cm (67%) in mean height and 18.3 cm (70%) in mean width was observed in the sub-sample from 1992 to 1998. We attribute this to browsing by mouflon sheep. Sixty-two percent (155) of plants showed browsing damage in 1998; this represented the highest level of browsing recorded during the study. Only 23% (34) of *Silene* were browsed in 1999, and evidence of browsing was seen in only 4% (5) of the sub-sample in 2000 (Fig. 15). Increases in mean height (2.1 cm) and mean width (1.5 cm) occurred in 1999, and plants continued to grow into 2000, as browsing pressure lessened. This decline in damage to *Silene* was likely due to management efforts to remove sheep from the unit.

Table 2. Mean height and width of *Silene hawaiiensis* in a sub-sample at the Central Lava Flow site in 1992 and 1998-2000.

Year	Number of Plants	Mean Height (cm)	SD	Mean Width (cm)	SD
1992 Sub-sample	206	27.6	15.7	26.0	27.9
1998	249	9.1	6.9	7.7	8.5
1999	111	11.2	7.5	9.2	6.8
2000	92	18.1	11.1	15.2	11.7

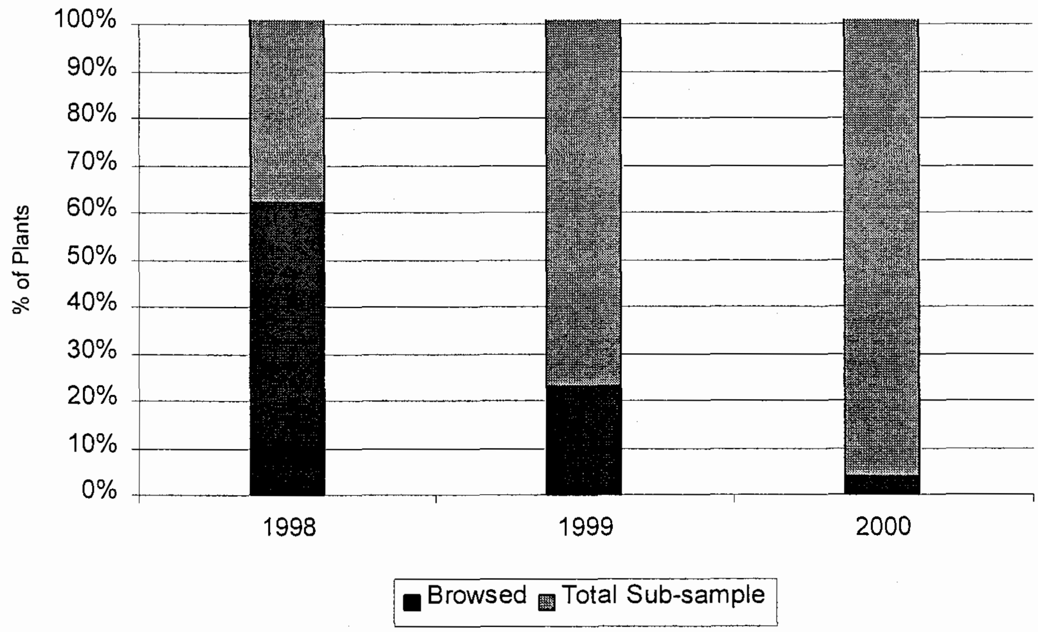


Figure 15. Percentage of *Silene hawaiiensis* plants with browsing damage at the Central Lava Flow site in the Mauna Loa SEA, 1998-2000.

To characterize the population structure of *S. hawaiiensis* at the Central Flow site, we divided the population into four classes based on height (cm). In 1992, 40% of *Silene* were in height class 4 (>30 cm), while the remaining plants were almost evenly distributed in the smaller three classes. By 1998, a dramatic shift in plant size had occurred, and the number in the largest class declined to only five plants or 2% of the population. Size class 1(1-10 cm) included 70% of the population in the 1998 sub-sample (Fig. 16).

Of the 174 plants in size class 1 in 1998, 75 represented new recruitment, while 82 plants had shifted from larger to the smallest size class. Only 17 plants had remained in the small class over the almost six-year period. The 11-20 cm class showed little overall change in numbers; there were 50 plants in 1992 and 59 in 1998. In addition to the survivors that remained within class, there were 25 plants that moved into size class 2 from larger size classes and 17 new recruits. More than 100 *Silene* plants in our sub-sample shifted size class downward as a consequence of mouflon browsing between 1992 and 1998. This skewed distribution of height classes was maintained into 1999 with 58% of the population in size class 1. Predominance of small size classes was coincident with mouflon browsing throughout 1998 and 1999. By 2000, size classes had regained a more even distribution, although fewer plants were present. Average heights and widths of *S. hawaiiensis* increased, indicating less browsing pressure.

In 1998, of the 155 *Silene* plants that were browsed, 103 (66%) were in the 1-10 cm class and 40 (26%) were in the 11-20 cm class (Fig. 17). The same browsing pattern was repeated in 1999. Of the 34 browsed plants in the 1999 sub-sample, 26 (76%) were in the 1-10 size class, and 7 (27%) were in the 11-20 class. Browsing declined in 2000 with only 5 plants of 116 (4%) exhibiting damage; these were all in the two smallest size classes. The decrease in browsing in 1999-2000 may be a function of fewer and smaller available plants distributed over a wide area; such scattered plants may be difficult for mouflon to locate. There may also have been changes in mouflon range or numbers in the area, as a result of management activities.

Mortality - The overall mortality in the sub-sample between 1992 and 1998 was 25% with 52 of 206 plants dead. If the losses were spread over the entire period this would amount to an estimated annual death rate of 4%. Percentage mortality was similar in the four height classes: 27% of plants 1-10 cm tall, 30% of those 11-20 cm, 18% of the 21-30 cm class, and 27% of plants >30 cm tall. Recruitment compensated for mortality in the *Silene* sub-sample in 1998, when 95 new plants were observed (Fig. 18).

In 1999, 104 plants that had been alive in 1998 were dead, a decrease of 42%. In 2000, 29 plants alive in 1999 were lost, a 20% decline over a year. Except for recruitment noted in 1998, the population trend for the sub-sample was downward in the following two years from 249 to 116 plants. This 53% mortality rate was more than double the mortality noted between 1992 and 1998.

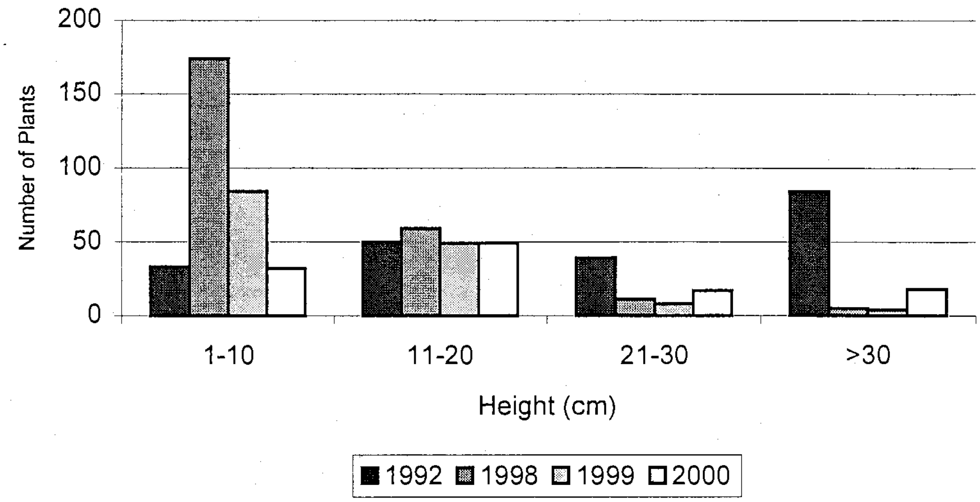


Figure 16. Size class distribution of *Silene hawaiiensis* in the monitored sub-sample at the Central Lava Flow site in the Mauna Loa SEA, 1992 to 2000.

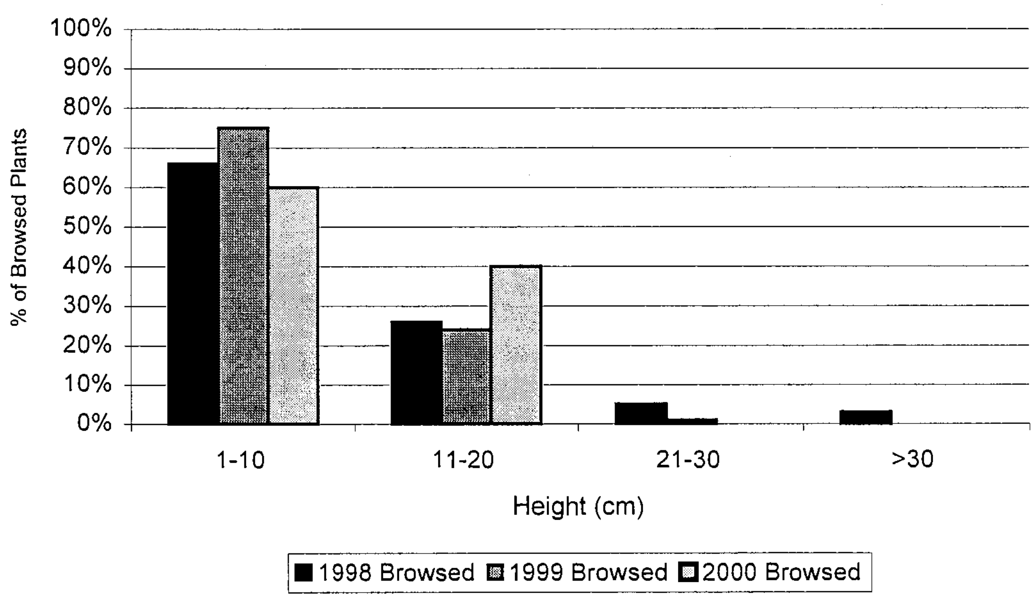


Figure 17. Size class distribution of *Silene hawaiiensis* browsed by mouflon sheep at the Central Lava Flow site in the Mauna Loa SEA, 1998-2000.

