

ALIEN PLANT CONTROL STRATEGIES IN HAWAII VOLCANOES NATIONAL PARK*

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ABSTRACT

Alien plants have greatly altered some native plant communities and threaten others in Hawaii Volcanoes National Park. The Park contains approximately 405 alien and 375 native vascular plant species. Desultory efforts were made to control alien plants until the 1980s, at which time a systematic program was initiated. The following strategies or actions have been taken to protect native species assemblages: 1) controlling feral pigs and goats; 2) excluding fire; 3) controlling localized alien plants throughout the Park; 4) controlling all disruptive alien plants in Special Ecological Areas (the most diverse and intact areas in the Park); 5) confining one widespread species, fountain grass (*Pennisetum setaceum*), to the area it currently infests; 6) developing herbicidal control methods for target species; 7) developing biological controls for some widespread species; 8) mapping the distribution of important alien plants; 9) researching the ecology, seed biology, and phenology of important alien plant pest species; 10) educating the public to the importance of alien plant control; and 11) working with other agencies and groups in alien plant management. Control of new introductions and incipient infestations and protection of some of the most diverse and intact areas in the Park have been very successful strategies. Biological control programs, now in the research phase, provide potential long-term solutions to the control of some widespread plant species.

INTRODUCTION

Alien plant problems have been recognized by park managers at Hawaii Volcanoes National Park since the 1920s. Desultory efforts were made to control alien plants until the 1980s, at which time alien plant management

*Adapted from Tunison 1991.

intensified in response to the rapid spread of several obviously disruptive alien plant species in the Park. During this period, the National Park Service also began to deal more forcefully with natural resource problems nationwide. By 1982, the most important alien plant species in Hawaii Volcanoes had been listed in order of priority, and an interagency cooperative agreement with State and other Federal agencies was drafted for initiating biological control research on some of the most disruptive alien plants in forests. Twenty-six species in the Park were targeted for mechanical and chemical control programs, and control efforts were applied to 14 of these. However, no species was considered controlled, and management was not applied to the entire geographical range of any target species in the Park.

The alien plant control program expanded and became more systematic in the mid-1980s. By 1988, work was in progress on 48 target species using herbicide or mechanical control measures, and biological control research on three target species was under way. Alien plant control accounted for approximately one-third of the Park's Division of Resources Management budget, which supported the equivalent of four full-time personnel per year for alien plant control.

In this paper I describe the current (1988) alien plant program at Hawaii Volcanoes National Park, emphasizing control strategies. The effectiveness of control programs, briefly summarized here, is discussed in detail in other papers in this volume and elsewhere (Cuddihy *et al.* 1988; Tunison, this volume; Tunison and Zimmer, this volume; Tunison 1991).

ALIEN PLANT PROBLEMS

Alien plants have invaded many modified plant communities in Hawaii Volcanoes National Park and are serious threats to the remaining intact communities. Smith (1985, 1991) has characterized alien plant problems in Hawai'i, delineated impacts, and identified disruptive species. In Hawaii Volcanoes, which has a native vascular plant flora of about 375 native species (Higashino *et al.* 1988), approximately 405 alien plant species are now naturalized. The Park's flora includes 34 of the 86 most disruptive introduced plant species in Hawai'i (Smith 1985) (Table 1). Park plant communities vary from essentially alien-dominated to native-dominated, with the degree of intactness increasing with elevation; in general, the coastal lowlands are dominated by alien plants, whereas the upper montane seasonal, subalpine, and alpine zones (above 4,620 ft or 1,400 m elevation) are dominated by natives. The submontane seasonal and montane rain forest zones between the two elevational extremes are a mosaic of native and partly native plant communities.

Disruptive alien plant species are capable of replacing native vegetation, often forming monospecific stands or significantly altering fire and nutrient cycling regimes (Smith 1985). Some of the most disruptive species such as firetree (*Myrica faya*), banana poka (*Passiflora mollissima*), bush beardgrass (*Schizachyrium condensatum*), and broomsedge (*Andropogon virginicus*) have expanded

Table 1. Important alien plant species in Hawaii Volcanoes National Park and their management.

