1994

Impacts of Biological Invasions on the Management and Recovery of Rare Plants in Haleakala National Park, Maui, Hawaiian Islands

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Introduction

Biological invasions assisted by humans are impoverishing biological diversity worldwide (MacDonald *et al.* 1989, Diamond 1989). Such invasions are particularly devestating to the biota of oceanic islands such as Hawaii (Williamson 1981, Brockie *et al.* 1988, Hawaii Department of Land and Natural Resources *et al.* 1991). Ecosystems of the Hawaiian Islands are much more vulnerable to biological invasions than are continental ecosystems, because the organisms in them have evolved in isolation from many of the forces that have shaped continental organisms, including foraging and trampling by herbivorous mammals, predation by ants and mammals, virulent diseases, and fires (Loope & Mueller–Dombois 1989). Lowland ecosystems of the Hawaiian Islands were substantially modified by Polynesians prior to western contact (Kirch 1982); after Cook's 'discovery' of the islands in 1778, the rate of modification accelerated and extended to higher elevations (Cuddihy & Stone 1990).

Ecosystems of low and middle elevations of the Hawaiian Islands have been drastically altered. Biological diversity has eroded more rapidly in Hawaii than in any other state. Though only 19 Hawaiian plant species have been federally designated as Endangered (US Fish and Wildlife Service 1990), it is estimated that of 1094 Hawaiian native taxa of flowering plants, 10% are extinct, 12% endangered, 4% vulnerable, and 12% rare (Wagner, Herbst & Sohmer 1990). Many Hawaiian botanists consider these figures conservative. Several conservation groups filed suit against the US Fish and Wildlife Service for listing few of the eligible Hawaiian species, and the Service agreed to propose 186 more species for listing by late 1992 (Anonymous 1990). The commitment of several state and federal agencies to the conservation of Hawaiian biological diversity has increased substantially during the past decade and, through interagency cooperation, the potential exists for substantial successes (e.g. Hawaii State Department

Published in RESTORATION OF ENDANGERED SPECIES, ed. Marlin L. Bowles and Christopher J. Whelan (Cambridge: Cambridge University Press, 1994).
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of Land and Natural Resources *et al.* 1991). An integrated effort combining land protection, management against exotic species, protection of listed species, both *ex situ* and *in situ* species recovery, and community restoration will be most successful in meeting this commitment.

Haleakala National Park: An Overview

Haleakala National Park is located on Maui, the second largest island (1864 km^2) in the Hawaiian archipelago. Maui is situated on two large shield volcanoes, and the National Park is on the larger and younger of the two (Fig. 6.1). The park consists of an 11 400 ha irregular wedge-shaped area that surrounds Haleakala volcano, extending from sea level up to the 3056-m volcano summit. Haleakala National Park was established as part of Hawaii National Park in 1916, and as a separate National Park in 1961. It preserves the outstanding biological, geological, and scenic resources of Haleakala volcano, Kipahulu Valley, and adjacent coastal lands for visitor enjoyment and scientific study. A