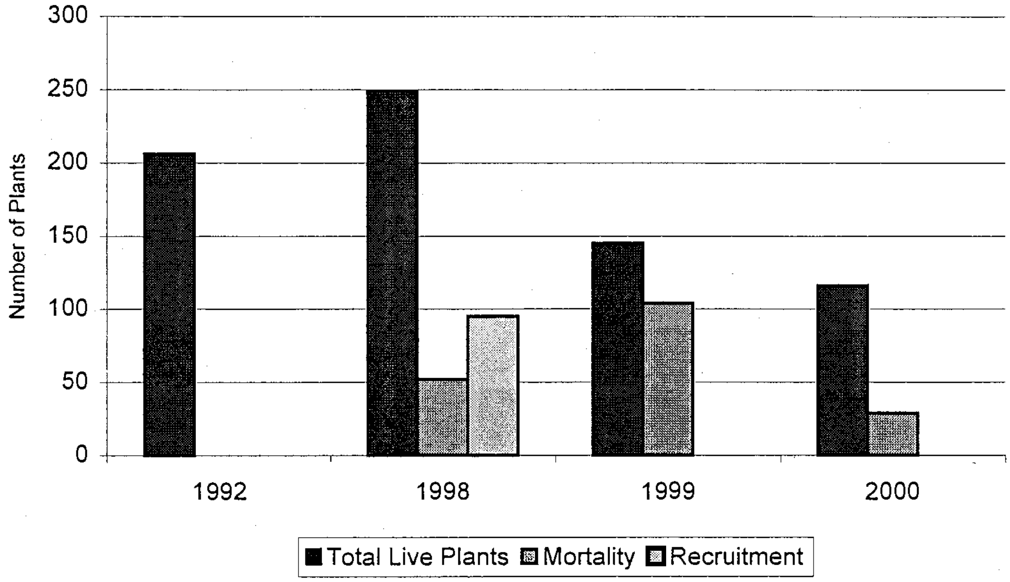


Figure 18. Mortality and recruitment of *Silene hawaiiensis* at the Central Lava Flow site in the Mauna Loa SEA, 1998-2000.

In 1998, the highest mortality was observed in the >30 cm height class (10% of sub-sample). Mortality shifted to the 1-10 and 11-20 cm classes in 1999, with losses of 32% and 11% of the sub-sample, respectively (Fig. 19). No mortality occurred in plants >30 cm in 1999 or 2000. Mortality changed from a distribution in all size classes in 1992-1998 to the smaller two classes in 1998-2000, mirroring the transfer of browsing pressure from large to small height classes after 1998.

Seedling Recruitment - In 1998, 95 new plants in the 1-10 and 11-20 cm height classes were recorded in our sub-sample. These seedlings were tagged and measured within the randomly selected plant groups of our sub-sample. Mean seedling height was 7.3 cm, and width averaged 3.1 cm. Twenty-six percent of the new plants showed signs of browsing, and over a third (34%) were rated in poor condition. Thirty-three of the recruits remained in 1999, representing a decrease of 65% from the previous year. Mean height of surviving young plants was 9.5 cm and mean width was 5.9 cm. In 2000, 27 tagged seedlings survived, a loss of only five plants from 1999. Mean height and width increased to 17.1 and 9.0 cm. In addition to the tagged seedlings in 1998, 23 tiny new plants were noted near one plant group but were too small to be given a tag; most of these (21) persisted in 2000. No new recruitment was recorded in 2000.

Phenology -For this study, the presence or absence of flowers and fruit was recorded during each monitoring period from 1992 to 2000 to evaluate "reproductive phenology" (Fig. 20). We noted whether plants were sterile, or had flower buds, open flowers, young fruit, or old fruit. For analysis, we combined

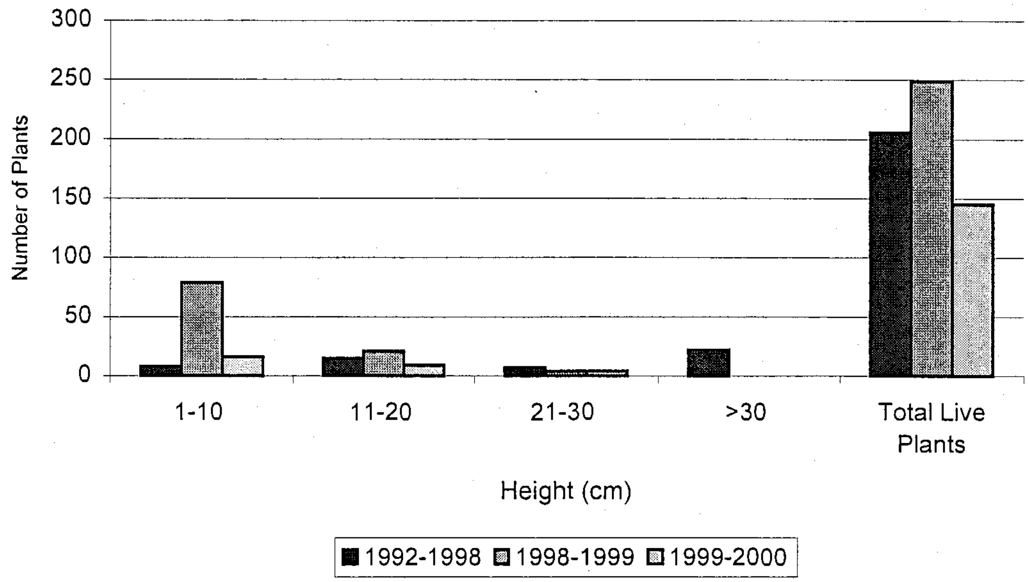


Figure 19. Mortality of *Silene hawaiiensis* in four size classes at the Central Lava Flow site in the Mauna Loa SEA, 1992-2000 (Total number of live plants on right).

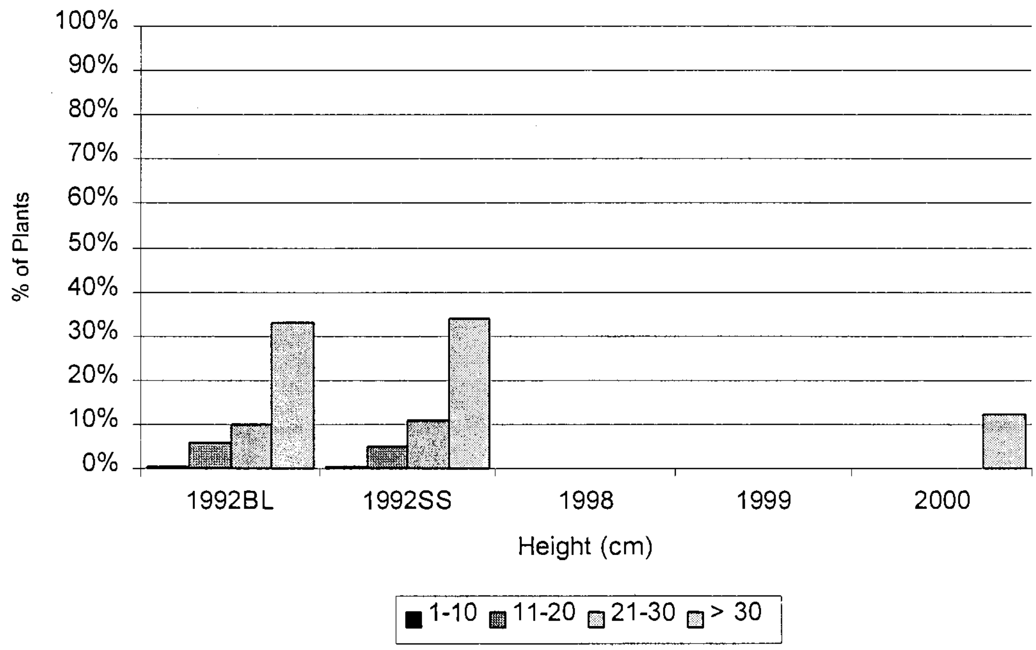


Figure 20. Percentage of fertile *Silene hawaiiensis* plants in four size classes at the Central Lava Flow site, 1992-2000 (BL is baseline; SS is sub-sample).

buds, flowers, and young fruit. The small urn-shaped fruit capsules of *S. hawaiiensis* are persistent, probably for more than a year. Plants that had only dry and empty "old fruit" in a monitoring period were regarded as sterile. Approximately half (51%) of the 1,162 plants examined in fall and winter of 1992 were sterile, and the other half (49%) had flowers and/or fruit. In the 1992 baseline of 548 tagged plants (groups 1-72), 283 (52%) were sterile, and 265 (48%) showed reproductive phenology. The 1992 sub-sample displayed a similar pattern, with 101 of 206 plants (49%) sterile, and 105 (51%) bearing flowers or fruit. In 1998 and 1999, no plants in the sub-sample bore flowers, and only two plants had old fruit. Of the 116 plants in the 2000 sub-sample, only 11 (9%) were fertile (Fig. 20).

Throughout the monitoring, presence of flowers or fruit was primarily a function of size class, with the larger size classes displaying the reproductive phenology. Of 265 plants in the baseline population that were fertile, most (68%) were in the >30 cm height class, about a quarter (22%) were in the 21-30 cm class, and very few (11% and 0.3%) were in the two smallest height classes. This pattern of large plants bearing flowers was repeated in the 1992 sub-sample with 70 flowering individuals (67%) in the >30 cm size class. In 2000, all the flowering and fruiting plants were >30 cm tall.

<u>Exclosure Experiment</u> - The objectives of the exclosure experiment were to detect browsing events at less than annual intervals and to follow growth rates and phenology of *Silene* plants protected from browsing. Plants were monitored once a month from June to August 1998 and at six-month intervals from August 1998 to March 2000. Six exclosures at plant group 73, a site with consistent, severe mouflon damage that had formerly supported more than 600 *Silene* plants, were monitored every six months between January 1999 and March 2000.

In the 20 plant groups randomly selected in 1998, mean height of controls was 9.0 cm, and that of protected plants was 11.7 cm. Growth rates were similar in both groups throughout the monitoring period (Fig. 21). In March 2000, after nearly two years of growth, mean heights were 24.0 cm in the control group and 28.8 cm in the exclosure group. Over 19 months, the control group increased in height by 15.0 cm and the protected plants increased 17.1 cm. The mean growth per month in the exclosure group was 0.9 cm, and that of the control group was 0.8 cm. In the controls, only two plants were obviously browsed during our monitoring. Mortality was higher in the control group, as six of 20 plants died while only two of the caged plants were dead at the end of the study. Only 7% of control plants bore flowers or fruit during the study period, while 77% of caged plants were fertile. At the last monitoring period in December 2000, a decline of 3.9 cm in mean height was recorded for the caged group while a larger decrease of 11.5 cm (48%) was noted in the control group. Though no fresh browsing damage was observed in December 2000, the decrease in height of unprotected plants suggests a browsing event occurred sometime between March and December. The overall change in height of protected plants over more than two years did not differ significantly from that observed in unprotected control plants ($t=0.404$; $p>0.500$).