Species	Common Name	Family	Distribution in Park	Management Status
<i>Acacia confusa</i> *	Formosan koa	Leguminosae	Localized	Controlled
<i>Acacia mearnsii</i> *	Black wattle	Leguminosae	Localized	Controlled; reduced to seedling stages
<i>Acacia melanoxylon</i> ⁺	Blackwood acacia	Leguminosae	Localized	Possibly eradicated
<i>Agave americana</i>	Agave	Amaryllidaceae	Localized	Possibly eradicated
<i>Agave sisalana</i>	Sisal	Amaryllidaceae	Localized	Mostly controlled
<i>Albizia</i> sp.	Albizia	Leguminosae	Localized	Possibly eradicated
<i>Andropogon virginicus</i> *	Broomsedge	Gramineae	Widespread	Not controlled; targeted for biological control research; comments for <i>Schizachyrium condensatum</i> apply
<i>Anthoxanthum odoratum</i> *	Sweet vernalgrass	Gramineae	Widespread	Not managed
<i>Ardisia crenata</i>	Hilo holly	Myrsinaceae	Localized	Controlled
<i>Arthrostem a ciliatum</i>	Arthrostem a	Melastomataceae	Localized	Partially controlled
<i>Benicasa hispida</i>	Chinese melon	Cucurbitaceae	Localized	Probably eradicated

Table 1, continued.

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Species	Common Name	Family	Distribution in Park	Management Status
<i>Casuarina equisetifolia</i> *	Ironwood	Casuarinaceae	Localized	Controlled with some resprouting
<i>Ehrharta stipoides</i> *	Meadow ricegrass	Gramineae	Widespread	Not managed, but research in progress for chemical control in localized sites in SEAs
<i>Eleagnus umbellata</i>	Oleaster	Eleagnaceae	Localized	Controlled
<i>Eriobotrya japonica</i>	Loquat	Rosaceae	Localized	Controlled; reduced to seedling stages
<i>Eucalyptus globulus</i> ⁺	Eucalyptus	Myrtaceae	Localized	Controlled except where planted in a campground
<i>Feijoa sellowiana</i>	Guavasteen	Myrtaceae	Localized	Probably eradicated
<i>Fraxinus americana</i>	White ash	Oleaceae	Localized	Controlled; reduced to seedling stages
<i>Fraxinus uhdei</i> *	Tropical ash	Oleaceae	Localized	Probably eradicated
<i>Grevillea robusta</i> *	Silk oak	Proteaceae	Widespread	Controlled in SEAs;# funding requested for parkwide control

Species	Common Name	Family	Distribution in Park	Management Status
<i>Hedera helix</i>	English ivy	Araliaceae	Localized	Controlled
<i>Hedychium gardnerianum</i> *	Kāhili ginger	Zingiberaceae	Widespread	Controlled in SEAs; funding requested for parkwide control
<i>Holcus lanatus</i> *	Velvet grass	Gramineae	Widespread	Not managed
<i>Hyparrhenia rufa</i>	Thatching grass	Gramineae	Widespread	Not managed
<i>Lantana camara</i> *	Lantana	Verbenaceae	Widespread	Partially controlled by biological control agents introduced to state
<i>Leucaena leucocephala</i> *	Koa haole	Leguminosae	Widespread	Not managed; funding requested for parkwide control
<i>Lupinus hybridus</i>	Lupine	Leguminosae	Localized	Controlled; reduced to seedling stages
<i>Melaleuca quinquenervia</i> *	Paperbark	Myrtaceae	Localized	Probably eradicated
<i>Melochia umbellata</i> *	Gunpowder tree	Sterculiaceae	Localized	Controlled; reduced to seedling stages

Table 1, continued.

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Species	Common Name	Family	Distribution in Park	Management Status
<i>Melinis minutiflora</i> *	Molasses grass	Gramineae	Widespread	Targeted for biological control research, but permission to import biocontrol agents problematical
<i>Myrica faya</i> *	Firetree	Myricaceae	Widespread	Controlled in SEAs; biological control research under way
<i>Olea europaea</i> subsp <i>africana</i> *	Olive	Oleaceae	Widespread	Controlled in SEAs; funding requested for parkwide control
<i>Opuntia ficus-indica</i>	Prickly pear cactus	Cactaceae	Localized	Biocontrol agents introduced to Park from west side of Island without noticeable effects
<i>Paederia scandens</i>	Maile pilau	Rubiaceae	Localized	Possibly eradicated
<i>Paspalum conjugatum</i> *	Hilo grass	Gramineae	Widespread	Not managed; research in progress for chemical control in localized sites in some SEAs