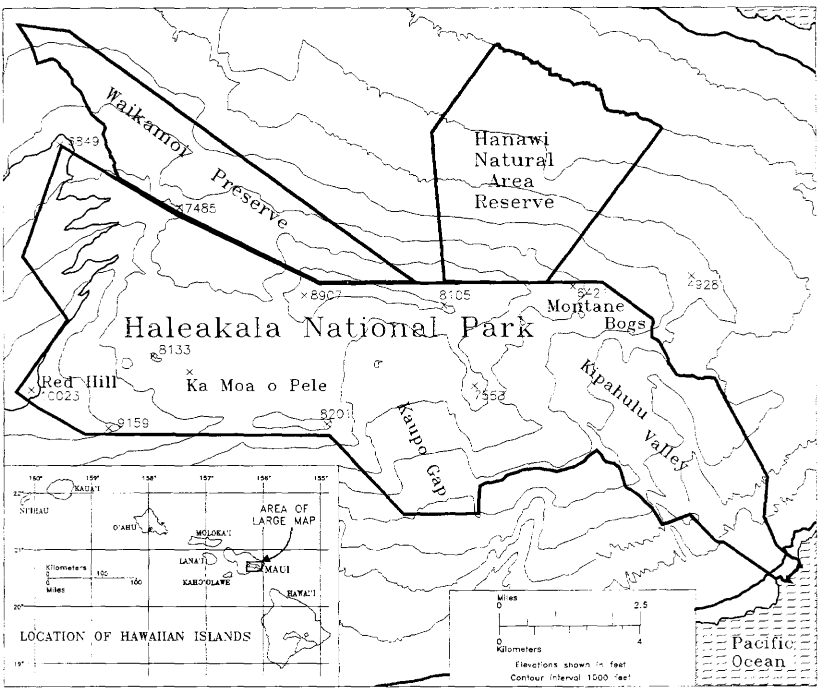

Fig. 6.1. Location, geography, and topographic relief of Haleakala National Park and adjacent natural areas on Maui, Hawaiian Islands.

large portion of the Park's rain forest is set aside as a Scientific Reserve and closed to the public. With adjacent conservation lands to the north, including Waikamoi Preserve (managed by The Nature Conservancy), Hanawi State Natural Area Reserve, and other state lands, the contiguous near-pristine area comprises over 20 000 ha.

Haleakala volcano is less than one million years old and has erupted as recently as about 200 years ago. It has a highly dissected topography, relatively well-developed soils, and a wide range of climatic conditions. Mean annual rainfall ranges from 100 cm to 1000 cm; most occurs on the windward slope, leaving a cinder desert within the rain shadow of the crater. This wide array of ecological factors supports a rich variety of forest, shrub, and alpine plant communities along elevational and moisture gradients. Relatively intact examples of these ecosystems remain, especially in extreme habitats such as at high elevations, on sparsely weathered volcanic substrates, on soils with aluminum toxicity, in caves, in montane bogs, and along coastal strand (Loope & Mueller-Dombois 1989).

About 95% of the park area (that above 600 m) is dominated by native species. This biota is rich by the standards of most isolated oceanic islands, consisting of 246 species of flowering plants, 104 ferns, 173 mosses and liverworts, 15 birds, one mammal, four fish, 23 known molluscs, and over 1000 known arthropod species. Over 90% of these species are endemic to the Hawaiian Islands, and many are endemic to Maui (Table 6.1). Some species of plants and invertebrates have their last refuge in the Park. Many invertebrates are likely to be undescribed local endemics. For example, during May–June 1991, 43 previously undescribed carabid beetle taxa were collected from East Maui (J. Liebherr, personal communication). Alien species are predominant below 600 m, and the alien biota of the entire park area includes 303 flowering plant species, 19 gymnosperms, 12 ferns, 9 mammals, 17 birds, 5 amphibians, 3 reptiles, 9 molluscs, and about 400 arthropods.

In spite of Haleakala's role as part of one of the most viable conservation units in the State of Hawaii, six of the Park's native bird species are federally endangered, and many invertebrate and plant species are sufficiently rare and threatened to merit listing. Seven plant taxa formerly native to the Park are known to be extinct, and 15 others have been extirpated from the Park in this century (Table 6.2). Active management has begun to reverse the chronic decline of the Park's resources.

Invasions and their effects on Haleakala National Park

Foraging and trampling by ungulates, especially feral goats (*Capra hircus*) and pigs (*Sus scrofa*), are widely recognized by scientists and managers in Hawaii

Table 6.1. *Endemic vascular plant species within Haleakala National Park restricted to Maui*

Nomenclature of flowering plants follows Wagner *et al.* (1990).