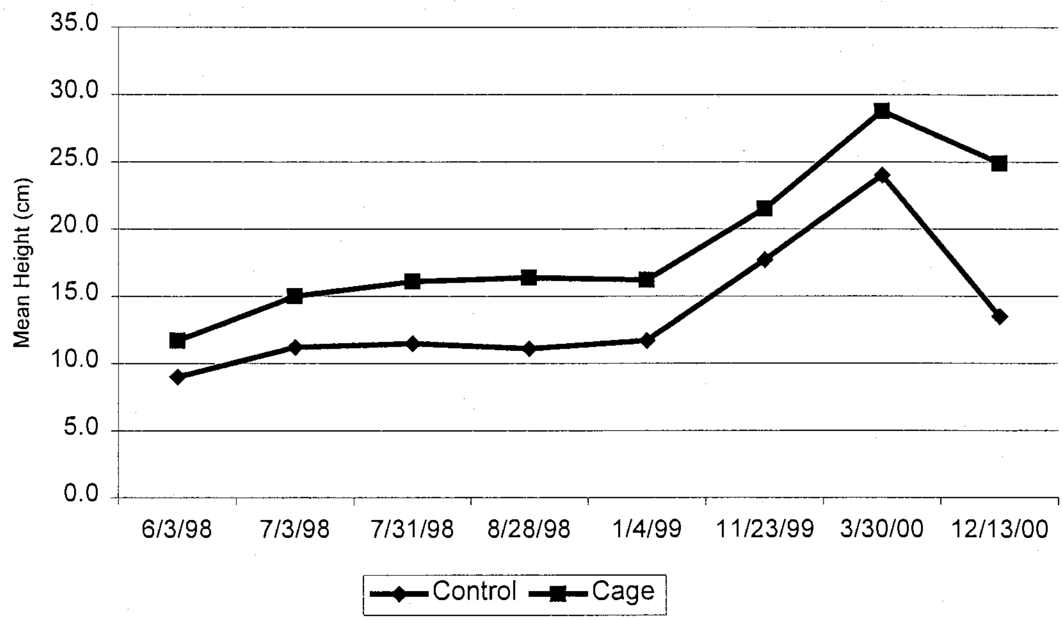


Figure 21. Growth of randomly selected *Silene hawaiiensis* inside and outside exclosure cages at the Central Lava Flow site in the Mauna Loa SEA, 1998-2000.

The exclosure experiment at plant group 73 illustrates the potential recovery of *S. hawaiiensis* when protected from browsing (Fig. 22). All 12 plants selected at this site had been previously browsed. Mean height at the beginning of the experiment was 9.3 cm for the control group and 7.6 cm for the caged group, and all were sterile. At the first monitoring period in November 1999, 50% of the control plants had been browsed, all were sterile, and the mean height remained 9.3 cm. The caged plants grew on average 19.4 cm, and 50% had flowers and/or fruit. In March 2000, the average height for control plants was 12.0 cm, all plants had been browsed again, and there were no flowers or fruits. The exclosure plants, by contrast, had grown an average 4.8 cm, their mean height was 31.8 cm, and four of six plants bore flowers. Extrapolated mean monthly growth for the protected plants was 1.6 cm over 15 months. In our last monitoring period of December 2000, a 2.5 cm increase in mean height was recorded for the caged group, while a much larger 8.7 cm increase was observed in mean height of the control group. This disparity suggests no browsing occurred in this area from March to December 2000. The smaller increase in height of plants in exclosures indicates that the wire cages were interfering with normal growth; cages were removed in 2001.

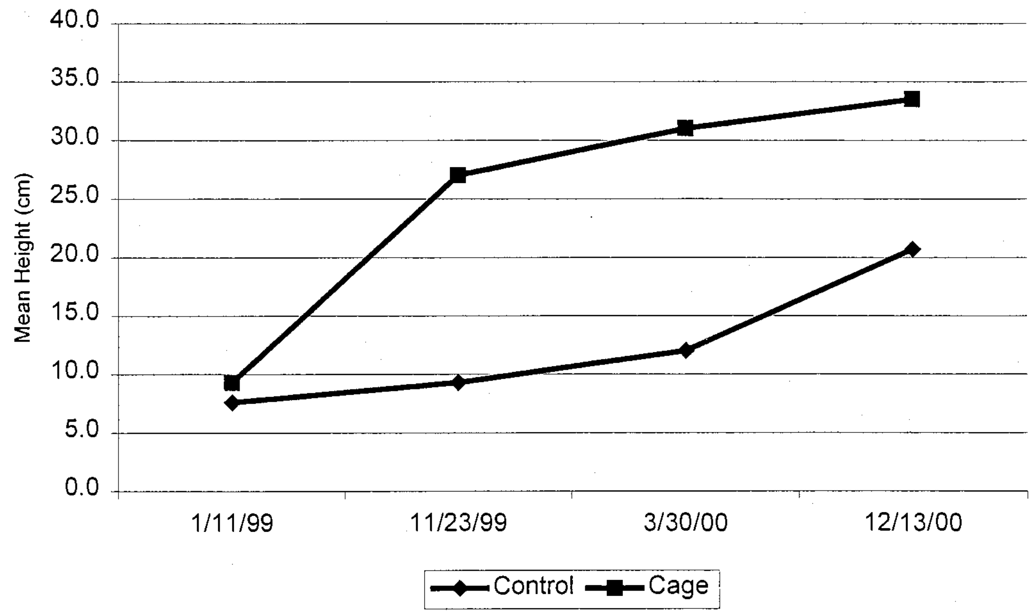


Figure 22. Growth of selected *S. hawaiiensis* inside and outside exclosure cages at Group 73 of the Central Lava Flow site in the Mauna Loa SEA, 1999-2000.

Silene hawaiiensis at the Ke`āmoku Lava Flow Site

In September 1994, we tagged and measured 628 *Silene hawaiiensis* plants concentrated on an arm of the Ke`āmoku lava flow at 1,710m (5,600 ft) elevation near the Mauna Loa Strip Road. This population was growing on flat open rocky substrate on a ridge at the edge of a lava flow channel. Surrounding vegetation was an open shrub community of *Dodonaea viscosa* (`a`ali`i), *Vaccinium reticulatum* (`ōhelo), and *Leptecophylla tameiameiae* (pūkiawe). We returned to re-monitor the population in June 1999, and found it had declined by 445 plants (71%), leaving 183 live plants. No sign of mouflon sheep browsing was observed at this site. In 1994, the mean height of *S. hawaiiensis* at this site was 28.5 cm, and mean width was 42.6 cm. Five years later, the mean height and width had declined by 6.5 cm and 4.6 cm, respectively (Table 3).

Height classes were the same used at the Central Lava Flow site. In 1994, 66% of the baseline population was distributed in the two largest size classes; 38% were >30 cm and 28% were 21-30 cm tall. The two smaller height classes of 1-10 and 11-20 cm contained 16% and 19% of plants, respectively. The 1999 population structure showed the 183 remaining plants evenly distributed throughout all height classes (Fig. 23). Mortality of *Silene* was very high in the five-year study period. Greatest losses were noted in the two upper height classes (Fig. 24), and many live plants shifted from larger to smaller size classes due to the death of terminal branches. Only the live part of shrubs was measured.

Table 3. Mean height and width of *Silene hawaiiensis* at the Ke`āmoku site in the Mauna Loa SEA, 1994 and 1999.

Year	Number of Plants	Mean Height (cm)	SD	Mean Width (cm)	SD
1994	628	28.5	16.0	42.6	29.4
1999	183	22.0	14.0	38.0	30.0

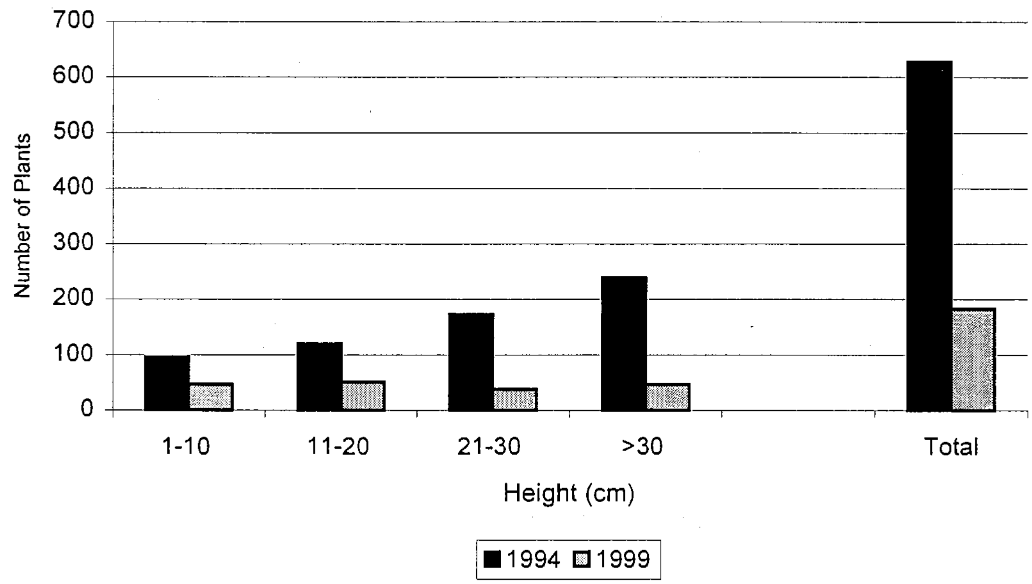


Figure 23. Height class distribution of *Silene hawaiiensis* at the Ke`āmoku site in the Mauna Loa SEA, 1994 and 1999.

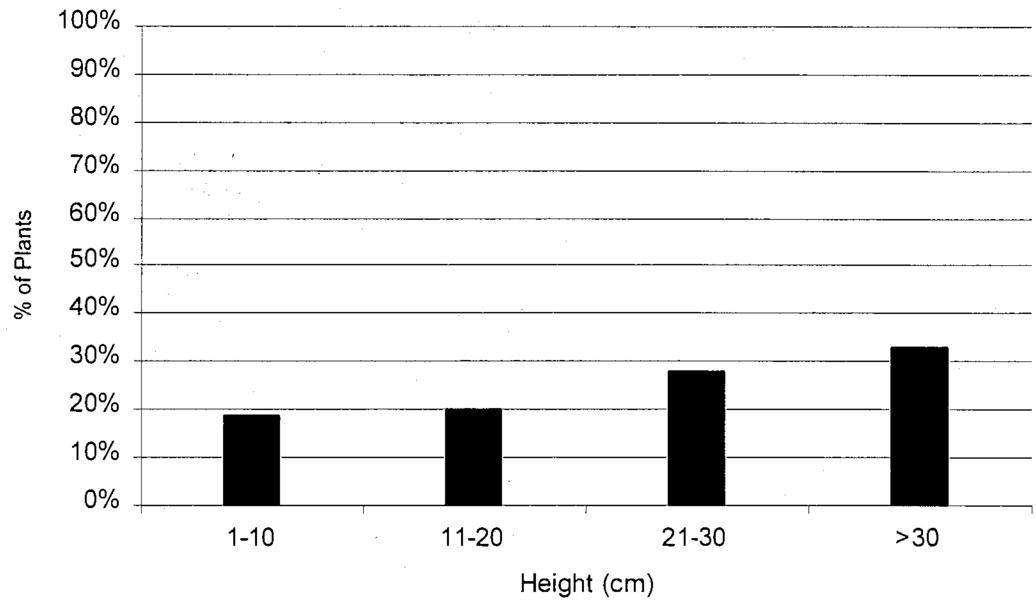


Figure 24. Mortality of *Silene hawaiiensis* in four height classes at the Ke`āmoku site in the Mauna Loa SEA between 1994 and1999 (N=445, total number of dead plants).