Species	Common Name	Family	Distribution in Park	Management Status
<i>Paspalum dilatatum</i>	Dallis grass	Gramineae	Widespread	Not managed; comments for <i>P. conjugatum</i> apply
<i>Paspalum urvillei</i>	Vasey grass	Gramineae	Widespread	Not managed; comments for <i>P. conjugatum</i> apply
<i>Passiflora mollissima</i> *	Banana poka	Passifloraceae	Widespread	Controlled chemically in SEAs; biological control research in progress, and first release in 1988
<i>Pennisetum clandestinum</i> *	Kikuyu grass	Gramineae	Widespread	Controlled in SEAs and other localized sites
<i>Pennisetum setaceum</i> *	Fountain grass	Gramineae	Widespread	Controlled in SEAs, in outlying populations, and on periphery of main infestation
<i>Phormium tenax</i>	New Zealand flax	Liliaceae	Localized	Controlled with some resprouting
<i>Pinus caribaea</i>	Slash pine	Pinaceae	Localized	Controlled to seedling stages

Table 1, continued.

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Species	Common Name	Family	Distribution in Park	Management Status
<i>Pittosporum undulatum</i>	Pittosporum	Pittosporaceae	Localized	Possibly eradicated
<i>Prosopis pallida</i> *	Kiawe	Leguminosae	Localized	Controlled with some resprouting
<i>Psidium cattleianum</i> *	Strawberry guava	Myrtaceae	Widespread	Controlled in SEAs; targeted for biocontrol research
<i>Psidium guajava</i> *	Common guava	Myrtaceae	Widespread	Controlled in some SEAs
<i>Pueraria lobata</i>	Kudzu	Leguminosae	Localized	Controlled with some resprouting
<i>Ricinus communis</i>	Castor bean	Euphorbiaceae	Localized	Controlled to seedling stages
<i>Rubus argutus</i>	Blackberry	Rosaceae	Widespread	Biocontrol research in progress
<i>Rubus ellipticus</i>	Himalayan raspberry	Rosaceae	Widespread	Targeted for biocontrol research
<i>Rubus glaucus</i>	Raspberry	Rosaceae	Widespread	Funding requested for parkwide control

Species	Common Name	Family	Distribution in Park	Management Status
<i>Schinus terebinthifolius</i> *	Christmas berry	Anacardiaceae	Widespread	Not managed, but funding requested for control in part of Park
<i>Schizachyrium condensatum</i> *	Bush beardgrass	Gramineae	Widespread	Not controlled; targeted for biocontrol but permission to import biocontrol agents is problematical
<i>Setaria palmifolia</i> *	Palmgrass	Gramineae	Widespread	Control only in SEAs
<i>Solanum pseudocapsicum</i>	Jerusalem cherry	Solanaceae	Widespread	Control only in SEAs
<i>Soliva sessilis</i>		Compositae	Localized	Controlled
<i>Syzygium cumini</i> *	Java plum	Myrtaceae	Widespread	Not managed
<i>Syzygium jambos</i> *	Rose apple	Myrtaceae	Widespread	One disjunct population controlled
<i>Tibouchina urvilleana</i> *	Glorybush	Melastomataceae	Localized	Partially controlled
<i>Trema orientalis</i>	Trema	Ulmaceae	Localized	Controlled to seedling stages

Table 1, continued.

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Species	Common Name	Family	Distribution in Park	Management Status
<i>Tropaeolum majus</i>	Nasturtium	Tropaeolaceae	Localized	Controlled
<i>Verbascum thapsus</i> *	Common mullein	Scrophulariaceae	Localized	Not managed

*Considered by Smith (1985) to be serious plant pests in natural communities in Hawai'i.

⁺ Considered by Smith (1985) to be potential plant pests in natural communities in Hawai'i.

[#]Special Ecological Areas (see text).

their ranges significantly in the Park within the last 25 years. These and many other alien weeds continue to expand and to increase in density (Warshauer *et al.* 1982; Whiteaker and Gardner 1985; Tunison *et al.* 1992). Twenty-nine disruptive alien plant species in the Park are now too widespread to control with herbicides or mechanical measures, at least at current funding levels (Table 1).