Species restricted to East Maui:	
Argyroxiphium virescens	Asteraceae
Artemisia mauiensis	Asteraceae
Calamagrostis expansa	Poaceae
Clermontia samuelii	Lobeliaceae
Clermontia tuberculata	Lobeliaceae
Cyanea aculeatiflora	Lobeliaceae
Cyanea pohaku	Lobeliaceae
Cyanea aff. *glabra*	Lobeliaceae
Cyanea horrida	Lobeliaceae
Cyanea longissima	Lobeliaceae
Cyrtandra hashimotoi	Gesneriaceae
Dryopteris sp.	Aspidiaceae
Dubautia dolosa	Asteraceae
Dubautia menziesii	Asteraceae
Dubautia platyphylla	Asteraceae
Dubautia reticulata	Asteraceae
Geranium arboreum	Geraniaceae
Geranium hanaense	Geraniaceae
Geranium multiflorum	Geraniaceae
Labordia venosa	Loganiaceae
Lobelia grayana	Lobeliaceae
Pelea balloui	Rutaceae
Pelea ovalis	Rutaceae
Peperomia kipahuluensis	Piperaceae
Pipturus forbesii	Urticaceae
Polystichum sp.	Aspidiaceae
Pritchardia arecina	Arecaceae
Santalum haleakalae	Santalaceae
Schiedea haleakalensis	Caryophyllaceae
Schiedea implexa	Caryophyllaceae
Silene cryptopetala	Caryophyllaceae
Silene degeneri	Caryophyllaceae
Stenogyne haliakalae	Lamiaceae
Stenogyne rotundifolia	Lamiaceae
Wikstroemia monticola	Thymelaeaceae
Species restricted to East and West Maui:	
Argyroxiphium grayanum	Asteraceae
Cyanea kunthiana	Lobeliaceae
Lobelia hillebrandii	Lobeliaceae
Phyllostegia bracteata	Lamiaceae
Pelea orbicularis	Rutaceae

Table 6.2. *Vascular plant taxa formerly occurring in Haleakala National Park that are now either extinct or extirpated from the park, with dates of last records*

Extinct	
Tetramolopium lepidotum subsp. *arbusculum* (1841)	Asteraceae
Silene cryptopetala (1870s)	Caryophyllaceae
Cyanea pohaku (1910)	Lobeliaceae
Schiedea implexa (1910)	Caryophyllaceae
Cyanea longissima (1927)	Lobeliaceae
Silene degeneri (1927)	Caryophyllaceae
Stenogyne haliakalae (1937)	Lamiaceae
Extirpated	
Huperzia haleakalae (1841)	Lycopodiaceae
Phyllostegia bracteata (1918)	Lamiaceae
Asplenium kaulfussii (1919)	Aspleniaceae
Clermontia lindseyana (1919)	Lobeliaceae
Clermontia peleana (1919)	Lobeliaceae
Lindsaea repens var. *macraeana* (1919)	Lindsaeaceae
Platanthera holochila (1919)	Orchidaceae
Solanum incompletum (1919)	Solanaceae
Vandenboschia draytoniana (1919)	Hymenophyllaceae
Panicum tenuifolium (1937)	Poaceae
Ranunculus hawaiensis (1945)	Ranunculaceae
Ranunculus mauiensis (1945)	Ranunculaceae
Argyroxiphium virescens (1959)	Asteraceae
Asplenium leucostegioides (1976)	Aspleniaceae
Gardenia remyi (1980)	Rubiaceae

as the most destructive forces in Hawaiian ecosystems. These animals have reduced or eliminated populations of native plants, facilitated alien plant dispersal and establishment, and hastened soil erosion (Stone & Loope 1987).

Other alien animals pose serious but more subtle threats to Haleakala ecosystems. Alien birds disperse alien seed, act as disease vectors, and compete with native birds (Scott *et al.* 1986). Alien rats (*Rattus* spp.) and mice (*Mus domesticus*) can damage native species (Stone & Loope 1987), and the predacious snails *Euglandina rosea* and *Oxychilus alliarius* are impacting native snails (Howarth & Medeiros 1989). Alien insects such as the predacious Argentine ant (*Iridomyrmex humilis*) and western yellowjacket (*Vespula pensylvanica*), the European earwig (*Forficula auricularia*), and a wasp (Encyrtidae: *Capidosoma bakeri*) that parasitizes native noctuid moths, threaten not only endemic invertebrate taxa, but entire ecosystems through impoverishment of pollinators and thus, perhaps, reduced seed set and fecundity of endemic plant species (Cole *et al.* 1992; Gambino, Medeiros & Loope 1987, 1990; Beardsley 1990).

