

**The Hawai'i-Pacific Islands Cooperative Ecosystems Studies Unit &
Pacific Cooperative Studies Unit
UNIVERSITY OF HAWAII AT MĀNOA**

Dr. David C. Duffy, Unit Leader
Department of Botany
3190 Maile Way, St. John #408
Honolulu, Hawai'i 96822



Technical Report 187

**A review of invasive plant management in Special Ecological Areas,
Hawai'i Volcanoes National Park, 1984-2007**

March 2014

Rhonda K. Loh¹, Timothy Tunison², Chris Zimmer¹, Robert Mattos¹

and David Benitez¹

¹ NPS, Hawai'i Volcanoes National Park, Resources Management Division, PO Box 52, Hawai'i National Park, HI 96718

² PO Box 754, Volcano, HI 96785

PCSU is a cooperative program between the University of Hawai'i and U.S. National Park Service, Cooperative Ecological Studies Unit.

Organization Contact Information:

National Park Service, PO Box 52, Hawai'i National Park, HI 96718, phone: 808-985-6098, fax: 808-985-6029

Recommended Citation:

Loh, R.K., T. Tunison, C. Zimmer, R. Mattos and D. Benitez. 2014. A Review of Invasive Plant Management in Special Ecological Areas, Hawai'i Volcanoes National Park, 1984-2007. Technical Report No. 187. Pacific Cooperative Studies Unit, University of Hawai'i, Honolulu, Hawai'i. 35 pp.

Key words:

Special Ecological Areas, alien species control, Hawaiian ecosystems

Place key words:

Hawai'i, Hawai'i Volcanoes National Park, Special Ecological Areas

Editor: David C. Duffy, PCSU Unit Leader (Email: dduffy@hawaii.edu)

Series Editor: Clifford W. Morden, PCSU Deputy Director (Email: cmorden@hawaii.edu)

About this technical report series:

This technical report series began in 1973 with the formation of the Cooperative National Park Resources Studies Unit at the University of Hawai'i at Mānoa. In 2000, it continued under the Pacific Cooperative Studies Unit (PCSU). The series currently is supported by the PCSU and the Hawai'i-Pacific Islands Cooperative Ecosystem Studies Unit (HPI CESU).

The Pacific Cooperative Studies Unit at the University of Hawai'i at Mānoa works to protect cultural and natural biodiversity in the Pacific while encouraging a sustainable economy. PCSU works cooperatively with private, state and federal land management organizations, allowing them to pool and coordinate their efforts to address problems across the landscape.

The Hawaii-Pacific Islands Cooperative Ecosystem Studies Unit is a coalition of governmental agencies, non-governmental organizations and universities that promotes research, education and technical assistance to support better stewardship of imperiled natural and cultural resources within the Pacific.

The HPI CESU is one of 17 cooperative ecosystem studies units across the U.S.

Table of Contents

	<u>Page</u>
List of Tables.....	iii
List of Figures.....	iii
Abstract.....	iv
Introduction.....	1
Methods.....	2
Study Area.....	2
Alien Plant Control.....	8
Control Methods	8
Weed Control Data Collection	9
Monitoring Alien Plant Distribution and Abundance.....	10
Results.....	10
Discussion.....	17
Conclusion.....	20
Literature Cited.....	22
Appendix A. Special Ecological Areas (SEA) in Hawai'i Volcanoes National Park, 1984-2007.....	24
Appendix B. Recently Established (Post 2007) and Proposed Special Ecological Areas in Hawai'i Volcanoes National Park.....	33

List of Tables

Table 1. Special Ecological Areas (SEA) in Hawai'i Volcanoes National Park, 1984-2007...	5
Table 2. Herbicide Control Methods for Target Invasive Weeds	9

List of Figures

Figure 1. Management Strategies at Different Stages of Plant Invasion.....	1
Figure 2. Map of Special Ecological Areas, 1984 to 2007	4
Figure 3. Aerial Application of Roundup on Fountain Grass	8
Figure 4. Number of Alien Plants Treated and Worker Days Spent in Six Mid-elevation Seasonally Dry Special Ecological Areas, 1984-2007.....	11
Figure 5. Total Number of Plants Treated in 'Āinahou SEA.....	12
Figure 6. Average Number of Plants Treated in Puaulu Buffer Blocks 3, 5A & B, & 10, 1984-2006.....	13
Figure 7. Number of Alien Plants Treated and Worker Days Spent in Three Rain Forest Special Ecological Areas, 1985-2007.....	14
Figure 8. Frequency of Occurrence and Percent Cover Abundance of Himalayan Yellow Raspberry in Plots Along Transect Lines in 'Ōla'a Koa Unit.....	15
Figure 9. Average Density of Target Invasive Species in Plots Located Along Transect Lines in Weed Control Blocks, Thurston SEA.....	15
Figure 10. Number of Alien Plants Treated and Worker Days Spent in Kīpuka Puaulu Special Ecological Areas, 1985-2007.....	16
Figure 11. Area Under Management and Worker Days in Special Ecological Areas,	19
Figure 12. Area Ground Swept and Worker Days in Special Ecological Areas.....	20

Abstract

In Hawai'i Volcanoes National Park (134,852 ha), management units called Special Ecological Areas (SEAs) were established to control 20+ highly disruptive invasive plant species perceived to be too widespread for parkwide eradication to be feasible. Instead control efforts were focused on excluding target weeds from high value areas. SEAs were prioritized for intensive weed management based largely on their 1) representativeness of a particular ecological zone or rarity of vegetation type, 2) manageability, areas are accessible, relatively intact and the potential for native species recovery is high, 3) species diversity and rare species, and 4) value for research and interpretation. Also important to the SEA concept was its flexibility. So while initial weed control focused on only a handful of the best areas, the number and size of units were expanded as additional resources were made available.

Between 1984 and 1986 the first six SEAs and a buffer unit (total area >5,000 ha) were established in wet 'ōhi'a/hapu'u (*Metrosideros polymorpha/Cibotium glaucum*) forest, mesic koa (*Acacia koa*) forest, and seasonally dry 'ōhi'a communities (Tunison and Stone 1992). After initial treatment of weeds, crews revisited sites at one to five year return intervals to remove any new weeds that re-established. Over the next two decades, additional funding was made available to increase the number and size of SEAs. By 2007, 27 SEAs and buffer units covering over 26,720 ha were managed to exclude target weeds. These included several more degraded areas that connected isolated units and served as buffer areas to reduce seed dispersal of weeds into adjacent SEAs that were more intact.

Control data of 10 SEAs for which we had the longest data sets were evaluated. Typically, initial control of large numbers of weeds (knockdown phase) was followed by subsequent revisits to keep infestations at low or manageable levels (maintenance phase) in SEAs. This was accompanied by a drop in labor cost as fewer worker days were spent searching and removing individuals from a management area. At the maintenance phase, wet forest SEAs still required intensive foot sweeps to search for plants, and were the most expensive to retreat (\$385/ha in 2007). Seasonally dry 'ōhi'a communities that employed a combination of aerial and foot sweeps were the least expensive (<\$2/ ha including the cost of helicopter rental). From 1985 to 2007, control efforts in SEAs expanded from 5,045 ha to 26,687 ha, a 500% increase in area. In contrast, annual labor cost spent in the field increased only about 50% (adjusted to 2007 dollars). This translated to a three-fold decrease in labor costs per hectare (\$28.96/ ha in 1985 to \$8.61/ha in 2007) across all units. Additional cost savings were made by improving the efficiency in search and treatment methods (e.g. aerial spray rig, chemical treatment of kāhili ginger).

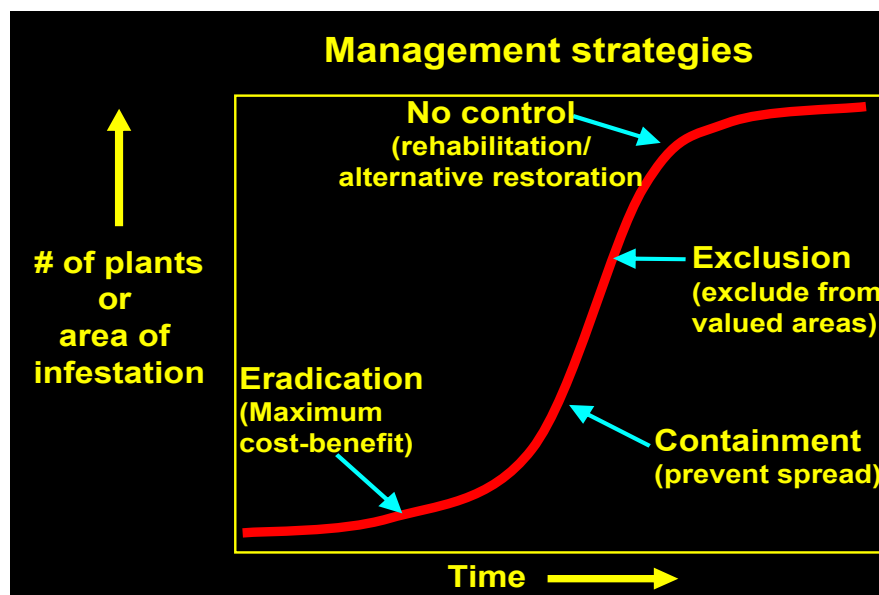
In summary, long-term maintenance of SEAs was possible when initial weed infestations could be reduced to low levels; subsequent recruitment of new alien weeds was low; and work loads dropped significantly after initial control efforts. Weaknesses of the SEA approach were that follow-up treatment was required indefinitely, weed infestations could increase in surrounding unmanaged areas and reinvasion into units could become unmanageable especially for small SEAs. In the future, managers will be challenged to secure funding to address ongoing weed maintenance; and maximize program effectiveness (e.g. optimizing intervals between follow-up treatments, applying new search and control technology). Developing effective partnerships with the community and adjacent landowners to expand management areas, creating buffer zones that will reduce seed dispersal into SEAs, and reconfiguring or abandoning small or ineffective SEAs are among some of strategies that could assist the long-term sustainability of the SEA approach.

1. Introduction

Invasive alien plants imperil native Hawaiian ecosystems by their ability to replace native species, alter vegetation structure, nutrient and hydrological cycles, and disrupt disturbance regimes (La Rosa 1984, Smith 1985, Vitousek et al. 1987, Cuddihy and Stone 1990, Hunnekke and Vitousek 1990, Stratton 1996, Vitousek et al. 1997). In Hawai'i Volcanoes National Park (134,852 ha), invasive plants are the major ecosystem modifiers in areas where large herbivores have been excluded. Among the estimated 600+ alien species in the park, there are over 100 species identified as invasive (Higashino et al. 1988, Benitez et al. 2012). These include widespread introduced grasses such as broomsedge (*Andropogon virginicus*) and meadowrice grass (*Ehrharta stipoides*) as well as other herbaceous plants (e.g. kāhili ginger (*Hedychium gardnerianum*), trees and shrubs (e.g., faya tree (*Morella faya*), strawberry guava (*Psidium cattleianum*), Himalayan yellow raspberry (*Rubus ellipticus*)) and more locally distributed species just beginning to establish or spread in the park (e.g., Australian tree fern (*Sphaeropteris cooperi*), gorse (*Ulex europaeus*) (Benitez et al. 2012).

Early efforts to stem the invasion of disruptive alien plants in the park date back to the 1920's, but were largely unsuccessful in eradicating or containing the spread of invasives (Tunison et al. 1992). In the 1980's a systematic approach to managing selected alien plants was established by park managers (Tunison 1992). Several control strategies were adopted based on the known distribution of a species: 1) eradication for species with very limited distributions, 2) containment and 3) exclusion of widespread species from high priority areas for which parkwide control was unfeasible (Figure 1). Both containment and eradication were species-based approaches to management that required periodic and expansive monitoring to follow an individual species spread across the landscape. In 2007, 58 species with limited distributions were targeted for parkwide eradication or containment (NPS 2007, Benitez et al. 2012). Because these plants were distributed across a small area they could be frequently remonitored, and control was effective in extirpating or limiting further spread of individuals. In contrast, containment and eradication of widespread species was less successful due to the large perimeter of the invasion front that needed to be continually monitored for seedling recruitment (Tunison unpublished). The resources needed to patrol the invasion front were often lacking. The one exception was fountain grass (*Cenchrus setaceus*, formerly *Pennisetum setaceum*) where considerable resources were committed to biannually searching and removing all plants parkwide (Tunison et al. 1994, Benitez et al. 2012).

Figure 1. Management Strategies at Different Stages of Plant Invasion.



Because resources were not available to control widespread invasive species across their entire extent in the park, park staff emphasized an area-based approach to management that focused on excluding multiple weeds from high priority areas. These areas would allow for the perpetuation of native-dominated plant communities, accommodate future restoration of rare species, and showcase native plant and animal habitat for interpretation by park staff to the public. Areas were prioritized for intensive weed management based on one or more of the following criteria: 1) representativeness of a particular ecological zone and/or rarity in the park or on the islands; 2) manageability, which includes the feasibility of controlling disruptive weeds, and intactness; 3) concentrations of species diversity and rare species; and 4) value for research and interpretation to the public. Consequently, focus was on native-dominated sites where invasive ungulates had been either excluded or managed to very low numbers and the potential for native species recovery was high (Tunison and Stone 1992). These intensively managed areas were called Special Ecological Areas (SEAs). The SEA approach was flexible so that while areas were prioritized and initial control was focused on only a handful of units, the number and size of units could be expanded as additional resources were made available.

Between 1984 and 1986 the first six SEAs and a seventh buffer unit that connected three SEAs were established. Together these areas covered 5,092 hectares (Figure 2) and included rain forest, mesic forest and mid-elevation seasonally dry 'ōhi'a (*Metrosideros polymorpha*) woodlands in the park. Inside each unit, ground crews systematically searched and removed as many as 11 target weed species from the area. Methods varied from manual uprooting to chemically treating individuals. In some open areas where infestations were very low helicopter searches assisted ground crews in locating and removing weeds. After initial treatment, crews would revisit sites at 1 to 5 year intervals to remove any new weeds that re-established from the soil seed bank or from seed dispersal into the area. As additional funding was made available, SEAs were expanded and new units established so that by 2007 there were 27 SEAs and buffer units covering 26,736 hectares. These expansions included montane forest and subalpine shrubland, coastal strand and dry native pioneer communities, as well as additional rain forest, mesic forest and mid-elevation seasonally dry 'ōhi'a woodlands and scrub. Also included were several more degraded areas or buffer units that were selected for weed management to provide connectivity among SEAs, reduce seed dispersal, and create a buffer around more intact SEAs.