Phenology and Condition - Phenology data were recorded at slightly different times of the year, September in 1994 and June in 1999. In 1994, 418 plants (67%) were sterile, and 210 (33%) had flowers and/or fruit. In 1999, 85% of the remaining 183 plants were sterile and 15% were fertile. In both monitoring sessions, the larger size classes carried the flowers and capsules. By 1999, reproduction was reduced in the larger size classes, as a function of fewer large plants and prevailing drought conditions. No seedling recruitment was observed in 1999.

Condition ratings of poor, fair, good, and excellent were assigned based on the appearance and vigor of plants, number of branches, and presence of flowers. In 1994, 17% of plants in this population were rated as poor, 53% were fair, 28% were good, and only 1% were in excellent condition. In 1999, 21% of plants were rated poor, 73% were fair, and only 6% were considered good. Overall, the population appeared to be in fair to good condition in 1994 and in only fair condition in 1999.

Species of Special Concern (SOC)

Sisyrinchium acre, Mau`u lā`ili

Sisyrinchium acre is the only endemic species of the iris family (Iridaceae) in Hawai`i. It occurs in habitats of open dry areas, bogs, and sub-alpine shrublands on East Maui and Hawai`i (Wagner *et. al* 1990). Apparently never a common plant, *Sisyrinchium acre* was recently placed on the informal list of "species of special concern" (U. S. Fish and Wildlife Service 1999).

During the rare plant survey of Mauna Loa SEA, *Sisyrinchium acre* was found along transects at only two sites in the upper unit; both were on the edge of the central lava flow of the Mauna Loa Strip. The species was more common in the sub-alpine shrubland of the alpine unit above the fenceline at 2,070 m (6,800 ft) elevation, where 53 individuals were found at eight sites. Most of these sightings were along transects in Kīpuka Mauna`iu near 2,135 m (7,000 ft) elevation (Fig. 1). A grass-like herbaceous plant, *Sisyrinchium* is inconspicuous and easily overlooked. There are likely to be more individuals within the two kīpuka, especially at higher elevations above the surveyed area. Although Degener (1975) reported *Sisyrinchium acre* from Kīlauea near the Park entrance in the 1930s, and Hillebrand (1888) wrote that the species was distributed as low as 1,070 m (3,500 ft) elevation, the plant now appears to be restricted to higher elevations in the Park. Fagerlund and Mitchell (1944) considered this species to be of frequent occurrence on Mauna Loa; thus it seems to have declined over the last 50 years. Loope and Medeiros (1990) implicated competition with alien grasses as a cause for the rarity of *Sisyrinchium acre* in Haleakalā National Park.

Rare and Uncommon Species

Exocarpos menziesii, Heau, and ***Santalum paniculatum* var. *paniculatum***, `Ili`ahi or sandalwood

Exocarpos menziesii or heau is a parasitic shrub in the sandalwood family (Santalaceae). This unusual plant is nearly leafless and supports many fine branches that are maroon at the tips. Within HAVO, this species has been reported recently only from elevations above 2,130 m (7,000 ft). No heau plants were found along transects in either the upper or alpine units of the Mauna Loa SEA. Subsequent to the survey eight plants were found within Kīpuka Kulalio between 2,200 and 2,320 m (7,200 and 7,600 ft) elevation (Fig. 25). No young plants have been observed, although plants have been observed bearing fruits in March and April. The causes for the rarity of the species are unknown, but it is possible that the Mauna Loa SEA of HAVO is on the edge of the natural range of the species (Degener and Degener 1962). *Exocarpos menziesii* was not reported on earlier checklists (Fagerlund and Mitchell 1944; Fosberg 1966), and no evaluation of population trend is possible.

Santalum paniculatum, the only species of `iliahi or sandalwood found in the Park, is an uncommon small tree distributed in dry and mesic vegetation from about 305 m (1,000 ft) to 2,440 m (8,000 ft) elevation in HAVO. During the survey of Mauna Loa SEA, no sandalwood trees were found in the upper unit and only one tree was seen on transect in the alpine unit. This lone tree was on the transect that skirted the eastern edge of Kīpuka Mauna`iu. This site supported one

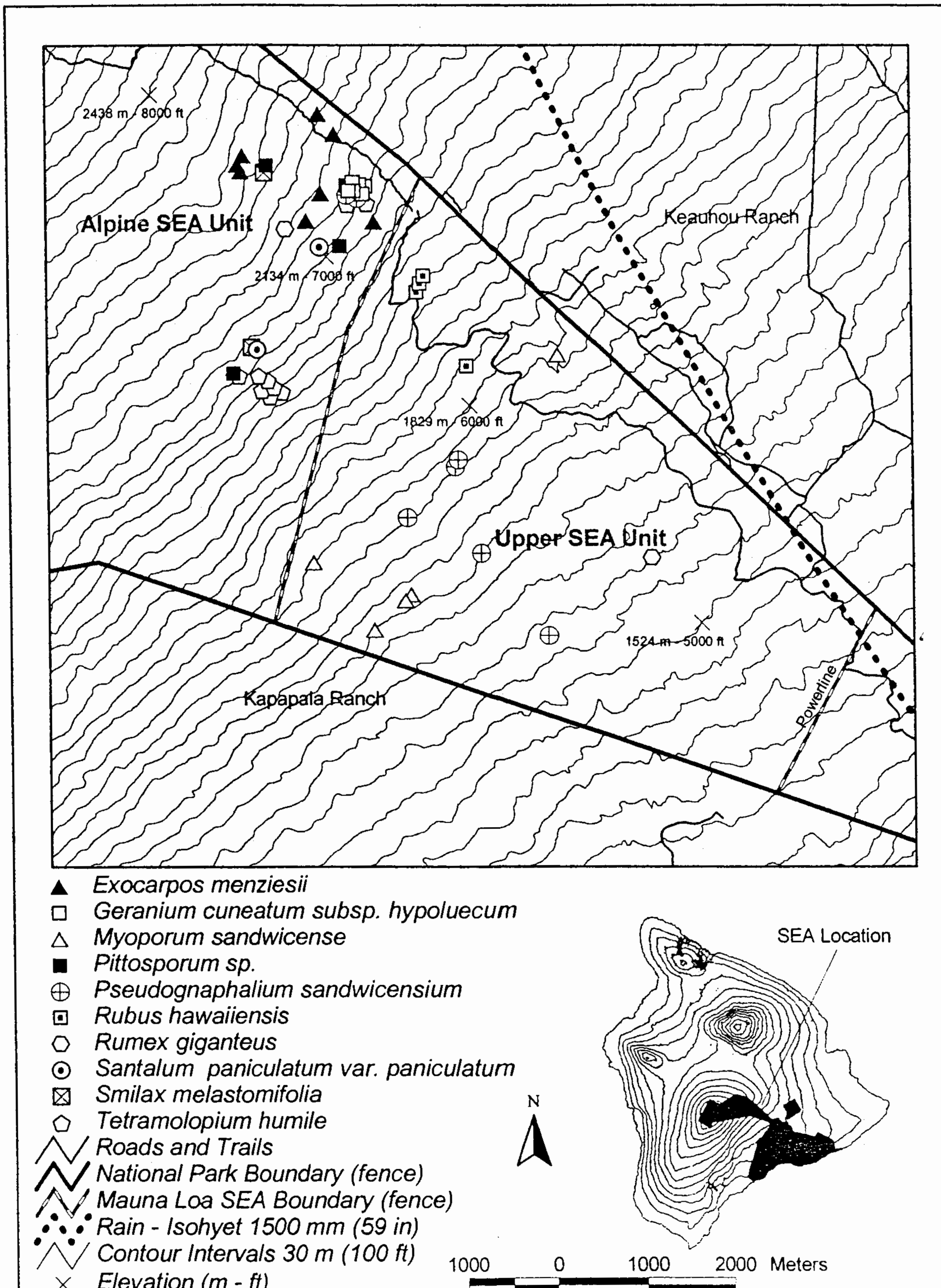


Figure 25. Rare and Uncommon Plant Species of the Mauna Loa Special Ecological Area, Hawaii Volcanoes National Park.

of only two *Smilax melastomifolia* (hoi kuahiwi) vines found in the Mauna Loa SEA. Subsequent to the survey, another single sandalwood was found on the western edge of Kīpuka Kulalio at 2,160 m (7,100 ft) elevation (Fig. 25). While it is likely that more sandalwood trees persist in un-surveyed portions of the study area, the alpine unit of the SEA is near the upper limit for the species on Mauna Loa.

Geranium cuneatum* subsp. *hypoleucum, Nohoanu

One of six species of *Geranium* endemic to the Hawaiian Islands, *G. cuneatum* is native to Hawai`i and Maui. The subspecies found in the Park (subsp. *hypoleucum*) occurs primarily on Mauna Loa, and may be distinguished from other subspecies by its green upper leaf surface and white, densely hairy lower surface (Wagner *et al.*1990). While not considered a rare plant island-wide, this *Geranium* is restricted to a localized habitat in the Park.

During the Mauna Loa rare plant survey, *Geranium* or nohoanu was not found along the six surveyed transects of the upper unit of Mauna Loa SEA. However, a large population of *Geranium* was observed along transects in the alpine unit of the SEA (Fig. 26). Most of the plants seen in the 1994 survey were in Kīpuka Kulalio, where they were densely concentrated in sub-alpine shrubland above 2,135 m (7,000 ft) elevation. More than 3,000 (3,262) plants were counted along five transects in Kīpuka Kulalio; plants were observed on transect 0 nearest the Mauna Loa Trail, but were not counted or mapped. The greatest number of plants (1,555) was seen along the westernmost transect 5 and the lowest number of plants (154) was on transect 2. The mean number of plants on the five 1,000 m-long belt transects that were counted was 652; this translates to an average density of 6.5 *Geranium* plants/100m^2. By contrast, only 27 *Geranium* plants were sighted along the five transects in Kīpuka Mauna`iu; these were at three sites in the upper reaches of the area surveyed (Fig. 26).

When *Geranium* plants were counted along the belt transects of the alpine unit, they were recorded in three height classes (<10 cm, 10-100cm, and >100 cm). In Kīpuka Kulalio, most plants (86%) were in the middle, 10-100 cm class, and very few (3%) were large shrubs >100 cm tall (Fig. 27). Eleven percent of *Geranium* sightings were in the <10 cm class, which represented seedlings and young plants. While monitoring was not continued to determine mortality and further recruitment, it appears that *Geranium* plants are reproducing and recruiting young plants into the population. Survey work was carried out in January when few shrubs were flowering; no phenological data were collected.