Invasive plant species that are spreading in the Park and threaten to replace native vegetation include molasses grass (*Melinis minutiflora*), strawberry guava (*Psidium cattleianum*), blackberry (*Rubus argutus*), Australian tree fern (*Cyathea cooperi*), kahili ginger (*Hedychium gardnerianum*), gorse (*Ulex europaeus*), three pine (*Pinus*) species, and blue gum (*Eucalyptus globulus*) (Loope, Nagata & Medeiros, 1992). The invasive Pampas grass (*Cortaderia jubata*) was recently established on East Maui and first observed in the Park in 1989. Other alien plant species present on Maui that threaten to invade and seriously impact Park vegetation include clidemia (*Clidemia hirta*), miconia (*Miconia calvescens*), banana poka (*Passiflora mollissima*), and fountain grass (*Pennisetum setaceum*).

Despite state and federal efforts to control the introduction and spread of alien plants and animals (The Nature Conservancy of Hawaii & Natural Resources Defense Council 1992), they appear to be the greatest long-term threat to the integrity of Haleakala's ecosystems. Although only a small fraction of alien introductions are likely to significantly affect native species, cumulative impacts may have a profound effect on long-term conservation. Haleakala National Park is increasing efforts to eliminate new alien species before they become so extensively established that mechanical and chemical controls are ineffective (Loope *et al.* 1992, Loope & Medeiros 1991).

Active management of biological invasions

Efforts to combat alien species at the landscape scale have had positive effects in Haleakala National Park. Park resource managers used fencing to essentially eliminate a population of about 2000 goats from the Park, including Haleakala Crater in 1986 and 1987, ending nearly 200 years of severe ecological damage. The release from heavy browsing has allowed the diversity and cover of native vegetation to increase through resprouting and reproduction from seed. Koa (*Acacia koa*), a tree of mesic to wet forests, is regenerating abundantly in eastern Kaupo Gap. The native shrubs mamani (*Sophora chrysophylla*), pukiawe (*Styphelia tameiameiae*), aalii (*Dodonaea viscosa*), ulei (*Osteomeles anthyllidifolia*), and ohelo (*Vaccinium reticulatum*) are becoming widely established, and in some areas are replacing the alien grasses that persisted under goat browsing.

Following the removal of the goats, however, some alien plants have also increased, and continue to threaten native ecosystems. For example, aggressive invasion by the fire-adapted molassesgrass (*Melinis minutiflora*) increases fuel loads in formerly barren mid-elevation habitats (Hughes, Vitousek & Tunison 1991). As a result, wildfires are now a serious threat to fire-sensitive native vegetation in Kaupo Gap. Early stages of molasses grass invasion are being retarded with herbicides, allowing greater, earlier native species recovery.

Table 6.3. *Federal listing status of plant taxa used as subjects of case histories*

Categories based on US Fish and Wildlife Service (1990, 1991): T = proposed federal threatened, E = proposed federal endangered, X = believed extinct, * = not proposed for listing, but rare in Haleakala National Park.

Taxon	Category
Argyroxiphium sandwicense subsp. *macrocephalum*	T
Mariscus hillebrandii	*
Bidens micrantha subsp. *kalealaha*	E
Schiedea haleakalensis	E
Plantago pachyphylla	*
Sisyrinchium acre	*
Argyroxiphium virescens	X

Feral pigs were effectively controlled by snaring in rain forests of the upper Kipahulu Valley in 1987 and 1988, but follow-up efforts are essential (Anderson & Stone 1993). The potential for recovery has been demonstrated in 10-year exclosures, where understory vegetation, especially ferns, small herbs, and bryophytes, has increased (A.C. Medeiros, unpublished data and personal observation). As recovery progresses, watershed conditions should improve because increased vegetation cover should buffer against rapid runoff and erosion and the consequent siltation of streams. Pigs are also being removed from non-forested units of the Park, and fencing now protects some montane bog and grassland habitats for rare species and communities.

Rare plant species and restoration case studies

The control of goats, pigs, and alien plants at Haleakala National Park constitutes a landscape-scale program of ecological restoration. Many rare plant taxa are being monitored to detect individual species responses to management, and to provide guidance for the restoration of some extirpated plants. The following case studies illustrate findings for seven plant species (Table 6.3), several of which are proposed as endangered or threatened by the US Fish and Wildlife Service.