Analysis of the first four years of control work (1985 to 1988) in six SEAs led to the conclusion that 1) populations of alien plants controlled in SEAs could be significantly reduced and maintained at very low levels after 3 to 4 years of control work; 2) recruitment of alien plant species was usually very low; 3) continued follow-up was required in all areas and would be needed indefinitely; and 4) workloads dropped significantly after initial control efforts (Tunison and Stone 1992). This report re-examines these initial conclusions using long-term data sets from an expanded set of SEAs and provides an analysis of the effectiveness and cost of control efforts.

2. Methods

2.1 Study Area

Between 1984 and 1989, the first nine control units encompassing over 5,800 ha were established in rain forest (Small Tract, Thurston), mesic forest (Kīpuka Puauulu), and seasonally dry woodland and scrub (Ke'āmoku, Keanakāko'i, Kīpuka Kahali'i, Puauulu Buffer, 'Āinahou North and South). Additional units were added in subsequent years as funding became available (Table 1). For some units, control work for a few target weeds had already begun before the SEA was formally established. These included areas where incipient infestations of localized species had occurred, along with parkwide containment of fountain grass and several attempts to remove faya tree from the Kīlauea summit area (Tunison et al 1992b, 1994, Tunison unpublished). A description of each SEA and buffer unit is provided in Appendix A. One unit was abandoned ('Āinahou South) and two units were eventually reduced to smaller areas (Puauulu Buffer block 5, Keanakāko'i west block) to make

them more manageable. By 2007, 27 control units were established that encompassed 26,736 ha. These included several more degraded areas or buffer units (e.g. Ka'ū, Puauulu Buffer) that were selected for weed management to provide connectivity among SEAs, reduce seed dispersal and create a buffer around more intact SEAs. No SEAs were established in the Kahuku unit (not shown in Figure 2). Kahuku was acquired by the NPS in 2003 and contains large numbers of introduced mouflon sheep (*Ovis gmelini musimon*), sheep (*Ovis aries*) and pigs (*Sus scrofa*) for which control measures are still being implemented.

Park boundary fences exclude feral goats (*Capra hircus*), cattle (*Bos taurus*) and wild mouflon sheep from sea level to ~2,700 m elevation in the Kīlauea and Mauna Loa Strip units of the park. Additional boundary and internal fencing exclude feral pigs from upper elevation units (>1,000 m elevation), and portions of rain forest in 'Ōla'a. Low densities of feral pigs remain in seasonally dry mid-elevation and dry lowland areas below 1,000 m elevation that include several SEAs (e.g., Hilina Pali, Kīpuka Kahali'i, 'Āinahou, 'Āpua, Hōlei, Ka'ū, Kahue, Kūkalau'ula).

The SEAs are spread across several ecological zones that vary by rainfall and elevation (coastal lowland dry grassland and shrubland, 50 to 150 cm/year, < 500 m elevation; mid-elevation seasonally dry woodland and scrub (also known as submontane seasonal), 50 to 150 cm/year 500 to 1,200 m elevation; montane rain forest, 220 to 350 cm/year, 1,000 to 1,500 m elevation; lowland rain forest, 220 to 350 cm/year, 700 to 1,000 m elevation; montane mesic forest, 150 to 220 cm/year, 1,200 to 2,000 m elevation; montane seasonal shrubland and forest, 100 to 150 cm/year; 1,200 to 2,000 m elevation; subalpine shrubland, 75 to 100 cm/year, 2,000 to 2,500 m elevation; alpine, 50 to 70 cm/year, > 2,500 m elevation). Some SEAs may include several vegetation types (e.g., Mauna Loa Upper SEA contains native shrubland, grassland and koa forest). Soils are derived from lava substrates and are typically young and poorly developed with the exception of some mesic (Kīpuka Puauulu and Kīpuka Kī) and rain forest ('Ōla'a Koa, Pu'u and Small Tract) SEAs on Mauna Loa flows.

Figure 2. Map of Special Ecological Areas (SEA) and Buffer Units, Hawai'i Volcanoes National Park, 1985-2007. See Table 1 for SEA and Buffer Units identified by numbers on this map.

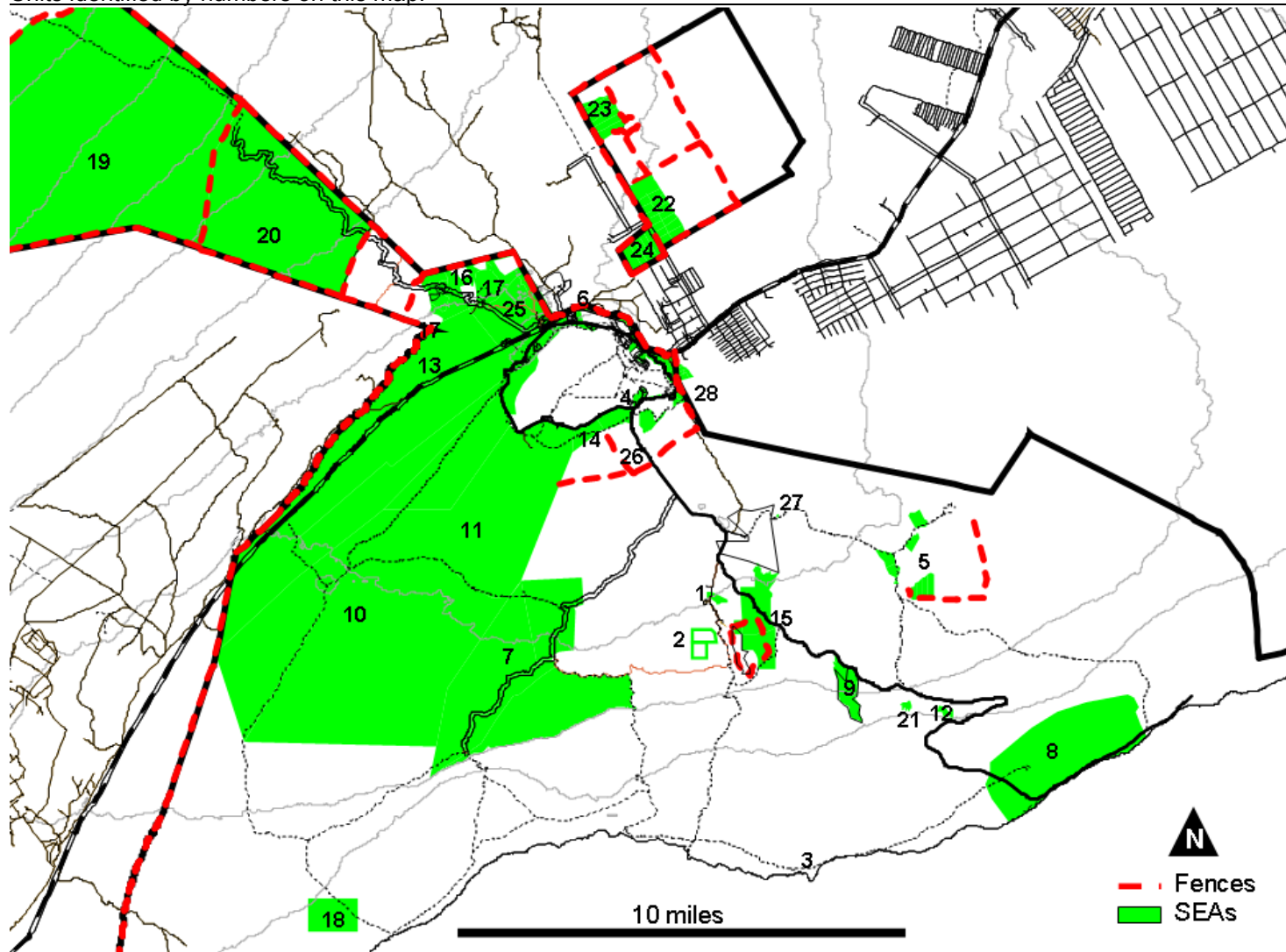


Table 1. Special Ecological Areas (SEA) and Buffer Units in Hawai'i Volcanoes National Park, 1984-2007. See Appendix A for more information on each SEA. * Acreage shown is from 2007. For some SEAs where only a portion is searched for weeds the treatment area and total size of the unit is provided.

SEA or Buffer Unit	Map Number	Year Established	Area (ha)*	Ecological Zone	Plant Community/ Vegetation Type	Selection Criteria	Primary Alien Plant Threats
'Āinahou North	1	1985	19	mid-elevation seasonal	'ōhi'a (<i>Metrosideros polymorpha</i>) woodland	representativeness, rare species, plant species richness	faya tree (<i>Morella faya</i>), olive (<i>Olea europaea</i> ssp. <i>cuspidata</i>), strawberry guava (<i>Psidium cattleianum</i>)
'Āinahou South	2	1985- (abandoned in 1994)	25	mid-elevation seasonal	'ōhi'a woodland	representativeness, rare species, plant species richness	faya tree, olive, strawberry guava
'Āpua Point	3	2000	66	coastal lowland dry	coastal strand	intactness, rare species, uniqueness in park,	Maunaloa (<i>Canavalia cathartica</i>)
Byron's Ledge Buffer	4	2006	43	montane rain forest	'ōhi'a/hāpu'u rain forest	interpretation, buffer area to reduce weed dispersal into nearby SEAs	kāhili ginger (<i>Hedychium gardnerianum</i>), strawberry guava, faya tree, yellow Himalayan raspberry (<i>Rubus ellipticus</i> ssp. <i>obcordatus</i>), palm grass (<i>Setaria palmifolia</i>), prickly Florida blackberry (<i>Rubus argutus</i>), Australian tree fern (<i>Sphaeropteris cooperi</i>)
East Rift	5	1998	170/ 1113	lowland rain forest	'ōhi'a/hāpu'u rain forest	representativeness, intactness, rare species	strawberry guava, faya tree, Himalayan raspberry, cane tibouchina (<i>Tibouchina herbacea</i>)
Highway 11 Buffer	6	1998	20	montane rain forest	'ōhi'a/uluhe rain forest	buffer area to reduce weed dispersal into adjacent SEAs	strawberry guava, faya tree
Hilina Pali	7	1989	1,590	mid-elevation seasonal	'ōhi'a woodland and scrub	representativeness, manageability, rare species, potential for interpretation	faya tree
Hōlei	8	2000	1,234	coastal lowland dry	pili grasslands/savanna	representativeness, intactness, interpretation, manageability, rarity in state	African thatching grass (<i>Hyparrhenia rufa</i>), fountain grass (<i>Cenchrus setaceus</i>)

Table 1 (cont'd). Special Ecological Areas (SEA) and Buffer Units in Hawai'i Volcanoes National Park, 1984-2007.

Kahue South	9	2000	117	mid-elevation seasonal	'ōhi'a woodland and scrub	representativeness, rare species	faya tree
Kamakai'a	10	2000	3,743	mid-elevation seasonal	'ōhi'a scrub, lava flows	representativeness, intactness, manageability, buffer area to reduce weed dispersal into adjacent SEAs	faya tree, fountain grass, silk oak (<i>Grevillea robusta</i>)
Ka'ū Buffer	11	2000	3,392	mid-elevation seasonal	native shrub/lava flows	representativeness, Intactness, buffer area to reduce weed dispersal into adjacent SEAs	faya tree, fountain grass, silk oak
Kealakomo	12	2000	10	coastal lowland dry	lama forest, lava flows	rare species, uniqueness in park, potential for interpretation	Lantana (<i>Lantana camara</i>), Christmasberry (<i>Schinus terebinthifolius</i>)
Ke'āmoku	13	1985	4,246	mid-elevation seasonal	'ōhi'a scrub, lava flows	representativeness, intactness, potential for interpretation	faya tree, silk oak, fountain grass
Keanakāko'i	14	1988	128	mid-elevation seasonal	'ōhi'a forest and woodland	intactness, manageability, representativeness, rare species, potential for interpretation	faya tree, strawberry guava, Himalayan raspberry, prickly Florida blackberry, kāhili ginger
Kīpuka Kahali'i	15	1986	368	mid-elevation seasonal	'ōhi'a woodland, lava flows	representativeness, intactness, manageability, rare species	faya tree, olive
Kīpuka Kī	16	1991	17/92	montane mesic forest	koa-mānele-'ōhi'a forest	uniqueness, rare species, potential for interpretation, rarity in state	kāhili ginger, strawberry guava, nasturtium (<i>Tropaeolum majus</i>), Jerusalem cherry (<i>Solanum pseudocapsicum</i>), prickly Florida blackberry, <i>Prunus persica</i>
Kīpuka Puaulu	17	1984	46/93	montane mesic forest	koa-mānele-'ōhi'a forest	uniqueness, rare species, potential for interpretation, rarity in state	kāhili ginger, strawberry guava, nasturtium, Jerusalem cherry, prickly Florida blackberry
Kūkalau'ula	18	2000	202	coastal lowland dry	alien grass savanna	rare species	fountain grass

Table 1 (cont'd). Special Ecological Areas (SEA) and Buffer Units in Hawai'i Volcanoes National Park, 1984-2007.

Mauna Loa Subalpine	19	1995	7,303	subalpine seasonal	native scrub, lava flows	representativeness, intactness, rare species	mullein (<i>Verbascum thapsus</i>)
Mauna Loa Upper	20	2000	2,281	montane seasonal	native shrubland, <i>Deschampsia</i> grasslands, koa forest, lava flows	representativeness, intactness, rare species	mullein, pink knotweed (<i>Persicaria capitata</i>), banana poka (<i>Passiflora tarminiana</i>)
Nāulu	21	2000	16	coastal lowland dry	lama forest, lava flows	rare species, species richness, uniqueness in park	lantana, Christmasberry
'Ōla'a Koa	22	1990	215/771	montane rain forest	'ōhi'a/ hāpu'u rain forest	representativeness, intactness, rare species	kāhili ginger, strawberry guava, banana poka, yellow Himalayan raspberry, Andean raspberry (<i>Rubus glaucus</i>), palm grass
'Ōla'a Pu'u	23	1997	155/245	montane rain forest	'ōhi'a/ hāpu'u rain forest	representativeness, intactness, rare species	kāhili ginger, strawberry guava, banana poka, yellow Himalayan raspberry, palm grass
'Ōla'a Small tract	24	1985	144	montane rain forest	'ōhi'a/ hāpu'u rain forest	representativeness, intactness, rare species	kāhili ginger, strawberry guava, banana poka, yellow Himalayan raspberry, prickly Florida blackberry, faya tree, palm grass
Puauulu Buffer	25	1985	841/934	mid-elevation seasonal	'ōhi'a woodland, koa forest, lava flows ¹²	buffer area to reduce weed dispersal into adjacent SEAs	faya tree, prickly Florida blackberry, firethorn (<i>Pyracantha</i> spp.), common guava (<i>Psidium guajava</i>)
Puhimau Hotspots	26	1995	10	mid-elevation seasonal	hydrothermal	uniqueness, rare species	none
Pu'u Huluhulu	27	2000	1	montane rain forest	'ōhi'a/ hāpu'u rain forest	representativeness, interpretation	faya tree, kāhili ginger, strawberry guava, yellow Himalayan raspberry
Thurston	28	1985	263	montane rain forest	'ōhi'a/ hāpu'u rain forest	representativeness, potential for interpretation	kāhili ginger, strawberry guava, faya tree, yellow Himalayan raspberry, palm grass

2.2 Alien Plant Control

2.2.1. Control Methods

Invasive species targeted for control varied by ecosystem type. A list of the primary target species is provided in Tables 1 and 2. As many as eleven weed species were targeted for eradication from a unit. Searches for target weeds were conducted on the ground (ground sweep) or by helicopter (helicopter sweep). For forest and thickly-vegetated units, workers were spaced 5 m to 10 m apart and walked parallel to each other searching and treating weeds until the entire unit was searched. In more open vegetation (e.g., grasslands, sparse woodlands and shrublands) and where visibility was greater at longer distances, workers were spaced 10 m to 25 m apart. For rain forest units and large units, areas were subdivided into smaller weed control blocks to make them more manageable for ground crews to navigate. Ground crews were composed of a combination of park staff, cooperators from the University of Hawai'i, and volunteers. Sanitation of boots and gear using boot brushes was not typically required unless individuals had previously worked outside the park or in an area from where new weed species could potentially be introduced into a unit. Work was primarily conducted during sunny or partly cloudy days. If sites were rainy, work was rescheduled. Beginning in Fall 2003, park control was assisted by a ground crew stationed in the park and funded by the Denver-based NPS Pacific Island Exotic Plant Management Team (PIEPM T).