Myoporum sandwicense, Naio

Myoporum sandwicense or naio is a common tree or shrub found on all the main Hawaiian Islands. It is widely distributed from the coast to tree line on Hawai`i Island and is a dominant species of sub-alpine forests (Wagner *et al.*

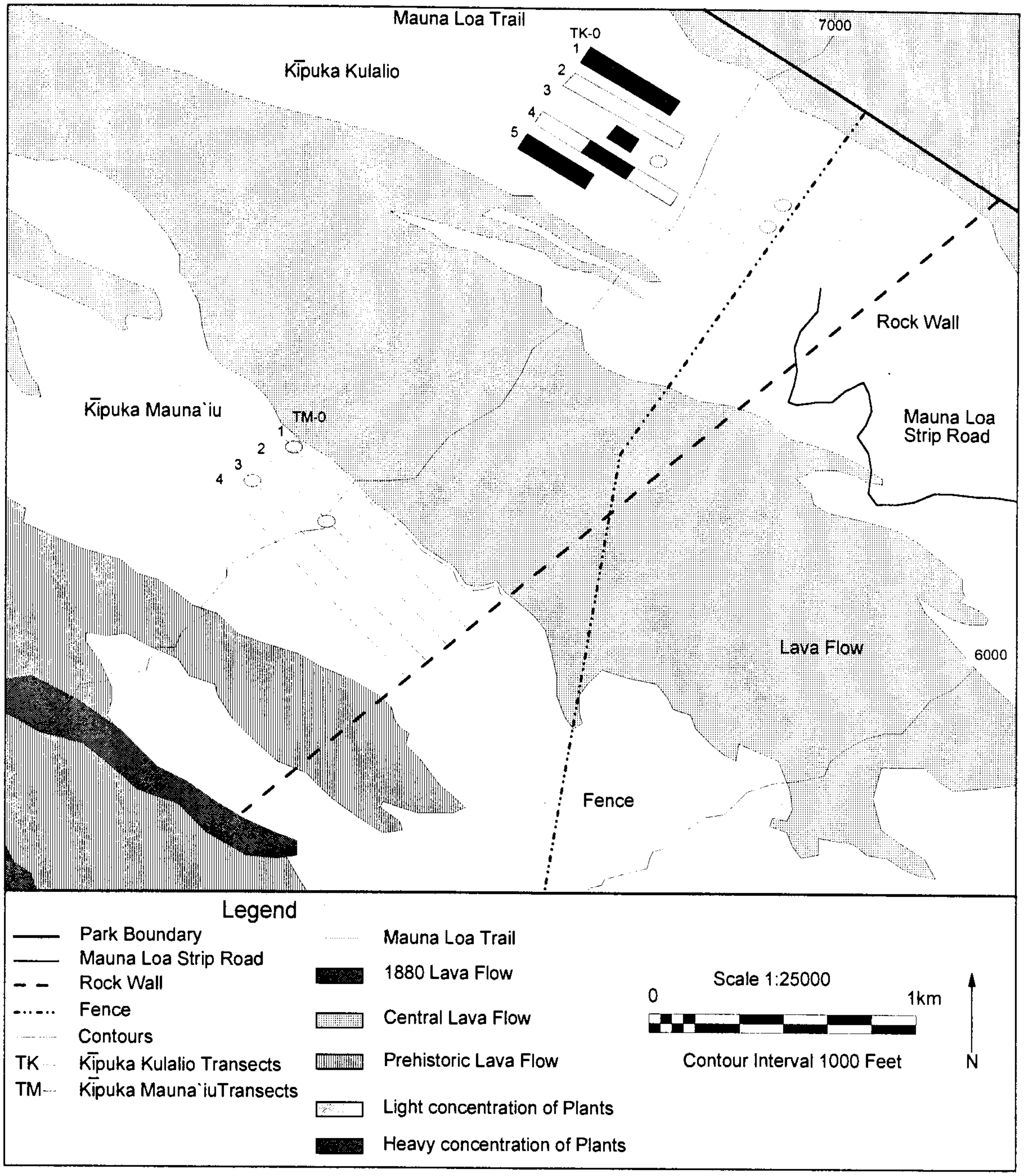
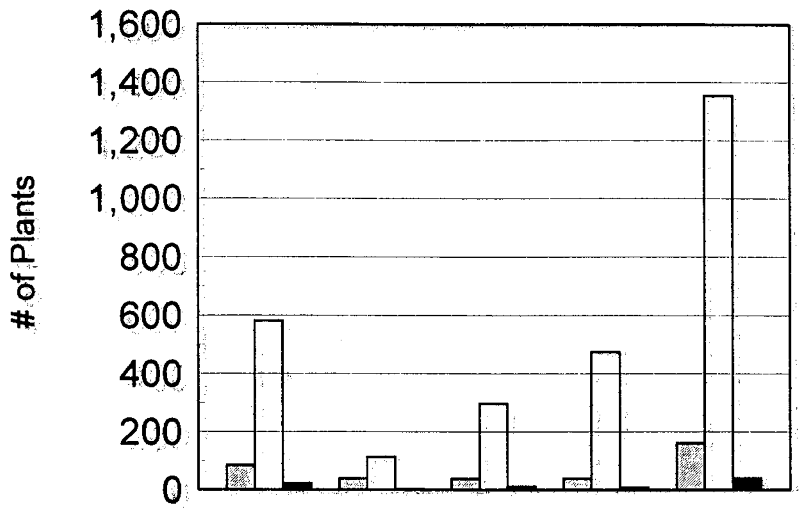


Figure 26. Distribution of *Geranium cuneatum* subsp. *hypoleucum* (nohoanu) on transects in the alpine unit of the Mauna Loa SEA, HAVO.

Geranium cuneatum



Transect	1	2	3	4	5
< 10 cm	84	39	38	39	161
10-100 cm	581	113	296	474	1,354
>100 cm	22	2	11	8	40

Figure 27. Height class distribution of *Geranium cuneatum* subsp. *hypoleucum* (nohoanu) on five transects in Kipuka Kulalio of the alpine unit, Mauna Loa SEA, HAVO.

1990). Although it occurs sparingly in wet forests, naio is primarily a component of dry and mesic vegetation. In Hawaii Volcanoes National Park, naio is very rare in coastal strand and uncommon in dry lowland forests and shrublands. The tree is most commonly seen in the mesic forests of Kīpuka Puaulu and Kīpuka Kī. Naio was very rare within the upper unit of the Mauna Loa SEA. Only 18 trees were encountered along transects; these were widely scattered at five sites between 1,525 m (5,000 ft) and 1,630 m (6,000 ft) elevation. Most of the observed *Myoporum* trees were growing in koa groves of Kīpuka Mauna`iu. No *Myoporum* trees were seen in the alpine unit of Mauna Loa.

***Pittosporum* sp.,** Hō`awa

Six native species of *Pittosporum* have been reported from HAVO (Higashino *et al.* 1988), but two of these have been subsumed into other species or are thought to represent planted material. The two species most likely to be found in the Mauna Loa SEA are *P. confertiflorum* and *P. terminalioides*; both of these species are distributed above 2,000 m elevation on Hawai`i Island (Wagner *et al.* 1990). Flowers or capsules are required for species determinations.

During the survey of Mauna Loa SEA, no *Pittosporum* trees were found along transects of the upper unit, and only three trees were observed in the alpine unit above 2,165 m (7,100 ft) elevation. Two trees were mapped on the eastern side of Kīpuka Kulalio and the third was in the center of Kīpuka Mauna`iu (Fig. 25). All trees were sterile, but they most resembled *P. confertiflorum.* Subsequent to the survey, one additional *Pittosporum* tree with seven seedlings was found on the western edge of Kīpuka Kulalio near 2,130 m (7,000 ft) elevation. Recently, another young *Pittosporum* tree was sighted on the eastern side of the kīpuka above the systematic transects; this tree was adjacent to one of the two *Smilax melastomifolia* known from the alpine unit of the SEA (Rick Warshauer pers. comm. 2001). The presence of young *Pittosporum* indicates that the species is able to reproduce in these high-elevation kīpuka. Although very rare in the sub-alpine zone of the Park, *P. confertiflorum* has been observed as high as 2,440 m (8,000 ft) on Mauna Loa (Fosberg 1966).

Pseudognaphalium sandwicensium, `Ena`ena, and ***Tetramolopium humile***

These two species in the sunflower family (Asteaceae) are not generally considered to be rare plants, but they are uncommon in the Mauna Loa SEA and may be indicator species for feral animal damage. Both have soft, fleshy leaves and are likely palatable to goats and sheep. *Pseudognaphalium sandwicensium* was noted rarely along three transects in the upper unit of the Mauna Loa SEA, where the perennial herb was largely restricted to sparsely vegetated lava flows. Both species occurred in the alpine unit above the cross fence at 2,070 m (6,800 ft). *Pseudognaphalium* was observed only in Kīpuka Kulalio, where 19 plants were scattered at four sites on three different transects; none was mapped in Kīpuka

Mauna`iu (Fig. 25). Transects were searched during winter and spring months, when these perennial plants might be expected to be flowering and flushing new leaves. *Tetramolopium humile*, a dwarf shrub with no common name, was noted in both Kīpuka Kulalio and Mauna`iu. Plants were relatively common in Kīpuka Mauna`iu, where 55 *Tetramolopium* were counted on transects clustered at seven sites in the middle of the surveyed area. By contrast, only 11 *Tetramolopium* were found at two sites along the westernmost transect in Kīpuka Kulalio.

Rumex giganteus, Pāwale

A woody species endemic to the islands of Maui, Moloka`i, and Hawai`i, this member of the buckwheat family (Polygonaceae) has the life form of a vine in montane rain forests, and that of a weakly erect shrub in sub-alpine and alpine ecosystems (Wagner *et al.*1990). In earlier HAVO plant checklists (Fosberg 1966, 1975), this species was not distinguished from *Rumex skottsbergii*, a plant of lower, drier sites. *Rumex giganteus* was observed at only one locality within the upper unit of the Mauna Loa SEA, on transect 10 near the lower tip of an `a`ā flow near 1,585 m (5,200 ft) elevation. An additional single plant was found in the alpine unit on the western edge of Kīpuka Kulalio near 2,210 m (7, 240 ft) elevation (Fig. 25); this site was west of the systematic transects in the kīpuka. It is highly probable that additional *Rumex giganteus* exist in the large expanse of suitable habitat between these two sightings separated by more than 6 km.

Rubus hawaiensis, `Ākala, Hawaiian raspberry

Rubus hawaiensis, a species native to four of the Hawaiian Islands, is a common shrub of montane wet and moist forests and sub-alpine vegetation (Wagner *et al.* 1990). Fosberg (1966) identified plants of the Mauna Loa Strip as the rare *Rubus macraei*, now considered a "species of concern." Fosberg's specimens in the HAVO Herbarium have now been determined to be *R. hawaiensis.* All plants found on Mauna Loa during the current survey appeared to be the more common species. During the 1992-93 survey of the upper unit of the SEA, a few individuals (11) of *R. hawaiensis* were observed at four sites on the two highest transects in Kīpuka Kulalio. Within the alpine unit, *R. hawaiensis* was noted only once as a cluster of five plants near the rock wall that was the lower boundary of the surveyed portion of Kīpuka Mauna`iu. Additional *R. hawaiensis* occur near the beginning of the Mauna Loa trail and in depressions adjacent to the Mauna Loa Strip Road, from the terminus downslope for approximately 3 km. Based on the results of this survey, Kīpuka Kulalio seems to support a larger number of the native raspberry than does Kīpuka Mauna`iu.