Mariscus hillebrandii (Cyperaceae)

The endemic sedge *Mariscus hillebrandii* has increased dramatically since the Park has been protected from goats. It is present, but uncommon, in \`a\`a lava fields at lower elevations in Maui, but within the Park it was collected—and noted as very rare—only in 1919 and 1937. It began to reappear within the Park in 1979, first in a fenced exclosure in western Kaupo Gap, and later along molasses grass monitoring transects (A. C. Medeiros & L. L. Loope, personal observation). *M. hillebrandii* has now been discovered to be widely scattered throughout a 100 ha area in western Kaupo Gap. We attribute this sudden appearance over a broad distribution to germination from soil seed banks.

Bidens micrantha subsp. kalealaha (Asteraceae)

The 19 Hawaiian *Bidens* species exhibit more morphological diversity than does the rest of the genus on five continents (Ganders & Nagata 1984). *Bidens micrantha* subsp. *kalealaha* is an erect shrub up to 1.5 m tall, with dissected leaves and yellow flower heads. This proposed federal endangered species probably was once widespread on East Maui and Lanai, but it has been reduced by feral goats to about 2000 individuals in four populations on inaccessible cliff faces on leeward East Maui (US Fish and Wildlife Service 1991). The Park population is found on the inner walls of Haleakala Crater at 1800–2320 m elevation.

In October 1990, three years after feral goats were eliminated from Haleakala Crater, seven juveniles and a larger flowering *Bidens micrantha* subsp. *kalealaha* appeared on talus slopes and along stream-courses at the base of the steep walls of western Kaupo Gap at 1800–1900 m. These plants were apparently the offspring of plants growing on the cliff faces above. This was the first time that this species has been found away from its now-typical cliff habitat. There appears to be ample habitat for a further increase of this species now that feral goat browsing has been eliminated.

Schiedea haleakalensis (Carophyllaceae)

Schiedea haleakalensis is a shrub 30 to 60 cm tall with narrow, almost needle–like leaves and clusters of small flowers that have reddish to green sepals and mature to woody capsules. Like *Bidens micrantha* subsp. *kalealaha*, *S. haleakalensis* has been confined to cliff habitat by goat browsing and is proposed as federal endangered. Only two populations, with a total of 100–200 individuals, exist, both within Haleakala Crater (US Fish and Wildlife Service 1991).

Schiedea haleakalensis is diclinous (S. Weller, personal communication) and possibly gynodioecious (A. C. Medeiros, personal observation), which would require mixed sexes within populations for successful cross-pollination and seed set. Although we have observed small flies and moths visiting flowers at both populations, natural reproduction has not occurred and may be limited

Table 6.4. *Frequencies of selected rare native plant species at study sites undergoing chronic damage by feral pigs in* Carex- *and* Oreobolus-*dominated montane bog communities*

Data based on presence in 1 m^2 plots (Medeiros *et al.* 1991).

	Carex communities		*Oreobolus* commmunities	
	1982	1988	1982	1988
Plantago pachyphylla	0.24	0.10	0.80	0.47
Argyroxiphium grayanum	0.43	0.31	0.07	0.04
Trisetum glomeratum	0.03	0.02	0.35	0.15
Carex thunbergii	0.29	0.19	—	—
Selaginella deflexa	—	—	0.30	0.08
Geranium hanaense	0.04	0.05	0.03	0.01
Viola maviense	—	—	0.06	0.03

by the plant's breeding system. However, fertile seeds were obtained from plants in 1991, and nine plants were greenhouse-propagated (S. Weller, personal communication). Thus, we are planning propagation of greenhouse and garden populations that can be used as sources of propagules for reintroduction.

Plantago pachyphylla (Plantaginaceae)

Plantago pachyphylla formerly occurred at medium to high frequencies in sedge-dominated (*Carex* spp. or *Oreobolus furcatus*) montane bogs at 1650–1905 m. *Plantago pachyphylla* and other bog vegetation declined precipitously between 1982 and 1988 as a result of feral pig digging and subsequent alien plant invasion (Medeiros, Loope & Gagne 1991). Although the pigs have been removed, the bog species have not recovered (Table 6.4), possibly because of the persistence of alien plants.

In one studied bog, *P. pachyphylla* has not recovered after pig removal even without competition from alien plants (Loope *et al.* 1991). Its frequency had declined from 60% in 1973 to 5% in 1981, when the bog was fenced. By 1984, the other native vegetation had regained its original cover, but even after six additional years of protection, *P. pachyphylla* had not increased significantly (Loope *et al.* 1991). Reproductive and demographic studies of this species are clearly needed to determine why community restoration management has not helped it to recover.