A low-flying helicopter was used to search for individuals and isolated infestations across large expanses of open habitat that included sparsely vegetated lava flows. Surveys were conducted at between 50 m and 100 m altitude above ground level (AGL). Maximum distance for detectability of target plants (primarily invasive faya tree, silk oak and faya) was between 50 to 150 m, with greatest detectability on lava flows that had little to no vegetation. Locations of plants were recorded by GPS, and ground crews were directed to the area to treat plants. Beginning in 2004, a spray rig was developed that could selectively deliver herbicide onto target plants from the air via remote control. This proved to be an effective method for treating isolated populations, while minimizing non-target effects, in remote or difficult-to-access areas (Figures 3).

Figure 3. Aerial application of Roundup on fountain grass (photo taken outside an SEA).



Plants were killed by manually removing or chemically treating individuals. Seedlings were typically uprooted. Larger individuals were treated with herbicide using the lowest effective dosage for a >90% kill rate (Table 2). After initial search and control of weeds in a unit, work crews revisited sites at 1 to 5 year intervals to remove any new weeds that re-established from the soil seed bank or from seed dispersal into the area, or plants that survived initial treatment.

Table 2. Herbicide Control Methods for Target Invasive Weeds.

Common Name	Scientific Name	Herbicide Control Method
Fountain grass	<i>Cenchrus setaceus</i>	15% Velpar, 5% Roundup Foliar, or 2% Arsenal
Silk oak	<i>Grevillea robusta</i>	15% Garlon 4/Diesel Basal Bark
Kāhili ginger	<i>Hedychium gardnerianum</i>	1g/l Escort
African thatching grass	<i>Hyparrhenia rufa</i>	1% Roundup Foliar
Lantana	<i>Lantana camara</i>	10% Garlon 3A Cut Stump
Faya tree	<i>Morella faya</i>	10% Garlon 3A Cut Stump, 50 % Garlon 3A Frill
Olive	<i>Olea europaea ssp. cuspidata</i>	10% Garlon 3A Cut Stump
Banana poka	<i>Passiflora tarminiana</i>	10% Garlon 3A Cut Stump
Pink Knotweed	<i>Persicaria capitata</i>	2-5% Garlon 4 Foliar
Prunus (Peach and flowering cherry)	<i>Prunus persica, P. serrulata</i>	10% Garlon 3A Cut Stump
Strawberry guava	<i>Psidium cattleianum</i>	10% Garlon 3A Cut Stump
Common guava	<i>Psidium guajava</i>	10% Garlon 3A Cut Stump
Firethorn	<i>Pyracantha angustifolia, P. crenatoserrata</i>	2% Garlon 4 Foliar
Prickly Florida blackberry	<i>Rubus argutus</i>	0.5% Garlon 3A Foliar
Himalayan yellow raspberry	<i>Rubus ellipticus spp. obcordatus</i>	10% Garlon 3A Cut Stump
Andean raspberry	<i>Rubus glaucus</i>	10% Garlon 3A Cut Stump
Christmasberry	<i>Schinus terebinthifolius</i>	5-15% Garlon 4/Diesel Basal Bark
Palm grass	<i>Setaria palmifolia</i>	1% Roundup Foliar
Jerusalem cherry	<i>Solanum pseudocapsicum</i>	1% Garlon 4 Foliar
Cane tibouchina	<i>Tibouchina herbacea</i>	10% Garlon 3A Foliar
Mullein	<i>Verbascum thapsus</i>	1% Roundup Foliar

2.2.2 Weed Control Data

For each SEA, number of worker days spent in the field searching and treating invasive plants, number of plants treated (uprooted or chemically treated), and herbicide applied were recorded for each treatment cycle. The time taken to complete a treatment cycle varied typically between 1 day to two years depending on the size of the unit or weed control block and availability of work crews. Time spent in the field did not include travel time for remote SEAs that required overnight camping. Seedlings, resprouts, and mature plants were qualitatively noted. Data were reported by work crews to their field supervisor in the field, who recorded the data in a field notebook and subsequently transferred the information onto data sheets in the office. Labor costs (\$ cost per hectare) spent in the field were used as a way of measuring cost effectiveness and were based on the average cost for one individual working an 8 hour work shift (salary + benefits = \$200/day in 2007) adjusted to 2007 dollars. Costs for the individual were calculated the same regardless of whether the person was NPS staff, (supervisor or worker), a University of Hawai'i cooperator or volunteer. Information on the cost of supplies and equipment (herbicide, protective equipment, spray applicators, vehicles), and indirect costs (e.g. administrative support, training)

was difficult to determine since these costs were often shared across several projects (e.g. weeding, fencing, animal control and native plant restoration) and over multiple years. Data used for analysis were collected between 1984 and 2007. Control work for a few target weeds begun before SEAs were established was not included. This included areas where incipient infestations of localized species had occurred, along with parkwide containment of fountain grass (Kā'u buffer and Kamakai'a SEA), and several failed attempts to remove faya tree from the Kīlauea summit area (Tunison et al 1992, 1994).

2.3 Monitoring Alien Plant Distribution and Abundance

In addition to weed control data, recurring monitoring of weed abundance along transects was conducted in three rain forests (Thurston, 'Ōla'a Small Tract, 'Ōla'a Koa) and one mesic forest (Kīpuka Puauulu) SEA. The total length of the transects varied according to the size of the unit (e.g., 1,000 to 1,200 m for Small Tract, 1,000 m for Koa unit, 200 to 1,050 m for Thurston, 250 to 700 m for Kīpuka Puauulu). In rain forest units, transects were subdivided into 50 x 5 m plots centered on the transect line. In Kīpuka Puauulu, 25 x 5 m plots were established along each transect. Within each plot, the target species presence and percent cover abundance (Kīpuka Puauulu, 'Ōla'a Small Tract, 'Ōla'a Koa) or number of plants (Thurston) were recorded. Cover abundance was recorded in the following classes (+ = 0-1%, 1 = 1.1 to 5%, 2 = 5.1 to 25%, 3 = 25.1 to 50%, 4 = 50.1 to 75%, 5 = 75.1 to 95%, 6 = 95.1 to 100%). Monitoring data were collected between 1986 and 2009.

To obtain independent samples for statistical analysis, a randomized subset of plots (n = 25 for rain forest; n = 40 for mesic forest) from the pooled set of transects for each SEA were analyzed. Changes over time in species presence in plots along transects were analyzed using a chi-square test. Changes over time in species abundance (cover or density) were analyzed using a paired t-test on log-transformed data. Datasets collected from the first (prior to weed control) and last (following at least two cycles of weed control) monitoring period were used for the analysis ('Ōla'a Small Tract 1990 and 2001, 'Ōla'a Koa 1998 and 2008, and Kīpuka Puauulu 1985 and 1997). No statistical analysis was performed on Thurston datasets due to changes in sample plot shape from circular (5 m radius) to rectangular (5 m x 10 m) over the course of the monitoring period. Instead, changes in species density per hectare from 1985 to 2003 were presented qualitatively in graphs.

3. Results

Weed control data of ten SEAs for which we had the longest data sets were evaluated and presented here. These included units for which we had data for at least three treatment intervals, and nine years of data. Six SEAs were located in the mid-elevation seasonally dry 'ōhi'a woodland and scrub communities on Kīlauea (Puauulu Buffer, Ke'āmoku, 'Āinahou North, Kīpuka Kahali'i, Keanakāko'i and Hilina Pali), three in montane rain forest on Kīlauea and in 'Ōla'a (Thurston, 'Ōla'a-Small Tract, and 'Ōla'a-Koa), and one mesic forest unit on Mauna Loa (Kīpuka Puauulu).

3.1 Weed Control

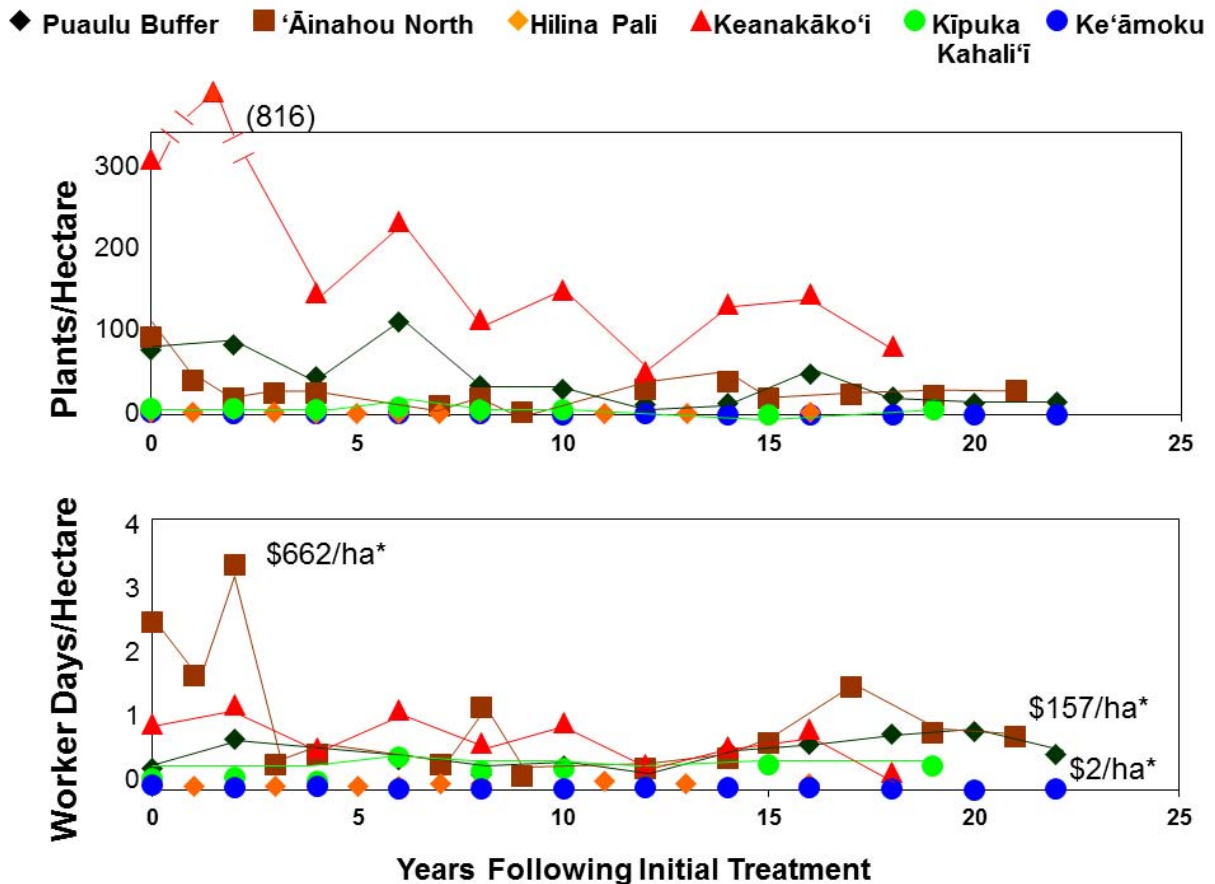
3.1.1 Mid-elevation Seasonally Dry 'Ōhi'a Communities

By 2007, there were a total of nine SEA and buffer units established in mid-elevation seasonally dry woodland and scrub communities. Nine of these were intensively managed to remove faya tree, silk oak (*Grevillea robusta*), olive (*Olea europaea*) and other target invasive species (14,329 ha). Puhimau unit (10 ha) was established as an SEA because of its unique location in a geothermal hotspot and critical habitat for the largest known population of the federally endangered 'ihi mākole (*Portulaca sclerocarpa*). However, no invasive plant species has been targeted for control in this area and only monitoring has occurred. A tenth SEA, 'Āinahou South (38 ha), established in 1985, was subsequently dropped from weed management in 1994 due to the unit being overrun by introduced molasses grass (*Melinis minutiflora*) that spread from the surrounding areas and made it difficult for work crews to navigate in the field.

Treatment data from management blocks for six SEA units with the longest datasets are presented in Figure 4. Because weed control management began in different years (Puauulu Buffer-1984, Ke'āmoku-1985, 'Āinahou North-1985, Kīpuka Kahali'i-1986, Keanakāko'i-1988 and Hilina Pali-1989), the x-axis depicts treatment data in all SEAs beginning with the initial year of control identified as year 0 and work done in subsequent years as year 1, 2, and 3 following initial treatment. Faya tree was the dominant invasive plant found in these units. Scattered individuals of olive, strawberry guava, common guava (*Psidium guajava*) and prickly Florida blackberry (*Rubus argutus*) were found in several units.

Based on the total number of individuals found at each treatment interval, there were two phases of control: 1) an initial knock down phase where the number of weeds was relatively high within a control unit, and a 2) maintenance phase- where crews were managing for low levels of weed infestations. How rapidly the maintenance phase was reached depended partly on the frequency of revisits to an area. For example, the number of target weeds significantly dropped by the third year in 'Āinahou SEA which was typically revisited at yearly intervals. In contrast, it took about eight years for infestations to reach maintenance levels in Puauulu Buffer and Keanakāko'i (2-3 year treatment intervals). For some SEAs where initial levels of infestations were already very low (e.g., less than 1 individual per hectare or concentrated in only a few sites), there was no apparent knockdown phase, and management began at the maintenance phase (e.g., Hilina Pali, Ke'āmoku, Kīpuka Kahali'i).