Endangered Species Planted in the Mauna Loa SEA

Argyroxiphium kauense**,** Hinahina, Ka`ū or Mauna Loa Silversword

There is no firm record of the Ka`ū or Mauna Loa silversword naturally occurring in the area now within HAVO, although Skottsberg (1926) reported sighting *Argyroxiphium* at high elevation on Mauna Loa in the 1920s, long before any Park out-planting programs. The U. S. Fish and Wildlife Service maps the probable historic range of the plant east and west of the Mauna Loa Strip, extending to the Park boundaries (U. S. Fish and Wildlife Service 1995). Currently, the species is extant in Kapāpala Forest Reserve approximately 10 km to the west of the Park, as well as in Kahuku Ranch farther to the southwest. The Ka`ū silversword is also known from a bog site northeast of the Park; the Mauna Loa SEA falls between these known silversword sites and should be considered within the natural range of the species. Approximately 200 individuals of this species were planted at three Park sites in the mid-1970s, including one site west of the top of the Mauna Loa Road (Fig. 1) and two goat exclosures along the Mauna Loa Trail (National Park Service 1974). At the site near the road, a few plants survived until 2000. No recruitment has been observed, despite occasional simultaneous flowering of several planted individuals. The fate of the out-planted individuals at two other, higher-elevation sites is unknown, but presumably these plants have been lost over the past three decades.

In 1953-54, *Argyroxiphium sandwicense* var. *macrocephalum*, the threatened Haleakalā silversword, was out-planted within the Mauna Loa SEA at several sites from the end of the Mauna Loa Road to Pu`u `Ula`ula. A decade later, only three stunted individuals remained at the site near the Mauna Loa Road (Morris 1967), and these had disappeared by 1974 (National Park Service 1974). An unknown number of Haleakalā silverswords survived at introduction sites above the current study area. In 1973, *Argyroxiphium sandwicense* var. *sandwicense*, the critically endangered Mauna Kea silversword, was out-planted at four sites in the Mauna Loa Strip, including the end of the Mauna Loa Road, two goat exclosures at elevations of 2,260 m (7, 400 ft) and 2,470 m (8,100 ft), and Pu`u `Ula`ula. These Mauna Kea plants survived only within the two exclosures (National Park Service 1974). A population of silverswords southwest of Pu`u `Ula`ula has not been identified to species, but probably represents progeny of earlier out-plantings of Haleakalā silversword. There were approximately 40 plants at this site when it was discovered in 1990. By 1998 only 12 plants remained, and no plants were found when the site was revisited in 2000 (Tim Tunison, pers. comm. 2000). None of the early silversword out-planting sites were visited in the course of this survey.

In the mid 1990s, Park managers obtained some viable seeds from two plants that had been out-planted within HAVO more than a decade earlier, and seedlings were propagated from these seeds. The origin of these out-plantings was the vulnerable population of Ka`ū silverswords on Kahuku Ranch. In 1996, more than 200 Ka`ū silverswords from this source were planted at a site below the cross fence in the Upper Unit east of the previous out-planting above the end of the Mauna Loa Road. These plants were later depredated by mouflon sheep, which had moved downslope from the unprotected upper reaches of the Mauna Loa Strip and had crossed the fence into the upper unit of the SEA. Browsing damage, coupled with dry conditions, resulted in the loss of nearly all out-planted individuals. Subsequently an exclosure of about 4 ha (10 acres) was created just below the cross fence, and an additional area of the alpine unit was enclosed, incorporating remaining plants of the Kīpuka Kulalio *Plantago* population. Park managers began coordinating silversword propagation and out-planting with other Federal and State agencies and University researchers, as part of a larger recovery program. Since then, 2,500 silverswords from Kapāpala Forest Reserve seed stock have been successfully planted within the two exclosures (Fig. 1), and survival has been excellent (>90%). More out-plantings are planned in 2002 within and adjacent to the exclosures; the goal of the overall program is a population of 12,500 Ka`ū silverswords within the Mauna Loa Strip by the end of 2004 (Tunison 2001).

Discussion

Habitat Preferences of Rare and Endangered Species

The three endangered species, one threatened species, and one species of concern within the upper and alpine Units of the Mauna Loa SEA varied in range from widely distributed populations of hundreds of plants to single or few individuals. The most widespread rare species was the threatened *Silene hawaiiensis*, which ranged in elevation from 1,500 to 2,200 m (5,100-7,200 ft). Despite its multiple occurrences, *Silene hawaiiensis* was concentrated at five primary sites on old pāhoehoe substrate, particularly flow channels within the massive lava flows of the upper unit. The second-most numerous rare plant in the SEA was the endangered *Plantago hawaiensis,* which was clustered in relatively compact sites near 2,135 m elevation within two well-vegetated kīpuka. Except for a few scattered high elevation outliers, the range of *Silene* and *Plantago* did not overlap. The endangered fern, *Asplenium fragile*, occurred in a very specialized habitat of large lava tubes; some occupied tube systems were near concentrations of *Silene hawaiensis*, but others were far removed from sightings of any other rare species.

The critically endangered *Phyllostegia racemosa* appeared to be limited to one site within koa forest of the upper unit; this habitat was shared by the uncommon *Myoporum sandwicense*, but no other endangered or threatened plants co-existed with it. Apart from the presence of these two rare or uncommon species, there was nothing that distinguished the koa forest of the *Phyllostegia* site from other forests of the SEA. *Sisyrinchium acre*, a species of concern and likely high-elevation specialist, was distributed in the alpine unit kīpuka within the same habitat that supported *Plantago hawaiensis* and also ranged downslope along the edges of the kīpuka.

It is clear from the widely scattered and rarely overlapping distributions of the endangered and threatened plants of Mauna Loa SEA that management of small areas would not be sufficient to protect multiple species or even multiple population nodes of single species. The current management approach of fencing and removal of feral ungulates from several thousand acres is likely to result in long-term survival of rare plants and their habitat, although small exclosures may be necessary to prevent immediate losses if animals prove to be difficult to remove from the upper reaches of the Park.

Most abundant of the localized high-elevation species was *Geranium cuneatum* subsp. *hypoleucum,* which was restricted to a very narrow elevational band above 2,135 m elevation, coinciding with the inversion layer on the slopes of Mauna Loa. *Geranium* was densely concentrated at slightly higher elevation than the known population of *Plantago hawaiensis* in Kīpuka Kulalio. *Exocarpos menziesii* (heau) was also restricted to higher elevations in Kīpuka Kulalio; this unusual shrub was extremely rare and widely scattered. It is likely distributed in the upper reaches of Kīpuka Mauna`iu as well, but that area was too remote for systematic survey in this study. *Santalum paniculatum* var. *paniculatum* (sandalwood), *Pittosporum* sp. (hō`awa), *Rumex giganteus* (pāwale), and *Smilax melastomifolia* (hoi kuahiwi) were all represented within the alpine unit by only one to three individuals. These rarities are probably high elevation remnants of populations formerly more abundant within the upper and lower portions of the Mauna Loa SEA. The few individuals of *Pseudognaphalium sandwicensium* (*`ena`ena*), *Tetramolopium humile,* and *Rubus hawaiiensis* (`*ākala*) encountered in the study area suggest that feral animals continue to deplete palatable herb and shrub species. In particular, the disparity in number of *Pseudognaphalium* and *Geranium* between the two kīpuka may be an indicator of greater browsing pressure on favored species in the more remote Kīpuka Mauna`iu. Kīpuka Kulalio receives much more regular human activity along the Mauna Loa Trail than does Kīpuka Mauna`iu, farther to the west.

Endangered Species: *Asplenium fragile* and *Phyllostegia racemosa*

Because *Asplenium fragile* var. *insulare* has such specialized habitat requirements, few were located on the survey of systematic transects that only rarely intersected lava tubes at conspicuous openings. Focused searches of lava tubes encountered on the ground or identified from aerial photographs were more successful at finding the fern. Recent finds have extended the known range of the species in HAVO almost 600 m (2,000 ft) elevation upslope and tripled the number of Park sites confirmed to support the fern. Even so, it is likely that *Asplenium fragile* var. *insulare* persists at more sites in the Mauna Loa SEA than we have identified. The habitat of *A. fragile* in the Park is consistently the moist and dark entrances of large, deep, high-elevation lava tubes. Elsewhere on the island, the fern has also been noted in deep cracks, tree molds (U. S. Fish and Wildlife

Service 1998) and on moist cliff faces and flow edges (Steve Evans, pers. comm. 2001).

Little is known of the life history and ecology of *A. fragile*. Researchers at Pohakuloa Training Area found no gametophytes and determined that all individuals in sampled populations were reproductive adults (Shaw 1992, cited in U. S. Fish and Wildlife Service 1998). Plants may be long-lived or able to persist at sites with appropriate habitat and little disturbance. Potential threats to *A. fragile* are browsing by feral goats and mouflon sheep. Predation of the fern has been reported at Pohakuloa (U. S. Fish and Wildlife Service 1998), but we found no evidence of animal damage to the species in Mauna Loa SEA. It seems that little management is needed beyond removal of feral ungulates (which is in progress) and prevention of human disturbance to potential habitat in high-elevation lava tube entrances.

The Mauna Loa Strip is on the western extreme of the range of *Phyllostegia racemosa* or kīponapona, and there is a gap of at least 8 km between the HAVO site and the nearest known kīponapona plant on Keauhou Ranch. The Mauna Loa SEA is certainly a drier site than known habitat of the species to the east; mean annual rainfall in the SEA is at least 500 mm less than that of the Keauhou Ranch site (Giambelluca *et al.* 1986). However, the protected and ungulate-free status of this section of HAVO makes it a potentially important part of an overall recovery strategy for this critically endangered species. With the loss of the species from HAVO, there are only two remaining populations with few individuals on the island (U. S. Fish and Wildlife Service 1997). If propagation material is obtained, *Phyllostegia racemosa* will be a likely candidate for rare plant reintroduction efforts in the Mauna Loa SEA. Even though *P. racemosa* has been found within the Park only in Kīpuka Mauna`iu, Kīpuka Kulalio also provides habitat suitable for the species, and this more accessible kīpuka is closer to the nearest known plants east of the Park.

Endangered Species: *Plantago hawaiensis*

Within the Mauna Loa SEA, the endangered *Plantago hawaiensis* was found only in sub-alpine vegetation of native shrubs and scattered `ōhi`a lehua trees within a narrow elevational band of 2,070 to 2,200 m (6,800-7,200 ft). Despite the extensive cover of such vegetation within the two older kīpuka of the alpine/sub-alpine unit, *Plantago hawaiensis* plants were concentrated on the eastern edges of both kīpuka. Such a distribution implies that some environmental condition is more favorable in these localities. Physical characteristics of rare plant concentrations were not measured in this study, but the presence of obvious water flow channels in the vicinity of the *Plantago hawaiensis* is evidence that water is periodically abundant in these regions, perhaps because of slope topography and runoff from the adjacent lava flows. The earliest description of *Plantago hawaiensis* habitat by Rock (1920) as dry cinder and lava fields was not supported by the results of the present survey. Rock's concept of the species' habitat preference was apparently influenced by cited collections from Hualalāi and Kahuku.