The solutions to alien plant problems in the Park are complicated by the following factors: 1) Most species are too widespread to be controlled islandwide by conventional means; reinvasion of the Park is inevitable in spite of successful parkwide control programs. 2) Quarantine programs for the State are inadequate; the Islands are visited by millions of tourists yearly (in addition to military and others), and newly introduced alien plant species are anticipated. 3) Various user groups (such as horticulturists, landscapers, local residents) do not understand the magnitude of the alien plant threat. 4) Alien plant seed banks in the Park are substantial. 5) Accurate knowledge of alien species distributions and control of alien plants are beyond current funding levels. 6) Control techniques are not known for many species and/or are not permitted by the National Park Service or other authorities.

ALIEN PLANT CONTROL STRATEGIES

The immediate objective of the vegetation management program at Hawaii Volcanoes is to protect native species assemblages from alien plants (National Park Service 1988). The long-range objective is to protect and promote natural processes, the evolutionary potential of native species, and the diversity of genotypes, species, and communities. Since alien plant species are well established in Hawai'i and the Park, managers must realistically accept some alien species, but only at population levels compatible with the survival of native species assemblages. Alien plant control is directed only at alien species that disrupt native ecosystems; the great majority of alien plant species probably do not significantly alter native plant populations or natural processes.

Alien plant management at Hawaii Volcanoes consists of the following approaches or actions: 1) controlling feral pigs and goats; 2) excluding fire; 3) mapping the distribution of important alien plant species; 4) controlling localized alien plant species throughout the Park; 5) developing biological controls for some widespread species; 6) controlling all disruptive alien plants in Special Ecological Areas; 7) confining one widespread species, fountain grass (*Pennisetum setaceum*), to the area it currently infests; 8) developing herbicidal control methods for target species; 9) researching the ecology, seed biology, and phenology of important alien plant pest species; 10) educating the public to the importance of alien plant control; 11) working with other agencies and groups in alien plant management.

Controlling Feral Pigs and Feral Goats

The success of alien species has been attributed, in part, to the fact that island ecosystems have developed in isolation from many of the

selective pressures found in continental systems (Mueller-Dombois *et al.* 1981; Loope and Mueller-Dombois 1988). Feral ungulates are probably the most important introduced selective force or disturbance factor (other than humans) in Hawaiian ecosystems. Hawaiian vegetation evolved in the absence of ungulates and lacks defenses against herbivory of introduced mammals. Alien ungulates browse and graze native vegetation, disperse alien plant seeds, and disturb the soil, favoring the establishment of alien plants.

A management strategy of removing ungulates to prevent or mitigate alien plant problems is predicated on observations of natural exclosures and data from experimental exclosures (Loope and Scowcroft 1985; Scowcroft and Conrad, this volume). Natural exclosures such as steep slopes or pit craters tend to be areas of pristine vegetation with few alien plants, suggesting that damage by ungulates is a prerequisite for many large-scale invasions of alien plants (Mueller-Dombois *et al.* 1981). Patterns of vegetation recovery in experimental exclosures from which ungulates are removed are less definitive. Native vegetation tends to hold its own or even recover dramatically in areas that are predominantly native. In areas that are mostly dominated by aliens, alien plants tend to persist or even increase, inhibiting the invasion of native vegetation (Loope and Scowcroft 1985).

Hawaii Volcanoes has achieved considerable success in eliminating feral goats (*Capra hircus*), and feral pig (*Sus scrofa*) control in management units is progressing slowly but effectively. Feral goats were essentially eradicated in the Park below 6,000 ft (2,000 m) elevation by the early 1980s, and removal of the few remaining goats above this elevation is planned. Feral pigs have been reduced to low levels in approximately 30% of the pig habitat in the Park (nine management units) totalling approximately 17,300 a (7,000 ha). Pigs will eventually be removed from additional areas in the Park, but not all pig habitat in the Park will be cleared, partly because some areas have degenerated to the point where plant restoration after pig removal would be too expensive.

The effect of ungulate control in reducing alien plants over large areas is not as well documented as for exclusion from small experimental exclosures. In most cases, feral goats and pigs have only recently been removed and trends are not yet apparent. Documenting the recovery of vegetation following ungulate removal is one of the most important research and monitoring activities in the Park.