Figure 4. Number of Alien Plants Treated and Worker Days Spent in Six Mid-elevation Seasonally Dry Special Ecological Areas, 1984-2007. \$/ha refer to labor costs in the field.



*Labor cost was calculated based on time spent in the field in 2007 dollars. Does not include time spent transporting individuals to remote locations or indirect costs (administrative support, training, paid holidays, annual and sick leave). Costs per individual were calculated the same regardless of whether the person was NPS staff, (supervisor or worker), a University of Hawai'i cooperator or volunteer.

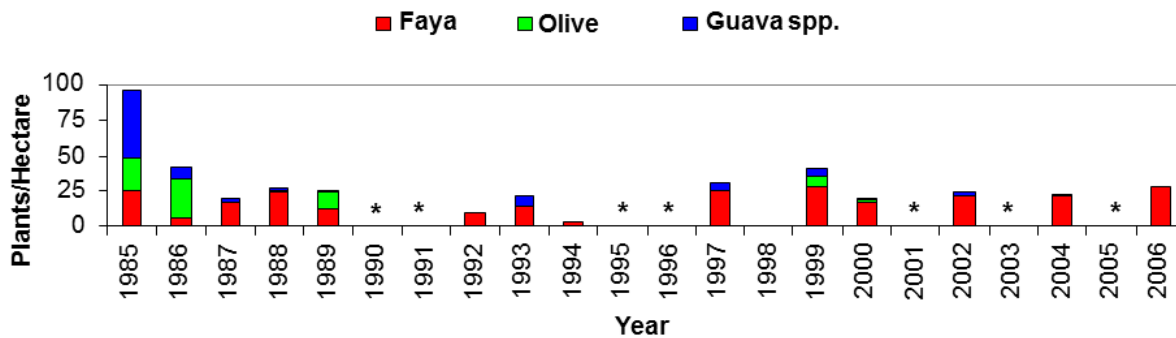
The level of weed infestation at the maintenance phase varied among the units from less than one individual per hectare (e.g., Hilina Pali, Ke‘āmoku, Kamakai‘a (data not shown)) to <15 individuals per hectare for Puaulu Buffer; and were much higher for units that were very small such as ‘Āinahou (19 ha, 25 average number of individuals per hectare for the last three treatment intervals) or were surrounded by heavily invaded forest, as was the case for Keanakāko‘i (124 average number of individuals per hectare for the last three treatment intervals).

In addition to reduced infestation levels at the maintenance phase, the size of invasive plants found in the units was typically smaller. For example, faya discovered were mostly seedlings or saplings that were easily uprooted. This made treatment much less arduous (no chainsaw work) and allowed for greater volunteer participation in control work. Volunteers were used to search more accessible and easily navigable units (e.g. Kīpuka Kahali‘i, ‘Āinahou North, Hilina Pali, Puaulu Buffer). Although some cost savings might be assumed (cost saving could not be calculated from the data), the ability and skill level of volunteers could vary quite a bit which would result in additional training and supervision by NPS staff, and sometimes more time required in the field to search for weeds in an area.

Some differences in intensity or thoroughness of effort by work crews across treatments may have explained some of the variation in the number of plants treated and labor spent in the field. For example, volunteers or new personnel less familiar with the area would be more likely to miss a target plant than a more experienced worker, or the former would be spaced more tightly together when conducting ground sweeps thereby increasing the time required in the field. Also, seasonal fluctuations in rainfall could have contributed to different amounts of invasive species recruitment within units.

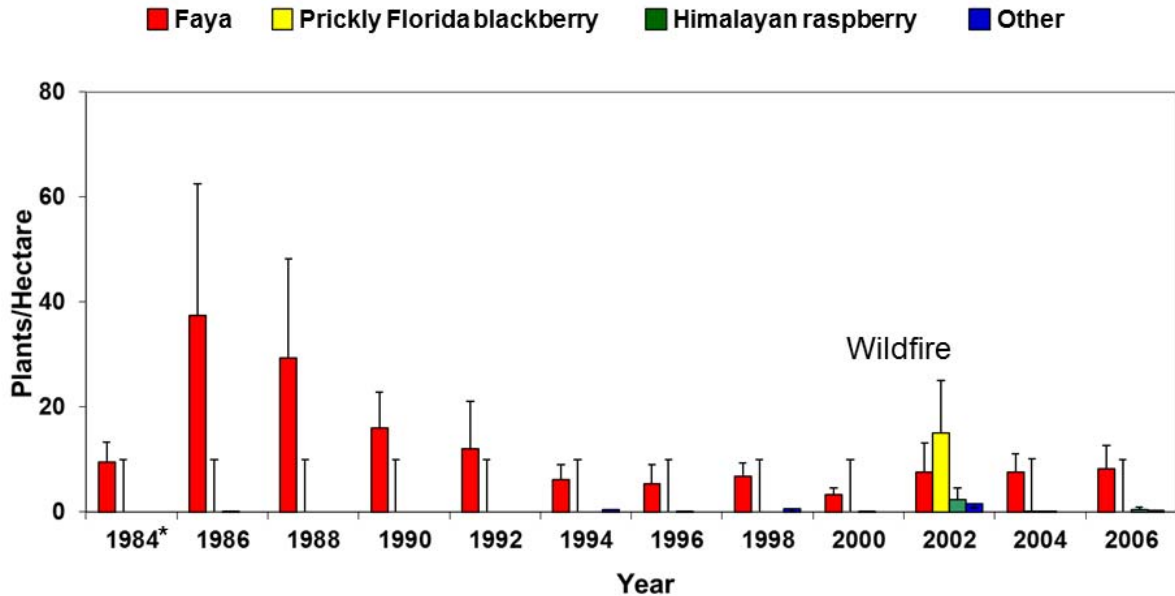
While faya was the primary target species in seasonally dry ‘ōhi‘a communities, olive, strawberry guava, common guava and blackberry were also routinely treated in several of the units. Typically their abundance was much lower than for faya (e.g. 10 to 100 fold lower) and numbers were reduced after several cycles of treatment (e.g., ‘Āinahou North, Figure 5). An exception occurred in several management blocks (3, 5A, 5B, 10) of Puaulu Buffer SEA, when a rapid invasion of prickly Florida blackberry and Himalayan raspberry occurred after a large wildfire swept through the area in the summer of 2000 (Figure 6). Plants were subsequently treated, and infestation levels returned to preburn levels.

Figure 5. Total Number of Plants Treated Yearly in ‘Āinahou North SEA, 1985-2006.



* denotes years where no control measures were conducted.

Figure 6. Average Number of Plants Treated in Puauulu Buffer Blocks 3, 5A & B, & 10, 1984-2006.



*initial treatment of weeds in units began in 1984 but was not completed throughout units until 1986.

As SEAs moved from knockdown to maintenance levels, the amount of worker days spent in the units dropped. Labor costs in the field fell from a high of \$662 (‘Āinahou North) to between \$70 and \$157 per hectare (adjusted to 2007 dollars) for units that were entirely swept on the ground at two- to four-year intervals (e.g. Kīpuka Kahali‘i, ‘Āinahou North, Keanakāko‘i, Puauulu Buffer). The use of a helicopter to aerially search and treat scattered individuals in open habitats further reduced costs to about \$2 per hectare (includes labor + helicopter time @ \$800/hr) for two units that relied on a combination of aerial and ground searches (Ke‘āmoku and Hilina Pali), and to <\$1 per hectare for units that relied almost entirely on aerial techniques to search and treat invasive plants (Ka‘ū, Kamakai‘a). In these units invasive weeds stood out conspicuously across the large expanses of lava, and could be detected from as far as 150 m from the helicopter with a typical above ground elevation (AGL) of 150 ft.

3.1.2 ‘Ōhi‘a Rain Forest

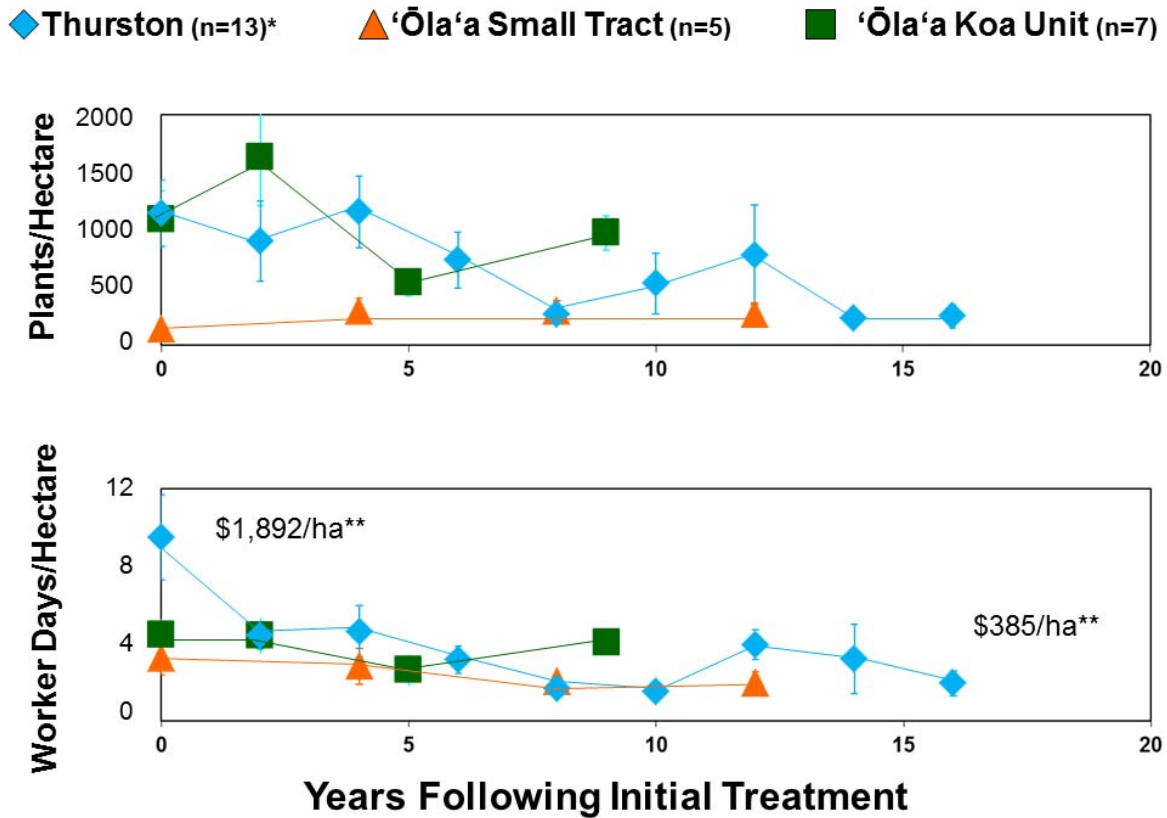
By 2007, there were eight units (1,008 ha) established in rain forest. Data for three SEAs (Thurston, ‘Ōla‘a Small Tract and ‘Ōla‘a Koa) with the longest datasets were presented below (Figure 7). SEAs were subdivided into several weed control blocks, and the number of plants treated and worker days spent locating/treating plants per hectare were presented as averages across weed control blocks. Because weed management for each SEA began in different years (Thurston-1985 to 1990, ‘Ōla‘a Small Tract-1985-1993, ‘Ōla‘a Koa-1998-1999), the x-axis depicted treatment data in all SEA blocks beginning with the initial year of control identified as year 0 and work done in subsequent years as year 1, 2, 3 (etc.) following initial treatment. Weeds targeted for control included banana poka (*Passiflora tarminiana*), Himalayan yellow raspberry, kāhili ginger, faya tree, strawberry guava and several other disruptive species (Table 1).

Similar to the mid-elevation seasonally dry SEAs, weed management in Thurston rain forest unit showed a similar transition from knockdown to maintenance phase following several treatment cycles (Figure 7). For ‘Ōla‘a Small Tract SEA, weed infestations were initially low and remained low or at maintenance levels. For both rain forest units, the average infestation level was ~250 individuals per hectare at the maintenance phase or <1% crown cover abundance. Across four treatment cycles, infestation levels remained relatively high for ‘Ōla‘a Koa unit (973 individuals per hectare). Intervals

between treatments varied from two years (Thurston SEA) to four or five years (‘Ōla’a Koa and Small Tract SEAs). More frequent treatment intervals may be needed to reduce plant numbers in ‘Ōla’a Koa unit to levels similar to Small Tract and Thurston SEAs.

As rain forest units moved from knockdown to maintenance levels, the amount of worker days or labor costs in the field fell almost five-fold in Thurston SEA from an average of \$1,892 to \$385 per hectare (adjusted to 2007 dollars). For ‘Ōla’a Small Tract SEA, weed infestations began at maintenance levels and costs dropped modestly from an average high of \$645 to \$391 per hectare (adjusted to 2007 dollars) largely due to plants being smaller and easier to kill during subsequent treatments. The average number of plants treated remained relatively high in ‘Ōla’a Koa SEA, and this is reflected in the high average labor costs at last treatment (\$810 per hectare adjusted to 2007 dollars). Beginning in 1989, control of k̄hili ginger was switched from a manual method that required work crews to uproot and haul out rhizomes to a foliar application of Escort. This change to a more efficient technique likely contributed to reduced labor costs in some of the weed control blocks that contained significant infestations of k̄hili ginger in Thurston SEA.

Figure 7. Average Number of Alien Plants Treated and Worker Days Spent in Weed Control Blocks (n) in Three Rain Forest Special Ecological Areas, 1985-2007.



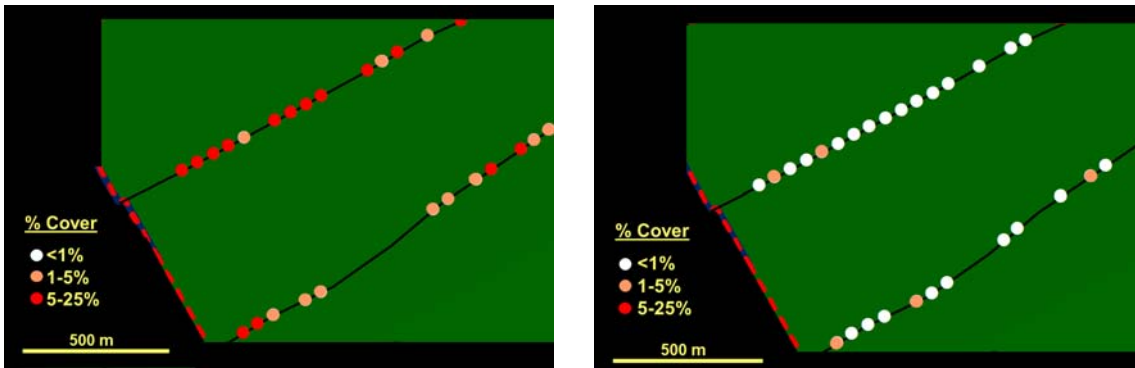
* n refers to the number of weed control blocks analyzed in each SEA unit.