The discovery of more than 600 individuals of *Plantago hawaiensis* within the alpine section of the SEA was somewhat unexpected, since previous incidental sightings near Park fencelines and study plots had consisted of few plants, and the species had not been included in early Park checklists (Fagerlund and Mitchell 1944; Fosberg 1966, 1975). Even though the number of individuals in the two kīpuka populations was similar when they were discovered in 1994, the persistence over six years and ultimate fate of the two separate groups of plants were very different.

Plantago hawaiensis at Kīpuka Kulalio

When the dramatic decline in the *Plantago* population at Kīpuka Kulalio was detected two years after its discovery, browsing by mouflon sheep (or possibly goats) was feared even though there had been no obvious sign of animal damage within the kīpuka. Sheep are known to browse preferentially on some native tree species, such as māmane, but also adversely affect native herbaceous species (Scowcroft and Giffin 1982). Browsing became less likely as a factor in the loss of the Kīpuka Kulalio plants after the population at Kīpuka Mauna`iu was revisited and found to be intact despite visible signs of sheep presence, including feces. Some minor browsing was observed on *Plantago* leaves and a few common plants. The Kīpuka Mauna`iu site is farther from human activity along the Mauna Loa trail, and at the time the alpine unit was unenclosed and both sites were open to access by feral animals.

Kalij pheasants (*Lophura leucomelana*) were seen in the study area of Kīpuka Kulalio, and their footprints, dustbowls and even eggshells from a nest site were noted near remaining *P. hawaiensis* plants. Kalij are considered omnivorous, but most of the plant food items identified from birds taken from various sites on Hawai`i Island were fruits, seeds, leaves, flower buds, or tree fern starch (Lewin and Lewin 1984). In their native habitat of Asia, kalij are known to eat roots and tubers, as well (Bohl 1971). However, kalij are also present at the intact *Plantago* population of Kīpuka Mauna`iu, and there is no evidence that food habits differ in the two sites. While pheasants might consume tender leaves of small plants or damage seedlings by scratching, it is unlikely that they would uproot large plants.

The probable cause of the loss of most of the population was suggested by leaf litter and woody debris observed in March 1996 along channels within the habitat of *Plantago*. During the second visit to the population in November, plants larger than seedlings were observed emerging from beneath soil and leaf litter apparently deposited by water. One or more episodes of heavy rainfall had scoured plants from near the intermittent stream channels or had buried them under deposits from which they continued to emerge. Because tagging of individuals and intensive monitoring had not yet commenced in spring 1996, it was unclear whether some size classes had fared worse than others. Preliminary observations on flowering in 22% of the 357 *Plantago hawaiensis* found in March 1994 indicated that almost a quarter of the population was at least large enough to be reproductive. However, the massive loss of most of the population within two years makes it likely that all size and age classes were involved in the decline. By the time of the first revisit in 1996, few large plants remained, as plants greater than 10 cm rosette diameter comprised approximately a quarter of the total population, and only five plants persisted in the two largest size classes. Many of the small plants that made up almost half the population were probably recent recruits.

Because visits to the *Plantago* population were so infrequent, it is not possible to determine when the heavy rainfall event occurred in Kīpuka Kulalio. Park precipitation records show an exceptionally large monthly total for November 1994; this was followed by a dry year in 1995 with just over half the average yearly rainfall (National Park Service, HAVO Fire Management Office, unpublished data). Plants of larger size may have been lost in 1994 before seed capsules were produced or seeds were ripe, and 1995 may have been a poor year for seedling establishment. Seed bank studies have not been carried out for this species, but other members of the genus *Plantago* are known to have persistent seed banks and seeds that show physiological dormancy broken by low temperatures (Baskin and Baskin 1998). Clearly by spring 1996, seedlings had become established from seeds remaining in the seed bank or recently produced by the few remaining large plants. Precipitation in 1996 was slightly above average. By the fall monitoring session, more young plants had been added to the population, or had emerged from litter. Other surviving plants had grown and entered larger size classes.

This promising trend did not continue, as the total population declined in both 1997 and 1998, and there was no indication of growth from smaller to larger size classes. The drought of 1997-98 was likely responsible for the loss of many of the small plants that had been present in 1996. Rainfall in 1999 was also less than average for the area (National Park Service, HAVO Fire Management Office, unpublished data). Few large plants remained to produce seeds, and by 2000 the population had been almost extirpated. The three remaining plants had persisted for at least four years, but all had greatly decreased in rosette diameter since 1996. The six-year decline and loss of what seemed to be a viable population indicate that the population size in 1994 was too small to withstand the "random catastrophes" of flooding and drought (Lande 1993). One study of population size in a long-lived, butterfly-pollinated, herbaceous plant affected by habitat fragmentation concluded that populations of at least 1,000-2,000 plants were a conservation goal. Reproductive studies of *P. hawaiensis* have not been carried out (U. S. Fish and Wildlife Service 1996), but other members of the large genus *Plantago* are wind pollinated (Cronquist 1968). Lack of dependence on insect pollinators and possible longevity of seeds in a seed bank may allow for viable populations composed of fewer that 1,000 individuals. The U. S. Fish and Wildlife

Service (1996) considers *P. hawaiensis* a short-lived perennial and proposes a recovery goal of 10 stable populations, each with 300 individuals.

<u>*Plantago hawaiensis* at Kīpuka Mauna`iu</u>

The population of *Plantago hawaiensis* at Kīpuka Mauna`iu did not suffer the catastrophic collapse of its counterpart in the eastern kīpuka, but slightly increased until 1999. When revisited and measured in 1997, the structure of the population was skewed toward the large size classes, and there were few obvious seedlings in the lowest size class. The low number of seedlings observed in 1997 and the first half of 1998 may be a reflection of poor recruitment in dry or drought years. By November 1998, young plants began to appear again, and compensated for small losses in the larger size classes. In constrast to Kīpuka Kulalio, larger (and preseumbly older) plants did not disappear from the population, although there is some indication that dry conditions caused some decrease in rosette size that resulted in shifts of large plants to smaller classes. In annual revisits in 1999 and 2000, the size class structure of the *P.* hawaiensis in Kīpuka Mauna`iu appeared to be that of a stable population with similar numbers of plants in the smallest and largest classes and most of the population of medium width (citation). Longevity of plants was good in this population, with approximately 90% of tagged individuals persisting more than three years. Site variables are likely the explanation for the difference in *Plantago* survival at the two populations. While the species may be able to eventually recolonize the eastern kīpuka without assistance, it would be prudent to obtain seeds from perhaps 50 individuals at Kīpuka Mauna`iu, propagate seedlings, and re-establish a larger population in Kīpuka Kulalio in suitable sites away from intermittant stream channels. Recently found small groups of *Plantago* growing elsewhere in Kīpuka Kulalio demonstrate that there are additional suitable sites for the species removed from the area of concentration monitored. Seed-bearing plants in these small clusters should also be used as propagule sources for augmentation in the kīpuka.

<u>Threatened Species: *Silene hawaiiensis*</u>

Silene hawaiiensis is adapted to the arid and dry conditions of the upper Mauna Loa SEA. Large plants have a well-developed tap root which stores water and nutrients. Stem growth, flower and fruiting do not seem to be strongly seasonal, as flowers and fruits were noted throughout the year. The reproductive strategy of the species may be keyed to periods of high rainfall, and seedling recruitment is likely dependent on successive months of favorable rainfall. Small plants and seedlings are susceptible to prolonged drought as they lack the reserve resources larger plants have. A good understanding of phenological patterns of *S. hawaiiensis* would require monitoring at more frequent intervals for several years.

From 1998 to 2000, two limiting factors, drought and browsing by mouflon sheep, had significant effects on the *S. hawaiiensis* at the Central Lava Flow study site. In 1998 and 1999, drought conditions prevailed in this section of the Park and throughout windward Hawai'i island. Simultaneously, browsing by few mouflon sheep (perhaps 3 to 6 animals) during 1997-2000 directly altered the *S. hawaiiensis* population at this site by physically reducing and stressing some plants beyond the point of recovery. Of the two limiting factors, neither can be isolated as the single cause of mortality of *Silene hawaiiensis.* However, by monitoring fates of individual plants, impacts from herbivores can be assessed on plant populations (Watkinson 1986). High rates of browsing were followed by high plant mortality. In our 1998 sub-sample of 249 plants, 62% had been browsed, and by 1999, 104 or 42% of those plants had died.

The number of plants in a given population is determined largely by weather conditions after seedling establishment (Dempster 1971). The loss of most seedlings observed in 1998 suggests that drought primarily affects plants in smaller size classes, including those newly recruited and established seedlings without a mature taproot. Most of these dead seedlings (79%) showed no sign of browsing damage. Browsing affects all size classes, particularly those larger than seedlings, and animal damage may inhibit the ability of plants to recover from drought stress. Browsing reduces plants to smaller size classes, and repeated browsing keeps the plant small even when re-growth occurs.

Browsing and drought both affect reproductive phenology. Drought seems to disproportionately affect seedlings and small plants and may reduce seedling recruitment, while browsing affects all plants of reproductive age. Browsed plants are prevented from reproducing. Since it is the larger size classes that carry the reproductive capacity of the population, repeatedly browsed plants cannot flower or fruit even when conditions are favorable, although they may be able to survive drought by conserving moisture and nutrient resources. Even though browsing was recorded only at annual monitoring periods, browsing on the sub-sample and the entire *S. hawaiiensis* population was chronic from 1997 to 2000, and animals probably visited the site repeatedly during each year. Browsing altered the size class distribution prior to 1998 with most plants of the largest size classes either destroyed or browsed into smaller size classes. Regardless of drought events, long-term browsing is a primary limiting factor of *S. hawaiiensis* populations. Unlike drought, to which plants have adapted, browsing can reduce populations beyond their point of recovery and eliminate populations over time (Janzen 1969). The Big Island plant cluster recovery plan that includes *S. hawaiiensis* lists feral animals as the primary reason for decline of the species (U.S. Fish and Wildlife Service 1996).

Impacts on plant abundance depend on the selectivity of the browser (Harper 1977). Browsing patterns of mouflon seem to be determined by forage availability and density of preferred plants at a particular site. At the Central Lava Flow site, mouflon had browsed *S. hawaiiensis* in preference to other native species, as we did not observe damage to any other plants in the immediate area. *Silene hawaiiensis* plants that had been browsed were re-browsed as the taproot put forth new growth. It appeared that mouflon were seeking out *Silene* while overlooking other, less palatable plants. Approximately 2 km downslope from this concentration of *Silene*, along forested margins and in small kīpuka on the edge of the flow, other plant species were observed with browsing damage. Bark stripping, broken branches, and leaf feeding were noted on young trees of *Acacia koa, Sophora chrysophylla,* and *Dodonaea viscosa*. Browsing of stem tips and leaves was conspicuous on *Stenogyne rugosa,* a few native ferns, and herbaceous alien plants, such as *Verbena littoralis, Verbascum thapsus*, and *Holcus lanatus*.