Sisyrinchium acre (Iridaceae)

Sisyrinchium acre is a small, yellow-flowered iris endemic to high-elevation (2000–2500 m) shrubland on Maui and Hawaii. In an opportunistic experiment, this species was found to be an excellent colonizer, but poor at competing with alien grasses. Several months after an eight-year-old tree fall of alien pines was removed, over 100 *S. acre* seedlings (which are easily identifiable by their distinctive glaucous foliage and morphology) appeared from a soil seed bank. This allowed their fates and the fates of other plants appearing from seed to be compared between a managed plot, from which alien plants were periodically removed, and an unmanaged plot.

In the managed plot, bare ground accounted for 90% of the cover. Half of the remaining cover of native plants was from *S. acre*, which increased from 76 to 376 individuals in one year. In the unmanaged plot, 49 *S. acre* plants increased to only 56 in one year, while alien grass and forb cover increased to 90% and overtopped the *S. acre* individuals. *Holcus lanatus*, the primary invading grass, may be allelopathic (Watt 1978). The more common native species that also appeared in the tree fall area included the sedges *Carex wahuensis* and *C. macloviana*, the rush *Luzula hawaiiensis*, and the herb *Gnaphalium sandwicensium* subsp. *hawaiiense*. The shrubs *Vaccinium reticulatum*, *Sophora chrysophylla*, and *Coprosma montana* resprouted from old stumps.

Argyroxiphium sandwicense subsp. *macrocephalum* (Asteraceae)

Argyroxiphium sandwicense subsp. *macrocephalum*, the Haleakala silversword or ahinahina, is one of 28 species in the endemic *Madiinae* complex, which is derived from a western North American ancestor that underwent spectacular adaptive radiation in the diverse Hawaiian environment (Carr 1985, 1987; Baldwin, Kyhos & Dvorak 1990). The molecular and physiological diversity of this group give it the potential to elucidate evolutionary processes and mechanisms (Carr 1987, Baldwin *et al.* 1990, Robichaux *et al.* 1990).

A. sandwicense subsp. *macrocephalum* is endemic to 1000 ha at 2100–3000 m in the crater and outer slopes of Haleakala volcano. It is considered rare because of its highly restricted distribution (Rabinowitz, Cairns & Dillon 1986), and has a current population of about 50 000 individuals (Loope & Crivellone 1986). This monocarpic, self-incompatible plant produces a flower stalk 1–2 m tall with 100–500 maroon–purple flower heads; it can flower in as little as three years in cultivation, but normally requires several decades in natural habitat (Kobayashi 1973, 1991).

By the 1920s, this species was nearly extinct because of browsing by goats and cattle and collection by tourists. Often a living silversword was pulled up and brought back from a trip up Haleakala to prove that the party had reached the very

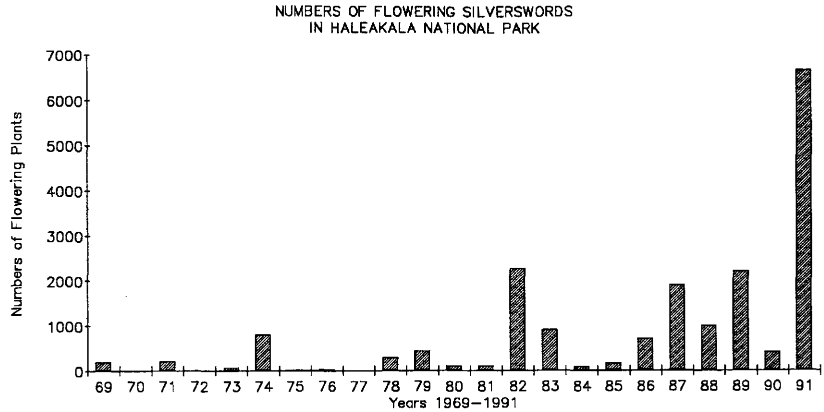

Fig. 6.2. Numbers of flowering silversword (*Argyroxiphium sandwicense* subsp. *macrocephalum*) in Haleakala National Park, 1969–91 (source: Kobayashi 1973, Loope & Crivellone 1986, unpublished data)