** Labor cost was calculated based on time spent in the field in 2007 dollars. Does not include time spent transporting individuals to remote locations or indirect costs (administrative support, training, paid holidays, annual and sick leave). Costs per individual were calculated the same regardless of whether the person was NPS staff, (supervisor or worker), a University of Hawai'i cooperater or volunteer.

In 'Ōla'a Koa unit, monitoring plots along transect lines that spanned management blocks provided an additional measure of the effectiveness of control efforts in rain forest units (Figure 8). By

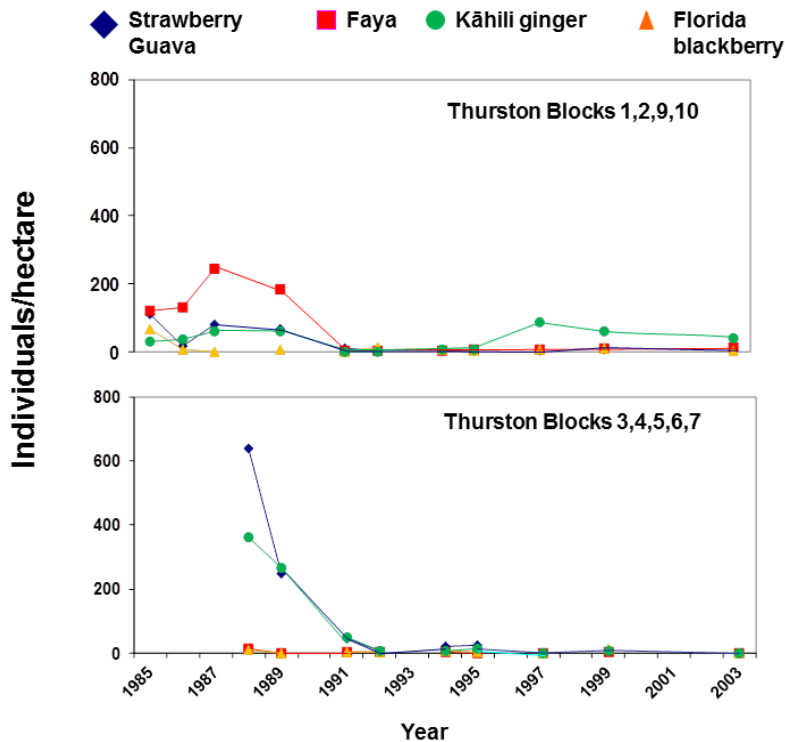
2008, weed species cover abundance was typically <1 % crown cover. This was a significant drop in cover abundance for kāhili ginger ($p = 0.006$) and for Himalayan yellow raspberry ($p = 0.002$). The frequency of occurrence of plants found in plots along the transect lines also dropped for kāhili ginger (48% to 24% of plots, chi square = 0.077); but did not significantly change for Himalayan raspberry (56% to 76%, chi square = 0.145), and increased for banana poka (16% to 64% of plots, chi square = 0.003).

Figure 8. Frequency of Occurrence and Percent Cover Abundance of Himalayan Yellow Raspberry in Plots Along Transect Lines in ‘Ōla’a Koa Unit, 1998 (left) and 2008 (right). Circles represent occupancy at the following percent cover abundances: white=<1%, pink=1-5%, red= 5-25%.



In ‘Ōla’a Small Tract SEA where initial levels of weed infestations were low, there were no significant changes in frequency of occurrence or percent cover abundance for most species following control. Numbers remained at <1% cover abundance. The exception was prickly Florida blackberry, which appeared to be spreading, becoming more frequent in transect plots (8% to 24% of plots, chi square = 0.013) but still remained at low cover abundance (<1 % crown cover).

Figure 9. Density of Target Invasive Species in Plots Located Along Transect Lines in Weed Control Blocks at Thurston SEA.



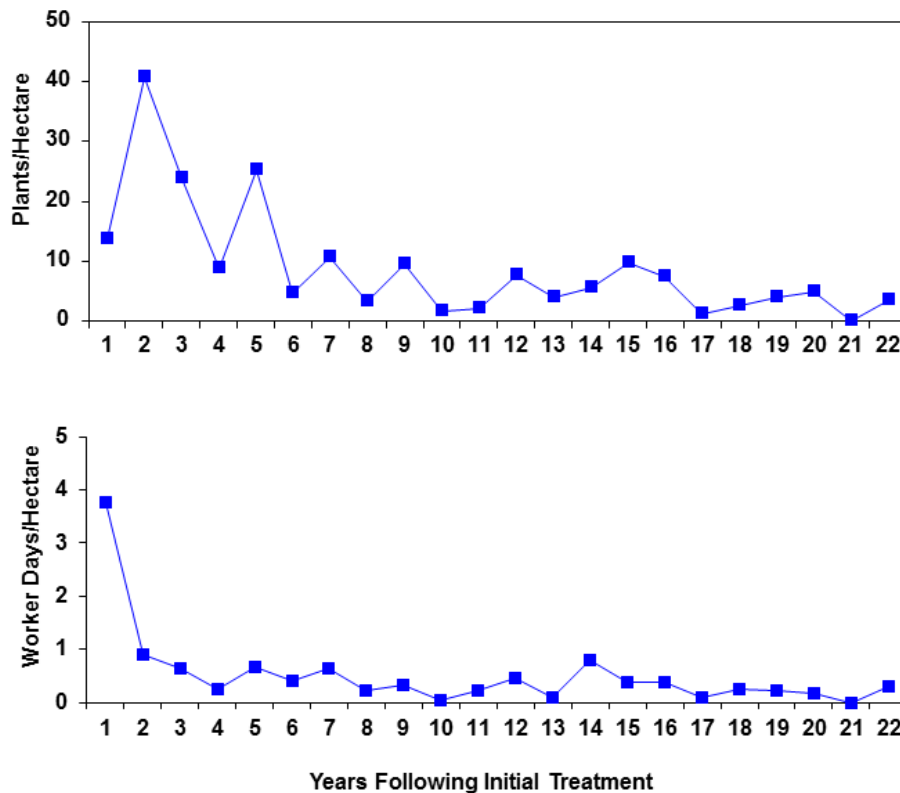
The numbers of target weeds (faya tree, strawberry guava and prickly Florida blackberry) decreased in plots along transects in several weed control blocks of Thurston SEA (Figure 9) following three to four treatment cycles. However, their frequency of occurrence along transects did not change significantly. They were still present but at much lower abundances. In weed control blocks where initial infestations of kāhili ginger were relatively high, abundance of plants decreased overtime with treatment cycles, but remained largely unchanged for other areas where initial infestations were lower.

Several weeds not observed during initial control work were discovered during subsequent ground sweeps. Among the more worrisome to park managers were Australian tree fern (*Sphaeropteris cooperi*) and Andean raspberry (*Rubus glaucus*).

3.1.2 Montane Mesic Forest

There were two SEAs established in the montane mesic zone. Both were located on the Mauna Loa Strip, Kīpuka Puaulu (93 ha) and Kīpuka Kī (92 ha), for which only portions of each SEA are under intensive weed management. Only data for Kīpuka Puaulu were analyzed. Roughly two-thirds of the unit was treated for target weeds, the remaining untreated areas contain invasive grass-dominated forest gaps and blackberry thickets within which restoration experiments that include native plantings were being carried out. Across the years the average number of worker days per hectare spent on controlling the initial target species (kāhili ginger, Jerusalem cherry, strawberry guava, faya and Himalayan raspberry) fell from 3.8 to <0.5 (\$760 to <\$50/ha) (Figure 10).

Figure 10. Number of Invasive Plants (kāhili ginger, Jerusalem cherry, strawberry guava, faya and Himalayan raspberry) Treated and Worker Days Spent in Kīpuka Puaulu Special Ecological Areas, 1985-2007.



Monitoring the occurrence of target species in plots located along transect lines showed a significant reduction in the distribution and abundance of kāhili ginger (48% to 8% of plots, chi square = 0.001, $p = 0.001$); and nasturtium (*Tropaeolum majus*) (28% to 10% of plots, chi square = 0.045, $p = 0.001$) following 12 years of control work; but very little change for other species that were initially present at low numbers. At the maintenance phase, species cover was typically <1 % crown cover along transect lines with the exception of prickly Florida blackberry (~15% crown cover), for which control work to remove thickets was still ongoing at the time of the last monitoring. Work crews freed from having to treat fewer weeds were re-allocated to expand experimental removal of blackberry, invasive grasses and nasturtium within the unit.

Discussion

Evaluation of treatment and monitoring data from over 20 years of SEA management were generally consistent with the initial conclusions by Tunison and Stone (1992): 1) populations of invasive plants controlled in SEAs could be significantly reduced and maintained at very low levels after several years of control work; 2) recruitment of invasive plant species was usually very low; 3) continued follow-up was required in all areas and would be needed indefinitely; and 4) workloads dropped significantly after initial control efforts.

Since implementation of the SEA approach in the park, the area under weed management expanded 500% from 5,045 ha in 1985 to 26,687 ha in 2007, while the annual number of worker days spent in the field increased only about 50% during the same period of time (Figure 11). Despite the added acreage under weed management, this translated to a three-fold decrease in \$ per hectare spent annually in the field. Cost reduction occurred because of 1) recurring treatments that reduced dense infestations to more manageable levels 2) increased use of helicopters that improved the search efficiency for locating weed infestations across large expanses of remote and open habitats; and 3) improved techniques for treating target weeds (e.g., replacing manual control with chemical treatment of kāhili ginger, use of an aerial herbicide delivery system). By 2007, the annual labor cost for search and control of weeds across all SEAs using a combination of ground and helicopter sweeps was about \$8.61 per hectare (2007 dollars). SEAs suited to helicopter searches had open to sparse vegetation where detection and treatment from the air was feasible (e.g., mid elevation seasonally dry woodlands and scrub, grasslands, shrubland communities on young lava flows). Cost of helicopter rental was expensive (\$800/hr in 2007) but was outweighed by savings in labor costs. This was particularly advantageous on open lava fields where target plants were sparsely distributed, conspicuous, and easily detectable from a great distance (150 m). More densely vegetated areas that relied solely on ground crews sweeping the area were more costly (Figure 12). Rain forest units incurred the highest labor costs (\$385 per hectare in 2007 dollars) as more workers were required to systematically sweep an area. This was because the dense vegetation required crew members to be more closely spaced (e.g., 5 m) during sweeps and to walk more slowly in order to effectively detect a target weed. However these areas were important to maintain because they were some of the park's most highly valued areas with high biodiversity, which provided habitat for a number of rare and endangered species and important ecosystem services (carbon storage, water cycling, and climate regulation). New technologies such as airborne imaging spectroscopy which can detect spectral signatures of invasive species in the understory beneath the forest canopy (Asner and Vitousek 2005) may assist park staff in locating isolated individuals in dense forest and save labor costs in the future.

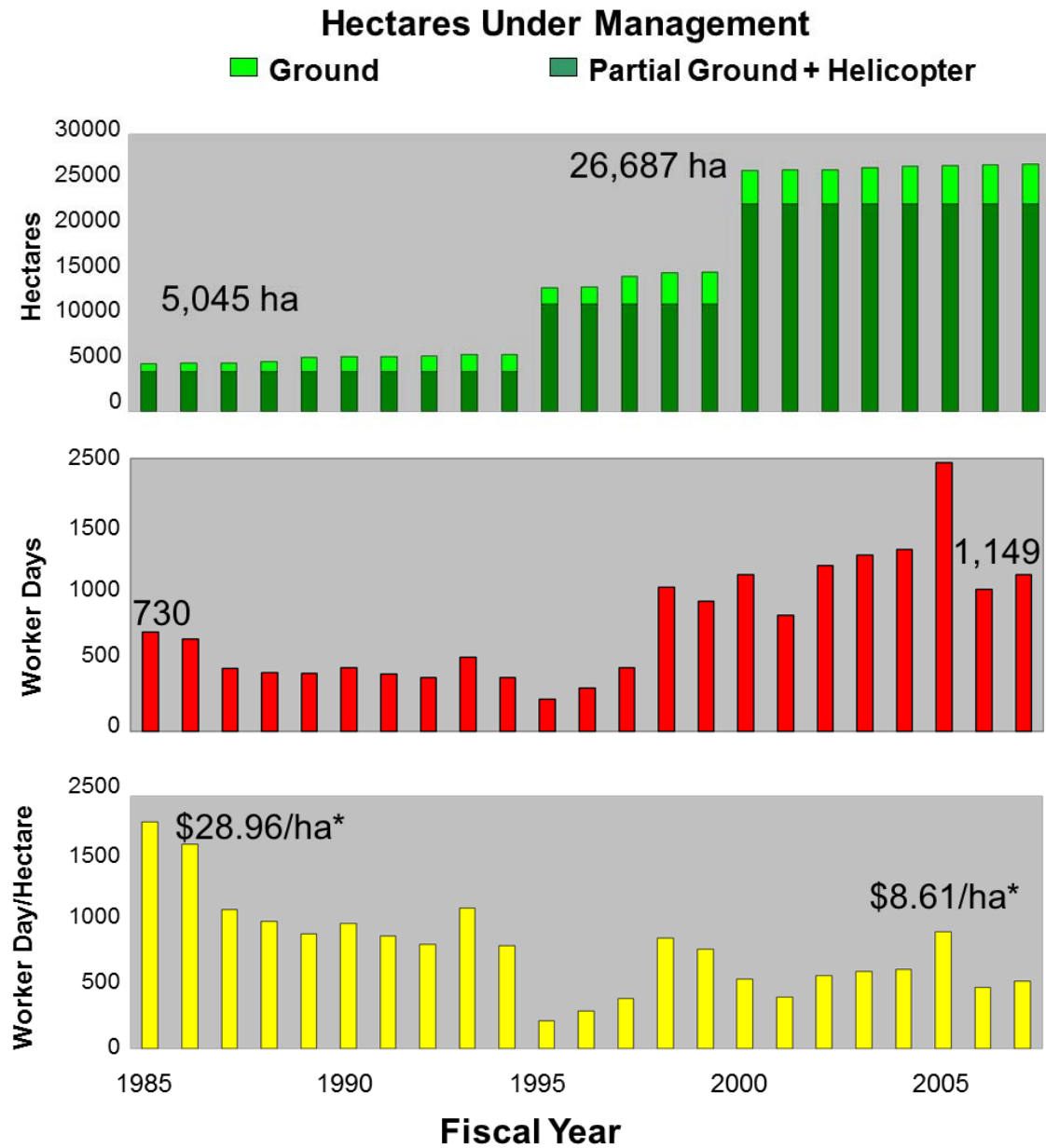
Complete eradication within SEAs was not expected and rarely achieved. Continued search and retreatment efforts offset re-establishment from seed dispersal from outside areas and expression of the soil seed bank so that units were maintained at some low level of weed infestation. Levels of infestation differed by species, vegetation type, size and shape of units, but were typically <1% crown cover. Several studies have focused on the impact of invasives on native plant communities in the park (Vitousek et al 1987, D'antonio and Vitousek 1992, D'antonio et al 1998). However none have focused on the threshold abundance needed for an invasive species to disrupt ecological processes at the landscape level. A localized effect following the death of faya tree, a nitrogen-fixer, showed selective establishment by native

sedges and invasive grasses beneath dead tree crowns in the mid-elevation seasonally dry woodlands of the park (Adler et al. 1998). But given the low densities and small sizes of target invasive individuals (primarily seedlings or saplings) that are typically encountered during the maintenance phase, landscape level effects would be unlikely in SEAs as long as the park was committed to maintaining areas. There were only a few instances where local eradication of a species was achieved, Formosan koa (*Acacia confusa*), koa haole (*Leucaena leucocephala*) and *Pittosporum undulatum* from Kīpuka Kahali'i, and *Ficus carica* from Kīpuka Puaulu. These were all species at an early stage of invasion. Seed dispersal from outside areas or expression of the residual seed bank countered eradication efforts (Benitez et al. 2012). For over 30 years, nasturtium has been the target of intensive efforts to eliminate it from mesic forest units, but the species continues to evade eradication.