Excluding Fire

The spread and intensification of alien grasses in the coastal lowlands and submontane seasonal zone have dramatically altered the natural fire regime in much of Hawaii Volcanoes in the last 20 years (Smith and Tunison, this volume). To prevent the loss of native vegetation and stimulation of alien plants, the Park has adopted a total fire suppression policy and does not allow natural fire and prescribed burning (National Park Service 1985). An active fire prevention program, emphasizing manual hazardous-fuel reduction along roadsides and construction of fuel breaks, was started

in 1988. Distribution maps of fuels are being prepared, and preliminary customized fuel models are being developed. An intensive effort to assess fire effects in both recent and old burns has been undertaken to determine the ecological impacts and the necessity for fire exclusion. The effectiveness of these research and management programs in reducing the impacts of fire in the Park cannot yet be predicted.

Distribution Mapping of Important Alien Plant Species

A systematic program to map the distribution of 38 alien plant species was conducted from 1983 to 1985 (Tunison *et al.* 1992). Prior to this, the paucity and quality of distribution maps hampered the alien plant control program. Systematic mapping was undertaken to achieve the following objectives: 1) locate every population of a target species to assure that all plants are treated once a control program commences; 2) determine the feasibility of controlling alien plant species targeted for management in the Resources Management Plan; 3) develop a strategy for controlling target species; 4) establish a baseline for assessing the spread of individual alien plant populations; 5) assess the effectiveness of control programs.

Distribution maps are very effective in helping understand the scope of the problem, develop control strategies, and establish workload requirements (Tunison *et al.* 1992). Mapping efforts allowed classification of the status of 12 species, changed the priority of currently targeted species, and indicated the locations of untreated populations. Finally, distribution mapping indicated that eight species were too widespread for control with the resources available. Control efforts for these species were shifted from a parkwide emphasis to control in selected areas with high biological values and a greater chance of success (Tunison and Stone, this volume).

Monitoring of alien plants continues through systematic distribution mapping. Research and Resources Management personnel are collecting data on approximately 75 alien plant species incidental to other field work. Research personnel collect distribution data on all alien plant species in rain forests while conducting surveys to help determine new areas to be managed and monitoring vegetation recovery after ungulate removal. Alien plants are also quantitatively monitored in a number of Special Ecological Areas by Research and Resources Management personnel.

Controlling Localized Alien Plant Species

Forty-one potentially disruptive localized alien plant species are controlled throughout Hawaii Volcanoes (Table 1). These species are represented by populations with a few to several thousand individuals that are localized in distribution. They are either new introductions to the Park or more-established populations now viewed as incipient infestations. Many alien species were planted for range or reforestation in a former inholding used as a sheep and cattle ranch, and many ornamental species were planted near Kilauea Caldera, the main visitor attraction in the Park.

Localized alien plant species are controlled to remove them from Park ecosystems and forestall future costly control programs. The spread of

kāhili ginger (*Hedychium gardnerianum*), an aggressive perennial herb now well established in Park rain forests, might have been curtailed in much of the Park if it had been removed when the first few plants were noticed in the Park residential area 40 years ago (Fagerlund 1947).

Target species are selected for localized control primarily on the basis of invasiveness in the Park or other parts of the State. Other considerations include viney habit, taxonomic affinities to invasive species, and potential for dispersal. Many aggressive aliens become established initially in ruderal habitats, from which they spread to natural communities. Therefore, roads, trails, and developed areas are surveyed at least annually.

Control efforts have been highly effective on 26 of the 41 target species (Tunison and Zimmer, this volume). Seed production and plant populations have been markedly reduced. Nine of the 26 species have apparently been eradicated in the Park. Seven others have been reduced to seedling stages, with eradication awaiting depletion of the seed bank. Control efforts have been partially successful on the balance of the 41 target species, with reductions in populations and seed production (Table 1).

Developing Biological Controls for Some Widespread Species

Biological control (biocontrol) is theoretically the best approach for alien plants that are widespread in Hawaii Volcanoes and/or present outside and have the potential to continually reinfest the Park (National Park Service 1988). For example, biological control is perceived as a long-range solution for banana poka and firetree infestations in Hawaii Volcanoes. These species are already too widespread in the Park for parkwide control by herbicides or other means, and reinvasion is inevitable because they are widely distributed on Hawai'i Island. Biological control programs have been effective in Hawai'i in controlling several alien plant species (Davis *et al.*, this volume).