summit. Haleakala silverswords have thrived under protection, increasing from 1470 plants in 1935 to 6528 plants in 1991 (Kobayashi 1991) on the Ka Moa o Pele cinder cone. Although flowering is variable, annual numbers of flowering plants have increased from the hundreds in the 1970s to the thousands by the late 1980s, with more than 6000 in 1991 (Fig. 6.2). In permanent plots, plant numbers have been stable or slightly increasing during the past decade, but with annual fluctuations in the recruitment and survival of juvenile plants (Loope & Crivellone 1986; Fig. 6.3). For the first few years after establishment, seedlings are very susceptible to the impact of heavy rains and the accompanying sheet erosion.

To reproduce, *A. sandwicense* subsp. *macrocephalum* relies on cross-pollination by insects, and it is vulnerable if pollinators are lost. Because the Hawaiian Islands lack endemic ants, native insects are not adapted to ant predation, and the recent invasion and spread of the predacious Argentine ant (*Iridomyrmex humilis*) may seriously threaten silverswords. Although it is presently found in only a small portion of upper-elevation habitats and has not expanded its range in recent years, the Argentine ant has the potential to spread throughout much of the Haleakala Crater and western slope ecosystem (Cole *et al.* 1992), where it could eliminate pollinators and curtail silversword reproduction. The Argentine ant's spread is being monitored, and control strategies are being developed.

Argyroxiphium virescens (Compositae)

Like other *Madiinae*, *Argyroxiphium virescens* is monocarpic and self-incompatible, and thus highly vulnerable to extinction from shrinking populations and loss of pollinators. This species is endemic to East Maui, and was abundant in

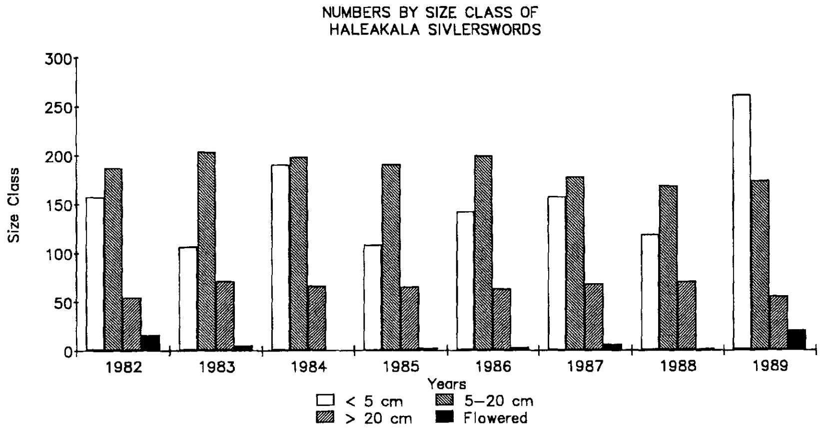

Fig. 6.3. Numbers by diameter classes of Haleakala silversword (*Argyroxiphium sandwicense* subsp. *macrocephalum*), 1982–89. Data summarized from eleven 5 m × 20 m permanent plots in Haleakala Crater.

Haleakala National Park in the early 1900s. By the 1940s, it was near extinction from cattle, goat, and pig grazing. The last known individual flowered and died in the park in 1959; however, two plants resembling this species were discovered in 1973, and one of these has been used in an eleventh-hour recovery attempt.

The two juvenile plants resembling *Argyroxiphium virescens* were discovered in Hanawi State Natural Area Reserve, adjacent to Haleakala National Park's northern boundary (B.H. Gagne, personal communication). The larger plant was already protected from grazing because it grew on a steep cliff; in 1982, the smaller plant was protected in an exclosure. In 1989, the larger plant flowered and was identified as either *A. virescens* or an *A. virescens* × *A. sandwicense* hybrid (G.D. Carr, personal communication). As expected, none of the 200 seeds from this individual were viable, although numerous potential pollinators had visited the flower spike (A.C. Medeiros, personal observation). Thus, only one known possible *A. virescens* remains.