In most cases a target weed's abundance was reduced or kept low, but spread was not necessarily contained or reduced. This was especially true for fast-growing herbaceous species in rain and mesic forest units. Instead, spread appeared to be dependent on a number of factors, including dispersal mechanism, growth behavior, and stage of invasion in addition to park control efforts. It's unlikely that one hundred percent removal of all target weeds during a treatment interval was achievable due to limitations on the ability of work crews to detect small individuals, particularly in densely vegetated rain and mesic forest communities. Only in the more highly infested areas, or when a species was approaching its full range potential within the unit, were conspicuous reductions in spread observed (e.g., kāhili ginger in Kīpuka Puaulu). In other instances, continued dispersal from outside control units countermanded efforts at local containment (e.g., blackberry in Kīpuka Puaulu, banana poka in 'Ōla'a Koa unit). Weed monitoring for both cover abundance (% crown cover or density in plots) and distribution in plots along transects was essential in evaluating species response to management inside rain and mesic forest SEAs. For other SEAs where recurring monitoring was not done, treatment data provided a reliable indicator of management effectiveness in reducing the numbers of invasive plants, but additional monitoring would have been needed to detect changes in range expansion or contraction.

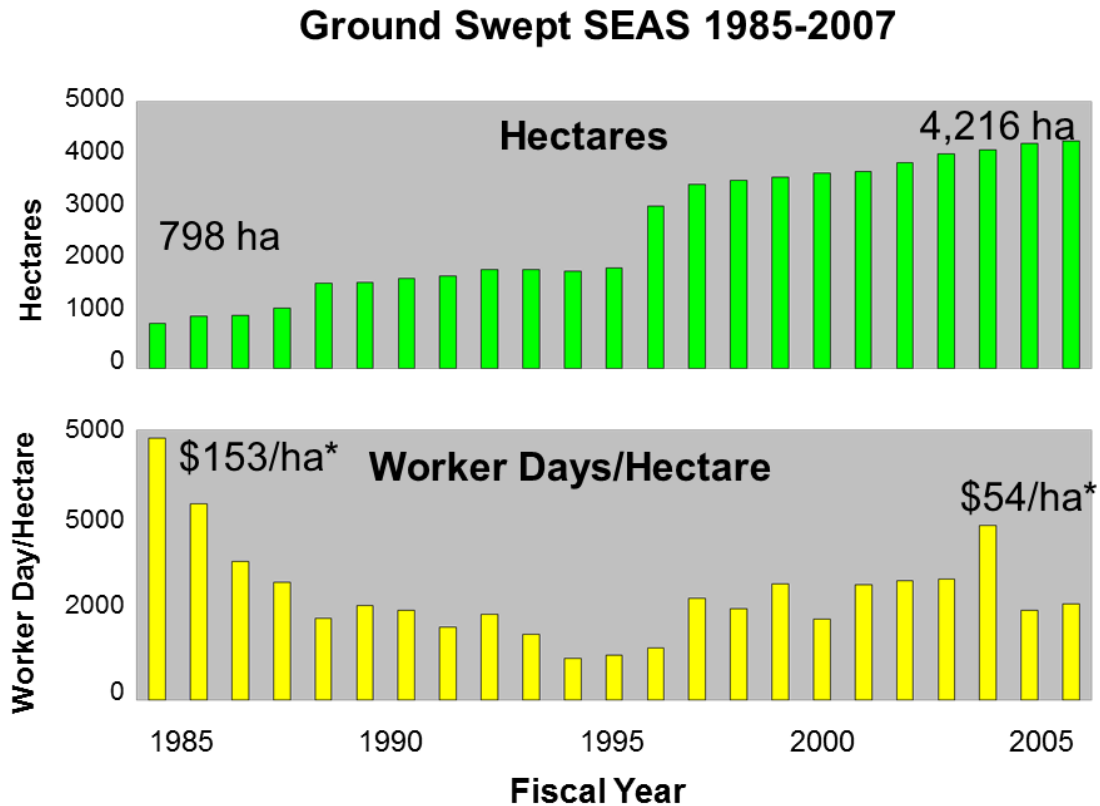
Important to the SEA concept was flexibility. While initial weed control may have focused on only a handful of the best areas, the number and size of units were expanded as additional resources were made available. Over the two decades since the first SEAs were established, SEAs and buffer units were expanded to include additional vegetation types and provide connectivity among units. Several of the new units were weedier or degraded areas that served as buffer zones to reduce seed dispersal of weeds into adjacent SEAs that were more intact. Twelve of the units established were proposed following initial review of the program in 1992 (Tunison and Stone 1992). From another perspective, maintenance to low infestation levels (rather than eradication) allowed for more flexibility in determining the time between treatment intervals. Throughout the 22 years of the program, annual budgets fluctuated and did not always allow for consistent timing between retreatments. The intervals between treatments varied between one to five years. While an unanticipated delay in the retreatment schedule caused a temporary setback, it did not prevent the park from eventually attaining or maintaining maintenance levels in SEAs.

Figure 11. Area Under Management and Worker Days in Special Ecological Areas.



*Labor cost was calculated based on time spent in the field in 2007 dollars. Does not include time spent transporting individuals to remote locations or indirect costs (administrative support, training, paid holidays, annual and sick leave). Costs per individual were calculated the same regardless of whether the person was NPS staff, (supervisor or worker), a University of Hawai'i cooperator or volunteer.

Figure 12. Area Ground Swept and Worker Days in Special Ecological Areas.



*Labor cost was calculated based on time spent in the field in 2007 dollars. Does not include time spent transporting individuals to remote locations or indirect costs (administrative support, training, paid holidays, annual and sick leave). Costs per individual were calculated the same regardless of whether the person was NPS staff, (supervisor or worker), a University of Hawai'i cooperater or volunteer.

Conclusions

Today besides the management of invasive species, SEAs provide sites for the active recovery of rare plant and animal species and also opportunities for researchers and the public to study and learn about native species and systems and park efforts to perpetuate them (Belfield et al. 2011).

The SEA approach has proven to be an effective management model for managing widespread invasive species in the park. Based on evaluation of 20+ year data sets, long-term management of SEAs can reduce weed infestations to low levels within 1-7 years; subsequent recruitment of new alien weeds is low; and work loads drop significantly after initial control efforts. Weaknesses of the SEA approach are that follow-up treatment is required indefinitely; weed infestations increase in surrounding unmanaged areas; and reinvasion into units may eventually become unmanageable if areas are too small. Another consideration for small isolated units is whether native communities can remain viable in the face of significant edge effects due to habitat fragmentation as surrounding areas continue to degrade. In lieu of abandoning, expanding the size of small SEAs, and coalescing isolated units into larger areas may overcome some of these challenges.

Long-term monitoring and control of invasives require substantial commitment of resources. Managers are continually challenged to secure funding to address ongoing weed maintenance. The addition of the new Kahuku unit (61,079 ha), which expanded the park by 50% and contains important habitat for highly endangered plants and animals threatened by invasive species, is expected to further stretch park resources dedicated to invasive weed control. Changes in species range habitat and vegetation types predicted by local climate models (Price 2007) underscore the need to reduce key stressors (such as invasive species) and provide connectivity among SEAs to allow for population and habitat shifts. Consequently, continuing effective invasive plant management in SEAs will require:

- Maximizing efficiency through optimizing search and control techniques (e.g., increased helicopter search and control, use of unmanned aircraft systems (UAS) and aerial imagery to detect infestations, release of biological controls that reduce reproductive success of target species), optimizing interval between retreatments; expanding size or reconfiguring shape of units and/or establishing managed buffer zones around smaller units to reduce seed dispersal from outside areas (recommendations for existing and proposed SEA units described in Appendix A and B).
- Developing new and strengthening existing partnerships with the community and adjacent landowners to expand weed management areas and create protective buffer zones around the park (e.g., Three Mountain Alliance, Big Island Invasive Species Committee).
- Research and development of new technologies-for detecting and treating target invasives such as airborne imaging spectroscopy (Asner and Vitousek 2005), and herbicide ballistic technology (Leary 2012).
- Additional monitoring to look at abundance and spread of target invasives inside and outside management units, and to look at changes in native plant communities with and without management. Such information could be used to help determine the levels of weed infestations that might be tolerated inside a management unit and optimizing the time interval between retreatments).
- Understanding future impacts of climate change on park habitats. Anticipating geographic shifts and habitat range reductions or expansions associated with climate change could be used to guide prioritization of new SEAs or expansion of existing ones so as to provide greater habitat connectivity for species inside the park and on adjacent lands.

Literature Cited

- Abbott, L. L., and L. W. Pratt. 1996. Rare plants of Nāulu Forest and Poliokeawe Pali, Hawaii Volcanoes National Park. Technical Report 108. Cooperative National Park Resources Studies Unit, University of Hawai'i at Mānoa, Department of Botany, Honolulu, HI. 65 pp.
- Anderson, R. C. and D. E. Gardner 1999. An Evaluation of the Wilt-causing Bacterium *Ralstonia solnacearum* as a Potential Biological Control Agent for the Alien Kahili Ginger (*Hedychium gardnerianum*) in Hawaiian Forests. *Biological Control* 15(2): 89-96.
- Asner, G. P. and P. M. Vitousek. 2005. Remote analysis of biological invasion and biogeochemical change. *PNAS* 102(12): 4383-4386.
- Belfield, T., T. Tunison, J. Chase, and S. McDaniel. 2011. Rare plant stabilization projects at Hawai'i. Volcanoes National Park, 1998-2008. Technical Report No. 174. Pacific Cooperative Studies Unit, University of Hawai'i, Honolulu, HI. 121 pp.
- Benitez, D., R. Loh, J.T. Tunison, N.G. Zimmer, J. Makaike, and R. Mattos and M. Casali. 2012. The Distribution of Invasive Plant Species of Concern in the Kīlauea and Mauna Loa Strip Units of Hawai'i Volcanoes National Park, 2000-2010. Technical Report No 179. Pacific Cooperative Studies Unit, University of Hawai'i, Honolulu, HI.
- Cuddihy, L.W., and C.P. Stone. 1990. Alteration of Native Hawaiian Vegetation, pp. 63-65. University of Hawai'i, Cooperative National Park Resources Studies Unit. Univ. Hawai'i Press, Honolulu, HI.
- D'Antonio, C. M., F. Hughes, M. Mack, D. Hitchcock, and P. M. Vitousek. 1998. The response of native species to removal of invasive exotic grasses in seasonally-dry Hawaiian woodland. *Journal of Vegetation Science* 9:699-712.
- D'Antonio, C.M. and P.M. Vitousek. 1992. Biological invasions, the grass-fire cycle and global change. *Ann. Rev. Ecol. Sys.* 23:63-87.
- Higashino, P. K., L. W. Cuddihy, S. J. Anderson, and C. P. Stone. 1988. Checklist of vascular plants of Hawai'i Volcanoes National Park. Cooperative National Park Studies Unit Technical Report 64. University of Hawai'i at Manoa. Honolulu, HI.
- Huenneke, L. F., and P. M. Vitousek. 1990. Seedling and clonal recruitment of the invasive tree *Psidium cattleianum*: Implications for management of native Hawaiian Forests. *Biological Conservation* 53:199-211.
- La Rosa, A.M. 1984. The biology and ecology of *Passiflora mollissima* in Hawai'i. Technical Report No. 50, pp 69-79. University of Hawai'i. Cooperative National Park Resources Studies Unit. Honolulu, HI.
- Leary, J., and J. Gooding, B. Mahnken, A. Radford, J. Chapman, L. Cox. Calibrating the herbicide ballistic technology (HBT) platform for helicopter operations targeting remote populations of Miconia (*Miconia calvescens*). Available at: http://www.ctahr.hawaii.edu/LittonC/PDFS/301_WeedScience.pdf.
- Loh, R. K., A. Ainsworth, B. Miner, R. Russell, J. Makaike, J. T. Tunison. 2000. Mullein Survey and Removal Efforts on Mauna Loa in Hawai'i Volcanoes National Park. Technical Report 126. Cooperative Parks Resources Studies Unit. University of Hawai'i, Honolulu.

Loh, R. Ainsworth, A., J. T. Tunison, and C. D'Antonio. 2009. Testing Native Species Response to Fire- A First Step Towards Building Fire Resilient Native Plant Communities at Hawai'i Volcanoes National Park. Technical Report 167. Pacific Cooperative Studies Unit, University of Hawai'i, Honolulu, HI.

Loh, R. K., and C. C. Daehler. 2007. Influence of Invasive Tree Kill Rates on Native and Invasive Plant Establishment in a Hawaiian Wet Forest. *Restoration Ecology*. Vol. 15, No. 2, pp. 199-211.

Loh, R. K., J. T. Tunison. 1999. Vegetation Recovery Following Pig Removal in Ola'a-Koa Rain Forest Unit, Hawai'i Volcanoes National Park. Technical Report 123. Cooperative Parks Resources Studies Unit. University of Hawai'i, Honolulu.

National Park Service. 2007. Hawai'i Volcanoes National Park unpublished data.

Pratt, L. W., J. R. VanDeMark, and M. Euaparadorn. 2011. Status and limiting factors of three rare plant species in the coastal lowlands and mid-elevation woodlands of Hawaii Volcanoes National Park. Hawai'i Cooperative Studies Unit Technical Report HCSU-024. University of Hawai'i at Hilo.