A Memorandum of Understanding has been established among the National Park Service, U.S. Forest Service, Hawaii Departments of Land and Natural Resources and Agriculture, and the University of Hawaii to intensify biological control efforts on forest pests in the State. A quarantine facility for entomological studies has been constructed in Hawaii Volcanoes and is staffed by the U.S. Forest Service and the State of Hawai'i. Studies on biocontrol with pathogens have been started by a National Park Service Research Scientist stationed at the University of Hawaii; however, facilities are inadequate for continued studies. Eight target species have been identified for biological control research, work is in progress on four of these species (Table 1), and one release of a biological control agent in the Park has been made.

Controlling All Disruptive Alien Plants in Special Ecological Areas

Since 1985, all disruptive alien plant species, including those too widespread for parkwide control, are now controlled in intensive management and research units called Special Ecological Areas (Tunison *et al.*

1986; Tunison and Stone, this volume). The Special Ecological Areas approach to alien plant control developed from these perceptions:

1. The impossibility of managing widespread alien plant species on a parkwide basis. Some alien species are too dense and/or widespread for control by herbicidal or mechanical means. The establishment of Special Ecological Areas is partly a concession that the alien plant problem in the Park is too advanced for conventional means of control except in localized areas, with current or expected funding.
2. The need to protect the most intact, most representative, and most biologically rich sites of the Park from disruptive alien species, and to begin control efforts in these areas while alien species are still localized and manageable by conventional methods.
3. The need to integrate alien plant control with feral animal control, with research on small mammals, arthropods, and ecosystem processes, with monitoring of key species, and with interpretation of biological resources to Park visitors.
4. The awareness that the most effective management of alien biota has occurred incrementally at Hawaii Volcanoes. As with feral ungulates, once alien plant populations reach maintenance levels, areas can then be expanded or new Special Ecological Areas can be managed. Special Ecological Areas can serve as models of successful management.

Control of widespread alien plants in Special Ecological Areas was started in 1985. All disruptive alien plant species controllable by chemical or mechanical means were targeted for control. Even species targeted for biological control were managed in Special Ecological Areas because the effectiveness and timeliness of biological control agents is uncertain at this time (Markin *et al.*, this volume). Considerable, and possibly irreversible, ecological damage may occur prior to effective biological control without deployment of other management strategies.

Eight Special Ecological Areas totalling 12,954 a (5,266 ha) (of approximately 172,900 a or 70,000 ha in Hawaii Volcanoes capable of supporting vegetation) are now managed. After four years of Special Ecological Areas management, populations of the eleven target plant species (Table 1) have been reduced to very low levels, seed production has been greatly reduced, and recruitment is low (Tunison and Stone, this volume). Workload requirements have dropped 73%.

Confining One Widespread Species (Fountain Grass) to the Existing Infestation

Widespread species are targeted for biological control and/or for conventional control in Special Ecological Areas. The management of one widespread species, fountain grass differs in that it also includes an attempt to confine this species to the existing infestation in the Park (Tunison, this volume). Most of the 19,760-a (8,000-ha) infestation in Hawaii Volcanoes is localized in the southwestern corner of the Park. Populations also occur along roadsides and in a few scattered outlying

populations. The management strategy for fountain grass is to control all outlying populations, scout the areas between these populations from a helicopter, and control the periphery of the main infestation. Fountain grass is also controlled in Special Ecological Areas. The fountain grass control program requires one-half the worker resources of the Special Ecological Areas management program.

The management strategy for fountain grass is an exception to the rule of controlling widespread species in Special Ecological Areas or through biocontrol for these reasons:

1. Fountain grass is capable of invading all Park plant communities, outside of closed rain forest, from sea level to 8,250 ft (2,500 m) elevation. It increases fuel loadings, thus increasing fire potential. It invades and reaches high densities on barren lava flows, which normally are pristine sites with few aliens, thus upsetting primary succession at an early stage.
2. Securing permits to import biocontrol agents is unlikely for any grass in Hawai'i (Markin *et al.*, this volume).
3. Fountain grass is mostly confined to one area of the Park and occurs at low densities. Almost all outlying populations, and those populations on the periphery of the main infestation, consist of one or two plants; average densities are two plants per 100 acres (5/100 ha).
4. Fountain grass appears to be dispersed short distances except along roads; thus, the zone of active population expansion is on the periphery of the main infestation.
5. Control of fountain grass was found to initially require approximately four to five full-time personnel equivalents per year, far beyond the means of Park management without major funding increases or reversals of long-standing priorities.