In late 1990, a plan was developed in cooperation with the Center for Plant Conservation to save *Argyroxiphium virescens*. This species is a good candidate for recovery because of the existence of natural habitat for reintroduction to the wild, the interest of state, federal, and private agencies in reintroduction, the availability of propagation facilities at Haleakala National Park headquarters, the potential for conservation of a silversword relative, and the challenge of recovering a near-extinct, self-incompatible species.

The *Argyroxiphium virescens* recovery plan objectives and accomplishments include:

1) A systematic search of potential habitat for additional individuals. Ground and helicopter surveys of potential *A. virescens* habitat in 1990 and 1991 failed to locate additional plants.

2) Experimental tissue culture of the surviving individual (as well as any new individuals that might be found), which offers the potential to propagate large numbers of plants from vegetative material (Ferguson & Pavlik 1990). Undifferentiated cells (callus) and shoots, but not roots, have been produced from leaf mesophyll at Mills College in early 1991 (Ferguson & Pavlik 1991).

3) Through chloroplast or nuclear DNA analysis, which has been conducted on the *Madiinae* (Baldwin *et al.* 1990), determine the taxonomic status of the surviving individual or individuals by comparison with living material of *A. sandwicense* subsp. *macrocephalum* and *A. grayanum* and, if possible, with dried herbarium specimens of *A. virescens*. Living tissue has been sent to the University of Arizona for analysis.

4) Attempt germination of *A. virescens* seeds from herbarium specimens. Approximately 200 *A. virescens* seeds from the B.P. Bishop Museum herbarium have been sent to the University of Arizona (L. Mehrhoff, personal communication). In general, seeds of the *Madiinae* are not known for longevity, and results are as yet unknown.

The single known living plant that could be *Argyroxiphium virescens* was double-rameted, and one of the ramets flowered in 1991. Although seeds were collected, they appear to be nonviable. Although efforts to reproduce this individual *in vitro* are encouraging, self-incompatibility is likely to prevent the production of viable seed from clones. Sporophytic self-incompatibility in the Compositae may be overcome to some extent by techniques such as bud pollination, use of microspores that have not yet received incompatibility proteins, use of foreign 'mentor' pollen to induce growth of normally incompatible pollen, or fertilization *in vitro* of excised ovaries (de Nettancourt 1977). Thus, it may be possible to promote seed production from flowering plants derived from tissue culture of the remaining plant. This, however, may ultimately be insufficient for recovery if only a single reproductive genotype occurs within a cloned population. Despite concerted efforts thus far, the survival of *A. virescens* is anything but assured.

Conclusions

Population depletion from past grazing and the continuing impacts of biological invasions present formidable challenges to the recovery of rare plants in Haleakala National Park. Faced with landscape-wide damage and limited staffing, Hawaiian resource managers have concentrated on ecosystem-level management; the management of individual Hawaiian species is in its infancy. With increasing conservation efforts, Hawaii will become a proving ground for integrated ecosystem and species restoration. Program strategies include sustained mechanical and chemical control of alien species, research and monitoring, public education, and enlisting the support of local and state government agencies. With continued active management, the prognosis for preservation of the remaining ecosystem components of Haleakala seems favorable.

Alien invertebrates pose complex problems requiring research and continual surveillance. Prospects for controlling many alien invertebrate species are not promising. A better understanding of the biological interrelationships between native and alien species may be crucial in the success of management and long–term conservation of native ecosystems.

The incipient recovery of *Mariscus hillebrandii* and *Bidens micrantha* suggests that the removal of feral ungulates and restoration of habitats have been effective. However, the lack of reproduction in *Schiedea haleakalensis* and *Plantago pachyphylla* shows that the removal of feral ungulates does not guarantee recovery of rare plant species. The recovery of *Sisyrinchium acre* may depend on its being protected from competition with aggressive alien plants. *Argyroxiphium sandwicense* subsp. *macrocephalum*, a spectacular species that has become a symbol of Haleakala National Park, has recovered dramatically over the past 50 years because it has been protected from grazing and collection, but it is vulnerable if alien insects impact its pollinators. *Argyroxiphium virescens* illustrates the potential and the pitfalls of working to save plant species on the verge of extinction. Long-term success in preserving all species will require cooperative efforts, often involving sophisticated propagation techniques as well as habitat protection.

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