Price, J. P., S. M. Gon, III, J. D. Jacobi, and D. Matsuwaki. 2007. Modeling plant species ranges in the Hawaiian Islands: Developing a methodology and associated GIS layers. Technical Report HCSU-008, Hawai'i Cooperative Studies Unit, University of Hawai'i at Hilo.

Smith, C.W. 1985. Impacts of alien plants on Hawai'i's native biota. In C.P. Stone, and J.M. Scott (editors), *Hawai'i's terrestrial ecosystems: preservation and management*, pp. 180-250. University of Hawai'i, Cooperative National Park Resources Studies Unit. Univ. Hawai'i Press, Honolulu, HI.

Tunison, J.T. unpublished report. Management of Faya Tree 1966-1996.

Tunison, J. T. 1992. Alien species management in Hawai'i Volcanoes National Park. Pages 666-704 *in* C.P. Stone, C.W. Smith, and J. T. Tunison (editors), *Alien plant invasions in native ecosystems of Hawai'i*. Cooperative National Park Resources Studies Unit, University of Hawai'i at Manoa, Honolulu, HI.

Tunison, J. T., and C. P. Stone. 1992. Special Ecological Areas: an approach to alien plant control in Hawaii Volcanoes National Park. Pp. 781-798 *in* C. P. Stone, C. W. Smith and J. T. Tunison (editors). *Alien Plant Invasions in Native Ecosystems of Hawaii: Management and Research*. University of Hawaii Cooperative National Park Resources Studies Unit. Honolulu, HI.

Tunison, J.T., L.D. Whiteaker, L.W. Cuddihy, A.M. LaRosa, D.V. Kageler, M.R. Gates, N.G. Zimmer, and L. Stemmermann. 1992. The distribution of selected localized alien plant species in Hawai'i Volcanoes National Park. Tech. Rep. 84, University of Hawai'i. Cooperative National Park Resources Studies Unit. Honolulu, Hawaii.

Tunison, J. T., N. G. Zimmer, M. R. Gates, R. M. Mattos. 1994. Fountain grass control in Hawai'i Volcanoes National Park 1985-1992. Technical report no. 91. University of Hawai'i. Cooperative National Park Resources Studies Unit. Honolulu, HI.

Vitousek, P.M., L.R. Walker, L.D. Whiteaker, D. Mueller-Dombois, and P.A. Matson. 1987. Biological invasion by *Myrica faya* alters ecosystem development in Hawai'i. *Science* 238:802-804.

Vitousek, P. M., C. M. D'Antonio, L. L. Loope, M. Rejmánek, and R. Westbrooks. 1997. Introduced species: A significant component of human-caused global change. *New Zealand Journal of Ecology* **21**:1-16.

Wagner, W. L., D. R. Herbst, and S. H. Sohmer. 1999. *Manual of the flowering plants of Hawai'i*. 2nd edition. Bishop Museum Special Publication 83. University of Hawaii Press and Bishop Museum Press, Honolulu, HI. 1854 pp.

Appendix A. Special Ecological Areas (SEA) in Hawai'i Volcanoes National Park, 1984-2007.

Āinahou North (17 ha) - This seasonally dry 'ōhi'a woodland unit is distinguished from the surrounding area by its rocky 'a'ā-derived substrate and native-dominated understory. Present inside is one of the few park populations of ko'o ko'o lau (*Bidens hawaiiensis*), a former USFWS Species of Concern (SOC), endemic to Hawai'i Island. Feral goats were removed in the 1970's. Pigs still utilize the general area but are infrequent and not regarded as an immediate threat to plant communities. The surrounding 'ōhi'a woodland is heavily invaded by faya tree and dense mats of invasive molasses grass (*Melinis minutiflora*), bushy beardgrass (*Schizachyrium condensatum*) and broomsedge (*Andropogon virginicus*). Work crews systematically sweep the unit on foot to remove all faya tree and other target woody invasives (e.g., olive, guava, strawberry guava). The current interval between control treatments is two years. Because the area is small and easy to access, students in the Youth Conservation Corps led by NPS work leaders have been doing the biennial treatments in recent years. This has made the cost of control effective despite abundant seedling recruitment of faya from the surrounding area. Management recommendation: Continue current management.

Āinahou South (25 ha) - This former dry 'ōhi'a woodland SEA provided habitat for several rare plants including the only individuals of *Exocarpus gaudiichaudii* in the park, and *Myrsine lanaiensis* on the Kīlauea side of the park. Feral goats were removed in the 1970's. Pigs still utilize the general area but are infrequent and not regarded as an immediate threat to plant communities. Until 1994, work crews systematically swept the unit on foot to remove all faya tree and other target woody invasives (e.g., olive, guava, strawberry guava). Work was subsequently abandoned when invasive molasses grass overwhelmed the unit, and work crews had a difficult time navigating through the thick grass mats.

Management recommendation: Since this area is no longer managed for weeds, park staff should monitor the status of rare plants in the area, and determine if additional actions are needed to perpetuate these species on Kīlauea in the park (e.g., localized weeding around naturally occurring individuals to manage the immediate habitat as a small plant sanctuary, or collection of plant material for propagation and planting into other areas of the park).

Āpua Point (66 ha) - This SEA contains the largest remaining coastal strand habitat in the park and is surrounded by historic lava flows from Mauna Ulu (1969-1974). Beach naupaka (*Scaevola taccada*) and the federally listed endangered 'ōhai (*Sesbania tomentosa*) dominate the vegetated landscape. The beach provides important nesting habitat for the endangered honu'ea or hawksbill turtle (*Eretmochelys imbricata*). Feral goats were removed in the 1970's and pigs have not been seen in years. A remote backcountry camp, this area is monitored by staff to prevent the establishment of target invasive plants (e.g. date palm (*Phoenix dactylifera*), maunaloa vine (*Canavalia cathartica*)).

Management recommendation: Continue current management.

Byron's Ledge Buffer (43 ha) - This area is frequented by park visitors who hike the Kīlauea summit trails. The area is free of ungulates. Until recently, this 'ōhi'a/hāpu'u forest was heavily infested by faya tree. In 2006, weed control was expanded to include this area of Kīlauea summit. Since then, park crews have worked intensively with chainsaw and herbicide to girdle individual trunks of faya using a method that leaves dead trees standing and optimizes native forest recovery (Loh and Daehler 2007). Individuals of Australian tree fern (*Sphaeropteris cooperi*) and Koster's curse (*Clidemia hirta*), two highly disruptive invasive species only recently documented in the park, were detected and removed by work crews during ground sweeps.

Management recommendation: Additional search and control work is needed to prevent re-establishment and intensification of kāhili ginger, yellow Himalayan Raspberry, Koster's curse, Australian tree fern, and other invasive species from the existing soil seed bank and propagule

dispersion from nearby areas. Although more degraded and disjunct, this unit includes part of the same 'ōhi'a/hāpu'u forest as nearby Thurston SEA and weed management should be expanded to include the intervening forest to unite the area with Thurston SEA.

East Rift (weed control focused in 170 ha of 1,113 ha) - Although the entire East Rift Forest SEA covers 1,113 ha, only 170 ha is actively managed for weeds. This SEA was originally proposed for weed management in 1992 (Tunison and Stone 1992). Along with pioneer habitat on young lava flows, the SEA includes the only protected lowland rain forest in the park. Federally listed species present in the unit include the Hawaiian Hawk (*Buteo solitarius*), Hawaiian Hoary Bat (*Lasiurus cinereus semotus*), Kihī fern (*Adenophorus periens*), one candidate endangered mint (*Phyllostegia floribunda*), five USFWS SOC (*Anoectochilus sandwicensis*, *Bobea timonioides*, *Eurya sandwicensis*, *Liparis hawaiiensis*, *Trematolobelia wimmeri*) and additional rare species. A 6-km-long galvanized steel fence excludes feral pigs. Additional measures are taken to monitor and remove invasive target weeds (e.g., strawberry guava, faya tree, Himalayan raspberry) from portions of the unit through systematic ground searches by work crews done at three to four year intervals. Initial efforts to control localized populations of cane tibouchina (*Tibouchina herbacea*) were abandoned when it was discovered this species was much more widespread than previously thought. The more remote location and difficulty for work crews to navigate in dense uluhe (*Dicranopteris linearis*) fern thickets further add to the labor cost in an already expensive rain forest SEA. Due to ongoing lava activity, hazardous volcanic fumes and high fire potential (portions of the SEA were ignited by lava and burned in 2003 and 2011) scheduling weed control work has been problematic in recent years. The environmental hazards combined with the high labor costs to ground sweep control blocks led park staff to temporarily suspend weed management in the SEA in 2008.

Management recommendation: Park staff should consider reviving weed control work in previously managed blocks and expanding management into new areas when volcanic hazards are no longer present and as funding/resources become available.

Highway 11 Buffer (6 ha) - This thin strip of 'ōhi'a rain forest located along Highway 11 serves as a managed buffer area to reduce seed dispersal of invasive plants into the Kīlauea summit area. The area is geologically unstable and contains many earth cracks hidden by dense uluhe fern thickets. As the terrain permits, work crews conduct systematic ground sweeps to locate and remove invasive faya, strawberry guava and kāhili ginger. Work was initially conducted in 1998, 2000, and again in 2003. Subsequent treatment has been confined to spot treatment of target species along the road.

Management recommendation: Continue current management to treat target weeds in accessible areas and along the roadsides.

Hilina Pali (1,590 ha) - The SEA is the largest tract of mid-elevation seasonal 'ōhi'a woodland and scrub managed for invasive weeds in the park. Present within the SEA are several federally listed and rare plant species (e.g. 'ōhai, 'ihi mākole (*Portulaca sclerocarpa*), akoko (*Euphorbia celastroides*), Kīlauea naupaka (*Scaevola kilaueae*) and nesting habitat for the endangered nēnē or Hawaiian goose (*Branta sandwicensis*). The SEA has been the focus of experimental restoration with fire-tolerant native species (Loh et al. 2010). Feral goats were removed in the 1970's. Pigs still occur in the area and can cause localized damage to plants as well as to nēnē eggs and goslings. Since its establishment in 1989, the unit has expanded over three-fold from 467 ha to 1,590 ha. Faya tree is the most abundant woody invader targeted for control by park staff. Silk oak and faya tree are also present in expansion blocks. Expansion of weed management has been possible due to savings in labor costs as staff moved from systematic ground sweeps to aerial surveys to locate individuals over the years. Areas close to the road and with higher recruitment of faya seedlings (from adjacent unmanaged areas) continue to be swept by ground crews. The interval between control treatments is typically two to three years.

Management recommendation: Continue current management. Expand management into adjacent unmanaged areas as funding/resources become available. Highest priority for expansion of weed management into new areas should be given to native dominated areas where woody invaders are only just becoming a problem (e.g., areas west of the SEA), areas slated for intensive restoration with fire-tolerant native species (to be determined), and areas that serve as important habitat for rare and endangered species (e.g., nēnē habitat east of the SEA).

Hōlei (1,234 ha) - This SEA contains the largest extent of pili grasslands in the park, a sizable population of the endemic sedge *Fimbristylis hawaiiensis* (a Species of Concern) and provides nesting and foraging habitat for the endangered nēnē. Feral goats were removed in the 1970's and pigs have not been seen in years. Park staff prevent the establishment of invasive fountain grass, and contain the spread of African thatching grass (*Hyparrhenia rufa*) by conducting systematic ground sweeps in a portion of the SEA that runs alongside the Chain of Crater Road and treating specific sites where individuals are reported.

Management recommendation: Continue current management.

Kahue South (117 ha) - Faya tree is the dominant woody invader in this 'ōhi'a woodland and scrub SEA. The area includes the lower half of a kīpuka formed by the Mauna Ulu lava flows (1969-1974) and divided by the Chain of Craters Road. Inside the kīpuka is Maua (*Xylosma hawaiiense*), a rare plant, and potential habitat for recovery efforts of a number of rare dry land species (Abbott and Pratt 1996). Feral goats were removed in the 1970's. Pigs still utilize the general area but are infrequent and not regarded as an immediate threat to plant communities. From 1999 to 2008, work crews conducted systematic ground sweeps to search and remove faya. Initial efforts to treat adult plants were labor intensive with work crews relying heavily on chainsaw to cut away the branches in order to get to the base of trees, fell, and treat stumps with herbicide. A total of 484 worker days were spent removing 7,010 individuals during the first round of treatment. A subsequent revisit of the area in 2009, was much easier for work crews because individuals were fewer and smaller: 32 worker days were spent removing 1,153 individuals during the 2nd round of treatment.

Management recommendation: Continue current management. If funding becomes available consider expanding weed management to the upper portion of the kīpuka (Kahue North).

Kamakai'a (3,743 ha) - This SEA was originally proposed for weed management in 1992 (Tunison and Stone 1992). Feral goats were removed in the 1970's and pigs occur seldom in this dry, sparsely vegetated area. Although formally established as an SEA in 2000, earlier actions to remove fountain grass from the area had begun in 1987 (Tunison et al. 1994). Low-elevation helicopter surveys are used to locate fountain grass and occasional faya biannually. Initially ground crews would hike/fly to treat plants once they were located from the air. Since 2005, detection and treatment of target weeds is done by helicopter and using a remotely operated spray rig at 6 to 8 month intervals. In 2002, silk oak was mapped parkwide, and large populations (>1000 individuals) were identified < 1 km to the southwest just outside the unit. Scattered individuals were located within the southeast corner of the unit. No management to remove plants has begun.

Management recommendation: Expand management to include removal of silk oak populations in the southeast portion of the unit.

Ka'ū Buffer (3,392 ac) - This area of sparsely vegetated lava flows and cinder fields is managed as a buffer zone that provides contiguous management of target weeds (faya, fountain grass) from Ke`āmoku to Keanakāko'i, and to Kamakai'a and Hilina Pali SEAs. Portions of the unit are exemplary of the early stages of native plant establishment in a harsh volcanic landscape. Feral goats were removed in the 1970's and pigs occur very seldom in this area. Similar to Kamakai'a SEA, low-elevation helicopter surveys are used to locate fountain grass and occasional faya followed by ground crews hiking out to control individuals. Since 2005, treatment of target weeds

is done by helicopter using a remotely operated spray rig at 6 to 8 month intervals. In 2002, approximately 300 silk oak individuals were mapped in the southwest portion of the unit, and a population of over 1,000 plants was mapped just beyond the unit. Control of the population outside of the SEA was begun in 2010. No management to remove plants in the SEA has begun. Since 2008, the entire upper portion of the SEA located above the Ka'ū desert trail has been closed to administrative staff because of heavy ash and volcanic fumes blown downwind from Halema'uma'u. As a result of no management, faya tree appears to be spreading into the unit from the northeast.

Management recommendation: Expand management to include removal of silk oak populations in the southwest portion of the unit. Should volcanic activity cease in the area, revive weed control work to remove faya tree from the unit.