The exclosure experiment at the Central Lava Flow site produced mixed results. Growth and mortality rates of a randomly selected unprotected (control) and caged group showed little difference from 1998 to 2000. Although mortality was higher in unprotected plants, loss in both groups was attributed to drought. At a site where intense mouflon activity had been previously observed and all plants showed signs of browsing damage at the outset of monitoring, different results were displayed by caged and unprotected plants. Plants in cages grew at a rate nearly twice that of control plants, and 75% of the protected plants produced flowers and fruits by the end of the monitoring period. Control plants experienced repeated browsing events and produced no flowers or fruits. Plants at this site (group 73) had originally been large and densely clustered in a small, flat area with conspicuous pockets of soil. By contrast, randomly selected caged and uncaged pairs of plants were scattered throughout the population on rocky substrates, including the edge of a flow channel. Mouflon may have preferred the site of group 73 for feeding and resting.

The results of the exclosure experiment suggest that *S. hawaiiensis* can tolerate some level of browsing and recover sufficiently to reproduce after browsing pressure is released. The plants seem to be tolerant of drought even under browsing pressure, and larger size classes of the population survive periodic drought events. Browsing appears a greater detriment to *S. hawaiiensis* populations than drought, as sustained browsing events are more likely to directly eliminate populations and suppress reproduction. Exclusion of large herbivores demonstrates the effects browsing animals have on the abundance of individual species (Mack and Thompson 1982). Toward the end of the study at the Central Lava Flow site, when normal rain patterns returned and the mouflon were reduced or removed by Park resource managers, the overall *Silene* population showed signs of recovery in growth and flowering patterns.

The Ke`āmoku Lava Flow study site is of particular interest because *Silene hawaiiensis* declined here in the absence of any detectable damage by mouflon. This site is separated from the Central Lava Flow site by a distance of 2.4 km and an elevational change of 122 m (400 ft). Size and density of the *Silene* population differ at the two sites. The Central Lava Flow site supporting *S. hawaiensis* is large in area (15,000 m^2), yet it had an original population of 548 scattered plants (not counting the concentrated plant group 73). The Ke`āmoku site had a similar number of plants (628) clustered in an area a quarter of the size (4,000 $m^2$) of the Central Lava Flow population. The Central Lava Flow site supports plants at a lower density than Ke`āmoku and covers a larger array of substrate types. Both sites contain old pāhoehoe and `a`ā substrates, but the Central Lava Flow site also has flat areas of shallow `a`ā with ash deposits. Nearly all the Ke`āmoku plants are on a well-drained pāhoehoe ridge or `a`ā covered slopes.

Despite the lack of browsing damage at the Ke`āmoku site, the monitored population declined by 445 plants or 71% from 1994 to 1999. The proximity of the two sites eliminates climate or general habitat differences as causes of the extreme decline in the Ke`āmoku population. The geometry of the plant is a useful indicator of vigor, condition, and age. There is a direct correspondence between height and width, so taller plants are also wider than average. Such larger plants are likely older plants. Mean height of the 1992 baseline population of 548 plants at the Central Lava Flow site (30.4 cm) was 2 cm more than that of the Ke`āmoku site (28.5 cm). By contrast, mean width of plants at the Central Lava Flow site in 1992 (before browsing was detected) was 28.0 cm, compared with a mean of 42.6 at the Ke`āmoku site in 1994. This size difference meant that Ke`āmoku plants were 50% larger than Central Lava Flow plants. Even after 71% of the population was eliminated at Ke`āmoku, the mean width of *Silene* plants dropped by less than 5 cm. The larger Ke`āmoku plants perhaps represented an older population than that of the Central Lava Flow site.

Westerbergh and Saura (1994) regarded *Silene* as colonizers of new lava flows that are out-competed as the substrate ages. As substrate ages and plant communities alter in response, *Silene* populations senesce and are naturally eliminated. Populations on older lava flows appear less vigorous than young populations and have low or no seed set. This is certainly the case at the Ke`āmoku site, where no seedlings were recorded and less that 1% of the population had fruit or flowers in 1999. In the view of Westerbergh and Saura, *Silene* populations are constantly on the move, establishing new populations and losing old ones. As pioneer species, they exhibit founder effects of genetic isolation, and gene flow is restricted between populations on different volcanoes and between adjacent populations. Natural population aging may be one of the ecological mechanisms contributing to the decline of the population at the Ke'āmoku site.

Management Considerations and Restoration Potential

Perhaps the greatest immediate threat to endangered, rare, and uncommon plant populations in the Mauna Loa SEA is the ingress of mouflon sheep within fenced Park boundaries. Throughout much of the *S. hawaiiensis* monitoring period a few sheep were present within the SEA and caused significant damage to at least one threatened plant species. Replacing or refitting the boundary fence is both labor-intensive and expensive, but this task will be necessary to effect protection of rare and endangered plants in the SEA. Resource managers should develop rapid methods of detection and removal of these animals. Both Kapāpala and Keauhou Ranch have significant sheep populations, and potential for ingress into the Park from these source populations will remain high into the foreseeable future.

A vigorous, on-going, monitoring program for rare plants is a high priority. Management goals, objectives, and methods to determine demographic trends for rare and uncommon plant species should be developed for the Mauna Loa SEA. A database for rare plant locations and formal sighting forms should be designed for Park use. Minimum standards for monitoring should be devised to indicate the direction and quantity of change within rare plant populations.

Rare plant monitoring should be combined with continuing rare plant surveys. Populations of rare plants in the Mauna Loa SEA have a wide distribution, and some species occur only as scattered individuals that are often cryptic in rocky or densely shrubby habitats. New locations for *Plantago hawaiensis*, *Pittosporum* sp., and *Exocarpos menziesii* were reported shortly before the completion of this report. Such widely scattered plants may be important as seed donors for future restoration and augmentation efforts. Continued surveys of appropriate rare plant habitat will likely produce further sightings, will contribute to our knowledge of rare plant species distribution, and will identify potential re-introduction sites. The vegetated upper reaches of Kīpuka Mauna`iu is one area in need of further attention; less than half of this large kīpuka was systematically surveyed during the current project. Lava tube systems are also worthy of additional survey. They are notable as habitat for the endangered fern *Asplenium fragile*, and collapsed sections may also provide refuges for other rare and uncommon plant species.

Though a number of invasive species are present within the Mauna Loa SEA, one species is of particular concern. *Verbascum thapsus* or common mullein has been mapped in the Mauna Loa strip (Loh *et al.* 2000), and control efforts are on-going in localized areas. However, mullein is widely scattered through the SEA, and often occurs in remote and difficult terrain. If rare plant habitat is to be protected from invasion by this species, confinement strategies must be devised. *Silene hawaiiensis* habitat along flow channels, sites along kīpuka edges preferred by *Plantago hawaiensis,* and potential rare plant habitat near lava tube systems are particularly vulnerable to mullein invasion. If funds are available to control mullein, Park managers should continue with aggressive management of this invasive species.

Successful out-plantings of endangered *Plantago hawaiensis* and *Argyroxiphium kauense* have been recently accomplished within the Mauna Loa SEA. Additional sites within Kīpuka Kulalio are available for these two species, and it is desirable to have at least five vigorous populations of each to insure against catastrophic losses at any one site (U. S. Fish and Wildlife Service 1996). Because the Kīpuka Mauna`iu population of *P. hawaiensis* seems to be persisting without assistance, it may be prudent to restrict any out-planting in this kīpuka to distant sites. This restriction will prevent inadvertent introduction of pests or diseases. Future out-plantings of *Scaevola kilaueae*, *Phyllostegia racemosa*, and *Fragaria chiloensis* are planned; propagation material for two of these must be obtained from sources outside the Park. *Scaevola* will likely be planted within Kīpuka Kulalio near 1,525 m elevation in vegetation similar to that of previous sightings in Kapāpala (Rick Warshauer pers. comm. 2000). Potential re-introduction sites for *Phyllostegia racemosa* are numerous in the upper unit, but sites in Kīpuka Kulalio near the Mauna Loa Road will permit a greater degree of post-planting care than more remote sites. *Fragaria chiloensis* is appropriate to the shrubby vegetation of the alpine unit. Although not listed on previous Park checklists, this native strawberry occurs on adjacent lands in sub-alpine habitat very similar to that of HAVO. Uncommon tree and shrub species, such as *Santalum paniculatum*, *Exocarpos menziesii*, and *Pittosporum* sp., are also candidates for augmentation to increase natural biodiversity and recover depleted species in the SEA. The Mauna Loa SEA has extensive suitable habitat for these and possibly other rare, high-elevation species. Out-planting sites should be characterized and mapped for future management purposes, and the success or failure of re-introductions and new population nodes should be well documented.

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Appendix 1
Rare Plant Species of the Mauna Loa SEA

Scientific Name (Recent Synonyms)	Status
Argyroxiphium kauense (Rock & M. Neal) Degener & I. Degener (Syn: *A. sandwicense* DC var. *kauense* Rock & M. Neal)	Endangered
Asplenium fragile Presl var. *insulare* Morton (Syn: *A. peruvianum* Desv.; name used by Palmer 2000)	Endangered
Exocarpos menziesii Stauffer	Rare in HAVO
Fragaria chiloensis (L.) Duchesne subsp. *sandwicensis* (Decne.) Staudt (Syn: *F. chiloensis* var. *sandwicensis* Degener & I. Degener; *F. sandwicensis* Decne.)	SOC*, lost from HAVO
Geranium cuneatum Hook. subsp. *hypoleucum* (A. Gray) Carlq. & Bissing (Syn: *G. cuneatum* Hook. var. *hypoleucum* A. Gray)	Rare in HAVO
Myoporum sandwicense A. Gray	Uncommon
Phyllostegia racemosa Benth.	Endangered
Pittosporum aff. *confertiflorum* A. Gray	Rare in HAVO
Plantago hawaiensis (A. Gray) Pilg. (Syn: *P. pachyphylla* A. Gray var. hawaiensis A. Gray)	Endangered
Pseudognaphalium sandwicensium (Gaud.) A. Anderb. (Syn: *Gnaphalium sandwicensium* Gaud.)	Uncommon
Rubus macraei A. Gray	SOC*
Rumex giganteus W. T.Aiton	Rare in HAVO
Santalum paniculatum Hook. & Arnott var. *paniculatum* (Syn: *S. ellipticum* Gaud. var. *latifolium* (A. Gray) Fosb.; *S. pilgeri* Rock var. *luteum* Rock)	Uncommon
Scaevola kilaueae Degener	SOC*
Silene hawaiiensis Sherff (Syn: *S. struthioloides* A. Gray var. *gracilis* Sherff)	Threatened
Sisyrinchium acre H. Mann	SOC*
Tetramolopium humile (A. Gray) Hillebr. subsp. *humile* var. *humile*	Uncommon

* SOC = Species of Concern