Results to date, using a strategy of confining fountain grass to existing locations, are somewhat promising. Workloads and populations are declining noticeably in portions of the control area on the periphery of the infestation managed for more than two years. There is only modest recruitment in these small populations. No long-range dispersal has been found. Control efforts will extend toward the central portion of the infestation or over its entire range in the Park as progress in control is made or additional funding becomes available.

Developing Herbicidal Control Methods for Target Species

Herbicides are needed to control most target species, because mechanical control methods are not feasible in native or semi-native communities in a park setting; because most target species resprout when cut; and because effective biocontrol agents are not available. Chemical means of control are not known for many target species in the Park or, in some cases, are known but not permitted in National Parks. Frequently, treatment methods must be developed by National Park Service researchers, who attempt to find

ecologically safe, sound, and efficient chemicals and application methods (Santos *et al.*, this volume).

Treatment methods have been developed by Park Service researchers for nine target species, with work in progress on six others. Effects on non-target plant species have also been investigated. In all but two cases, cut-stump techniques have been found to localize and minimize pesticide application; less than 9.25 gal (35 l) of herbicide were used in alien plant control and research combined in 1987.

Research on the Ecology, Seed Biology, and Phenology of Important Alien Plant Species

Understanding the biology of disruptive alien plant species is important to: 1) identify species requiring control; 2) predict the ranges and densities of invasive species; 3) identify vulnerable links in the life cycles of managed species to formulate control strategies; and 4) monitor the impacts of alien plants and control programs on park ecosystems. These objectives can be achieved by understanding features such as dispersal, factors limiting establishment, alien plant population dynamics, and interactions of alien species and native species.

One alien species, firetree, has been studied in depth in the Park (Whiteaker and Gardner 1986; Vitousek *et al.* 1987; Vitousek and Walker 1989). Researchers have studied biological factors responsible for the success of this species such as demography, growth rates, phenology, and seed biology (including dispersal and viability in the soil), and soil nutrient changes resulting from the invasion of this nitrogen-fixing species. Vitousek and other researchers are now assessing the impacts of firetree on the vegetation of invaded sites and determining what may limit its distribution in the Park. Studies of banana poka have also been conducted (see LaRosa, this volume), and research addressing limiting factors are in progress for fountain grass (R.N. Mack, pers. comm.). Population and genetic studies of strawberry guava (*Psidium cattleianum*) are in progress (Huenneke 1991; C.W. Smith, pers. comm.). Population data have been collected for a number of rain forest species while monitoring recovery of vegetation following ungulate removal, or comparing rain forest areas in setting priorities for management of alien biota. Seed viability and germination studies have been conducted on a number of alien plant species.

The biology of other alien plant species has not been as thoroughly studied as that of firetree. As a result, managers have established priorities for management and developed control strategies subjectively from distribution maps, qualitative observations, and the advice of local botanists. However, alien plant population dynamics, impacts, and even limiting factors are evident in some cases, or can be determined through monitoring control programs. Minimal research seems warranted to effectively manage target species that are localized in distribution and amenable to mechanical control. However, thorough weed ecology studies are needed for widespread disruptive species requiring a great investment of resources to manage.

Educating the Public and Organizations

Resource managers and researchers try to educate the public about alien plant problems so that they will develop an understanding of and support for alien plant control programs. Alien plant problems are a minor theme of some park interpretive programs that emphasize geological, cultural, and other biological messages. The Resources Management Division in the Park has an active volunteer program but has been able to generate little sustained interest in alien plant control activities; volunteers prefer assignments with wildlife (e.g., nēnē (*Nesochen sandwichensis*) or turtle programs) or fire (Misaki and Tunison, this volume). On the whole, it has been very difficult to interest the public in alien plant problems and the need to control alien plants. One reason is that Hawai'i Island has a mostly rural and small-town culture with little interest in conservation. A shortcoming of the alien plant control program has been the inability to find a way to make alien plant problems important to the public.

In contrast, education of conservation groups and scientists about alien plant problems has been exemplary. Alien plant problems were the theme of a three-day symposium held in Hawaii Volcanoes in 1986 (results published in this volume), and a number of papers presented at the biennial science conferences and symposia held at the Park since 1976 have addressed alien plants.

Working with Other Agencies and Organizations

Alien plants are a statewide problem in Hawai'i, not only in natural areas, but also on agricultural lands, rangelands, and watersheds. Some alien plant pests are common to all these areas. However, some species are disruptive to native ecosystems, yet beneficial on rangelands or otherwise considered desirable plants in Hawai'i. Cooperation among managers of natural areas and most State agencies is not expected for these species.

The Hawaii Department of Agriculture, the lead State agency in alien plant control, employs a small crew to manage some alien plant species using mechanical or chemical means. This agency confines most of its efforts to species affecting rangelands. The State is also the lead agency in an interagency effort to control gorse (*Ulex europaeus*) Statewide with herbicides, grazing, reforestation, and biocontrol.

Common interests have developed in biocontrol of some alien plants disruptive to rangelands or forests (e.g., banana poka, firetree, and gorse). State cooperation is needed in biocontrol research because the State determines which biocontrol agents may be imported; it does not allow importation of biocontrol agents for target alien plant species that are closely related to economically valuable species or desirable plants. On the whole, cooperation with local agencies has improved in the 1980s, particularly in biocontrol.

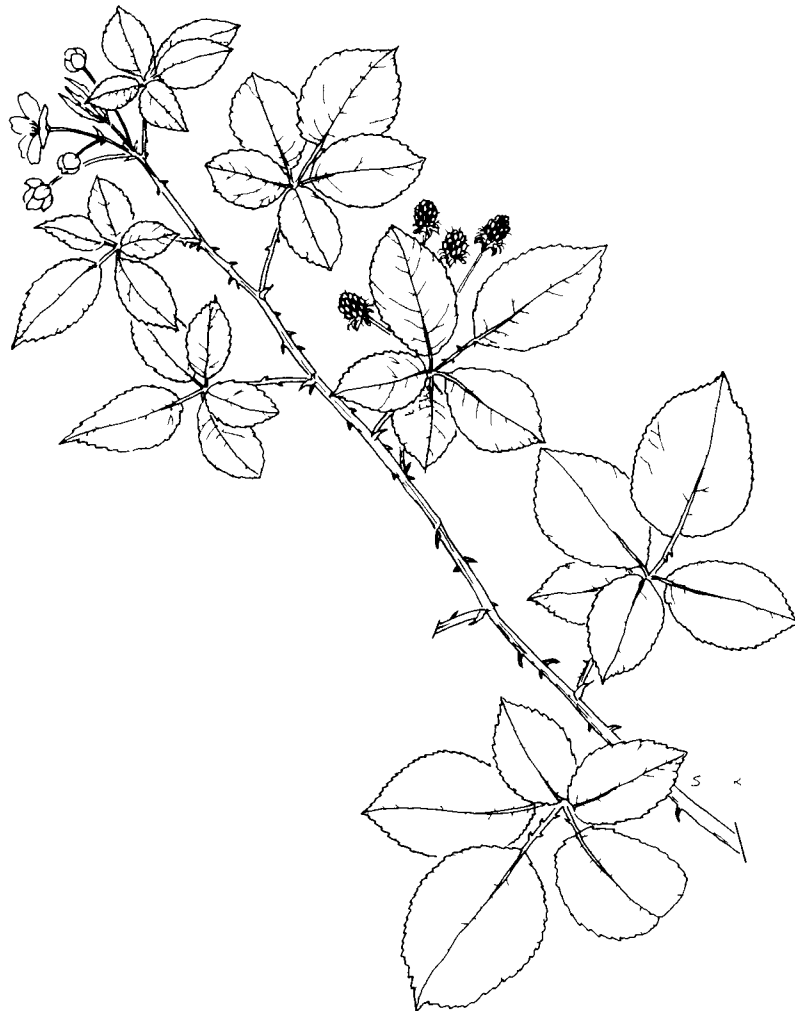
CONCLUSIONS

The long-term effectiveness of control programs at Hawaii Volcanoes National Park cannot be predicted at this time because of uncertainties

about the effectiveness of biological control, potential invasion of new alien plants, the eventual impacts of uncontrollable plant species, and the uncertainty of support for continued programs. The alien plant control program is still growing but lags behind successful ungulate control programs in funding and success. However, the short-term effectiveness of localized alien plant control and Special Ecological Areas management has given managers considerable hope where little progress had been made previously, where the best biological resources of the Park are threatened, and where alien plant populations are expanding very rapidly. Productive approaches could be expanded to larger areas of the Park with similar effectiveness, given sufficient funding.

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