Kealakomo (10 ha) - Lama forest has become a very rare community in the park because of lava flows from 1969-1972 and 1996 to the present. Two of the three remaining stands of lowland, dry lama forest in the park are found in Nāulu and Kealakomo SEAs. The overstory and secondary canopy of Kealakomo are dominated by native woody plant species but the ground cover is largely alien. The main invasive plant problems are low open stands of lantana (*Lantana camara*) and christmasberry (*Schinus terebinthifolius*) in the understory, along with locally dense patches of alien sword fern (*Nephrolepis brownii*) and grasses. Feral goats were removed in the 1970's and pigs occur seldom. Native plants include the endangered halapepe (*Pleomele hawaiiensis*) and 'aiea (*Nothocestrum breviflorum*), and four SOCs, 'ahakea (*Bobea timonioides*), kauila (*Alphitonia ponderosa*), 'ohe (*Polyscias sandwicensis*), and wiliwili (*Erythrina sandwicensis*). The area has also been used for planting three locally rare species, hame (*Antidesma pulvinatum*), 'āwīkīwī (*Canavalia hawaiiensis*), and kūlū (*Nototrichium sandwicense*). In 2002, stands of lantana and swordfern were treated with herbicide prior to planting of several hundred rare native plants (Belfield et al 2011). No subsequent management has taken place.

Management recommendation: Alien plants need to be controlled in the remainder of the kīpuka to restore native understory and allow for additional planting of rare and uncommon native plants. Monitoring for biocontrol agents of lantana is needed to determine if they are present and should be reintroduced if they are missing.

Ke'āmoku (4,246 ha) - Located along Highway 11, this SEA offers wide expanses of 'ōhi'a scrub and native pioneer habitat on lava flows. Feral goats were removed in the 1970's and pigs occur very seldom and are quickly removed by park when reported. The area is a potential reintroduction site for the endangered 'ihi mākole (*Portulaca sclerocarpa*). Faya tree, silk oak, fountain grass are the primary targets for weed control by work crews who systematically ground sweep the northeast portion of the unit. In remaining areas, ground crews are directed to specific sites to treat individuals located from the air. Two years is the typical return interval for retreating areas that are systematically ground swept, and between two to four years for other areas. Populations of silk oak located in the southwest portion of the unit have been mapped but remained untreated.

Management recommendation: Continue current management. Expand management to include removal of silk oak populations in the southwest portion of the unit as funding becomes available.

Keanakāko'i (128 ha) - Faya tree, Himalayan raspberry, strawberry guava, blackberry are the major alien plant threats to this 'ōhi'a woodland which has been free of ungulates since the 1980's. Since 1988, ground crews have systematically swept the area to remove these species. Seed rain from adjacent unmanaged areas has contributed to prolific seedling recruitment and relatively high labor costs to retreat areas compared to other seasonally dry woodland SEAs. Work crews typically return at two year intervals to retreat an area. The SEA is a planting site for the endangered *Spermolepis hawaiiensis* (Belfield et al. 2011), and nesting habitat for the nēnē, and until recently was a popular scenic place for visitors hiking the Crater Rim Trail or driving along the Crater Rim Road. Since 2008, the portion of the SEA located west of Keanakāko'i

Crater has been closed to administrative staff because of volcanic fumes emitted from Halema'uma'u. As a result of no management, faya tree is spreading into the western end of the unit.

Management recommendation: Continue current management. As funding becomes available, expand control to the surrounding areas (e.g., Devastation area, unmanaged portions of Thurston SEA) to reduce weed dispersion into the area. Should volcanic activity cease in the area and administrative access reopened, revive weed control work to remove faya tree and other target invasives from the western end of the unit.

Kīpuka Kahali'i (368 ha) - This seasonally dry 'ōhi'a woodland habitat is distinguished for the deep cinder deposited by the Mauna Ulu eruption (1969-1974) and the number of rare plants historically documented in the area (Pratt et al. unpublished data), in addition to providing important nesting habitat for the endangered nēnē. Feral goats were removed in the 1970's. Pigs still occur in the area and can cause localized damage to plants as well as to nēnē eggs and goslings. Faya tree is the main invasive plant threat and prolific seedling recruitment occurs along the western boundary of the unit that lies adjacent to dense stands of faya. Other weeds encountered and treated during systematic ground sweeps conducted by work crews are olive, guava and blackberry. Over the years, the interval between control treatments has lengthened from two to four years; and the area under weed management from 93 ha to 368 ha. With the exception of several small kīpuka heavily infested by alien grasses and mature stands of faya and olive and located below the Chain of Craters Road, the area is largely weed free.

Management recommendation: Continue current management. If funding becomes, available consider expanding weed management of invasive woody plants to include kīpuka infested by faya and olive, and the surrounding Mauna Ulu flows to reduce a source of weed dispersion into the SEA.

Kīpuka Kī (weed control focused in 17 ha of 92 ha) - Kīpuka Kī and Kīpuka Puaulu SEAs contain the park's most biologically rich sites including many rare, threatened and endangered species (Pratt et al. 2011). The old ash substrates support the extremely rare koa-mānele forest type which is listed as globally imperiled by the International Union for Conservation of Nature (IUCN). By the 1990's, exclusion of ungulates had led to recovery of the tree canopy, but only limited recovery of understory species. Natural recruitment of understory species from the soil seed bank and seed rain was patchy because of the widespread occurrence of alien grasses (*Cenchrus clandestinus*, *Erharta stipoides*), Jerusalem cherry (*Solanum pseudocapsicum*), and Florida blackberry that formed dense thickets that prevented native seedling establishment. Also, kāhili ginger, strawberry guava, faya tree, and nasturtium (*Tropaelum majus*) were beginning to establish. Intensive herbicide control of alien species began in 1992. Initial efforts by ground crews were slow and required multiple retreatments within a year to remove alien grasses and nasturtium; and annual or semiannual retreatments to remove Florida blackberry and Jerusalem cherry thickets. Over the years, as infestations were knocked down, weed management was expanded, and dramatic recovery of native tree and understory species occurred. By 2007 ~17ha was under intensive weed management. Efforts to re-establish and introduce several rare plant species into the kīpuka were also begun in the late 1990's (Belfield et al 2011).

Management recommendation: Expand weed management of invasive species to include the entire 92 ha kīpuka as funding and resources become available.

Kīpuka Puaulu (weed control focused in 46 ha of 93 ha) - Along with Kīpuka Kī SEA, this ungulate-free area is among the park's most biologically rich sites, and supports the rare koa-mānele forest type and harbors a number of rare plant species, including an endangered hau kuahiwi (*Hibiscadelphus giffardianus*) unique to the area and the largest population of the endangered Hawai'i Island endemic, alani (*Melicope zahlbruckneri*). The kīpuka was initially fenced to exclude cattle in the 1920's and was used as a planting site for several rare plants from around the island and Maui. Currently, the area is a focal place for interpreting efforts to restore

native forest habitat and rare plants to park visitors. When the SEA was established in 1984, initial weed control was focused on systematic ground sweeps to remove kāhili ginger, strawberry guava and Jerusalem cherry from a 13 ha area located inside the 1.4 km loop trail. Nasturtium populations were mapped and treated with work crews revisiting infestations at quarterly intervals. All other areas are treated annually or biennially. Over the years, weed management expanded to include areas beyond the loop trail and removal of grasses and blackberry from forest gaps. By 2007, approximately 46 ha of mesic forest were under intensive weed management and introduction of several endangered, rare, and depleted native plants had begun (Belfield et al. 2011). The proliferation of strawberry guava just east of the kīpuka (located in an unmanaged portion of Puauulu Buffer unit) is a concern as increased dispersal of fruits into the SEA may require more intensive efforts to keep the unit free of target weed species.

Management recommendation: Expand weed management of invasive species to include the entire 93 ha kīpuka as funding and resources become available.

Kūkalau'ula (202 ha) - This dry coastal mixed pili-alien grassland unit supports several individuals of the endangered 'ōhai (*Sesbania tomentosa*) and the locally rare 'awikiwiki (*Canavalia hawaiiensis*). This is the only SEA located in the southwest portion of Kīlauea. Goats were removed from the area in the late 1970's, pigs still occur in the area. Fountain grass has been controlled in this unit since the 1980s, first with ground crews and more recently using a helicopter to detect individuals and chemically control plants using a remotely operated spray rig.

Management recommendations: Continue current weed management.

Mauna Loa Subalpine (7,303 ha) - The subalpine area is composed of low-statured 'ōhi'a and native-dominated shrublands. Fenced and ungulate free, the unit includes habitat for the endangered 'ūa'u (*Pterodroma sanwicensis*), several thousand plantings of the Ka'ū silversword (*Argyroxiphium kauense*), the fern *Asplenium peruvianum* var. *fragile*, the threatened *Silene hawaiiensis* and additional rare plants and animals. Few invasive weeds have been identified in this area. Annual aerial surveys of the lower elevation are conducted to detect mullein (*Verbascum thaspus*) on 'a'ā flows and ground crews are directed to infestations to uproot individuals and prevent the spread of plants to higher elevations.

Management recommendation: Continue current management to remove mullein from the unit and monitor for new invasive species.

Mauna Loa Upper (2,281 ha) - The vegetation in this ungulate free unit is a mosaic of native pukeawe (*Leptecophylla tameiameia*) shrubland, *Deschampsia nubigena* grassland, and koa forest divided by historic lava 'a'ā flows that are sparsely vegetated. Beneath the koa canopy, native shrubs and alien meadow rice grass (*Ehrharta stipoides*) dominate the understory. Mullein infestations are widely distributed on and along the edges of 'a'ā flows (Loh et al. 2000). In 1994, ground crews began efforts to remove all but the densest infestations in an attempt to reduce the range of this species. Ground crews systematically swept 780 ha of 'a'ā flows located between 1,500 m and 2,200 m elevation (including portions of Mauna Loa Subalpine SEA). However, annual efforts to retreat these areas proved too costly for park staff to maintain. By 2008, efforts were refocused to control mullein only along its upper and lower elevation extent to prevent further spread of this species. In 2005, biannual control of banana poka (*Passiflora tarminiana*) by ground crews began shortly after several plants were discovered in koa forest along the lower elevation boundary of the unit. Initial searches were confined to a 9 ha area that straddled the unit and the adjacent unmanaged forest. Helicopter mapping and control work in 2008 identified a much larger infestation distributed over 36 ha.

Management recommendation: Continue current management to remove banana poka and contain spread of mullein. As funding becomes available, expand control of mullein to protect important habitat for the endangered *Plantago hawaiiensis*, as well as for Ka'ū silversword,

Asplenium peruvianum var. *fragile*, and *Silene hawaiiensis*, and control in low and moderate density infestations to reduce its current range in the SEA.

Nāulu (21 ha) - Nāulu is the largest remaining kīpuka of 'ōhi'a/lama (*Diospyros sandwicensis*) forest in the park. The kīpuka harbors several rare dryland species and has been the focus of plantings of a dozen rare species including kauila, hame, 'ahakea, 'āwikiwiki, naio (*Myoporum sandwicense*), 'aiea, halapepe, kolomona (*Senna gaudichaudii*), 'iliahi (*Santalum paniculatum*), 'ohe, hao (*Rauvolfia sandwicensis*), and maua. Similar to Kealakomo SEA, the main invasive plant problems are low open stands of lantana and christmasberry in the understory, along with locally dense patches of alien sword fern and grasses. Feral goats were removed in the 1970's and pigs occur seldom. In 2002, chemical control to remove lantana and swordfern by ground crews was done in conjunction with planting of several hundred rare native plants (Belfield et al 2011). No subsequent management has taken place.

Management recommendation: Alien plants need to be controlled in the remainder of the kīpuka to restore native understory and allow for additional planting of rare and uncommon native plants. Additional dry lowland 'ōhi'a/lama forest kīpuka occur in Kū'e'e located on the southwest slope of Kīlauea and should be considered for management under the SEA system. These areas support several endangered species including 'ōhai, halapepe and the Species of Concern kauila. Also, monitoring for biocontrol agents of lantana is needed to determine if they are present in the area and should be reintroduced if they are missing.

'Ōla'a-Koa unit (weed control focused in 215 ha of 771 ha) - Koa unit is among three rain forest SEAs in 'Ōla'a tract. 'Ōhi'a is the dominant forest tree with hāpu'u (*Cibotium glaucum* and other species) forming a dense mid-tier canopy. The entire 771 ha unit was fenced in 1989 and ungulate free by 1994. Himalayan raspberry, kāhili ginger, strawberry guava, banana poka are significant plant pests in the unit. Early efforts to control these weeds and others through systematic ground sweeps of the area by work crews were begun in 1998. Current control is focused in sixteen control blocks that form a 1,000 m x 3,200 m swath along the southwest fence boundary adjacent to Wright Road. The interval between treatments has varied from two to five years. Current retreatment is done at four- to five-year intervals. High concentration of weeds in 'Ōla'a-Ag unit, a 162 ha fenced unit unmanaged for weeds, add adjacent areas outside the park may have contributed to significant weed dispersal into the unit and higher rates of weed infestations in Koa unit than in the other two weed management units in 'Ōla'a (Pu'u and Small tract). Since 2001 this SEA along with 'Ōla'a-Small tract have been the focus of plantings of several endangered and rare plants and contains natural populations of two endangered plant species, two candidate species, and at least four Species of Concerns (Pratt and Abbott 1997, Belfield et al. 2011).

Management recommendations: Continue current management of weeds in SEA. Expand control of weeds to the adjacent 'Ōla'a-Ag fenced unit to reduce weed dispersion into the unit and throughout the remaining areas of Koa unit as funding becomes available.

'Ōla'a-Pu'u (weed control focused in 155 ha of 245 ha) - Pu'u unit is an 'ōhi'a/hāpu'u rainforest located at the northeast end of 'Ōla'a tract. The 245 ha unit was fenced and ungulate free by 1986, and intensive efforts to remove Himalayan raspberry, kāhili ginger, strawberry guava, and banana poka and other invasive weeds was begun in 1997. One hundred and fifty-five ha of the unit had been systematically groundswept by work crews by 2004, with retreatment (six-year interval) occurring across 126 ha of the unit. The unit is the farthest removed from the road and agricultural areas, and weed abundances have been relatively low compared to other rain forest SEAs. Travel times are significantly higher relative to other more accessible rainforest SEAs.

Management recommendations: Continue current management of weeds in SEA. Expand control of weeds throughout the unit as funding becomes available.

‘Ōla’a-Small tract (144 ha) - Small tract unit is the first of three ‘ōhi’a/hāpu’u rainforest SEAs established in ‘Ōla’a tract. The 144 ha unit was fenced and ungulate free by 1984, intensive efforts to remove Himalayan raspberry, kāhili ginger, strawberry guava, and banana poka and other invasive weeds was begun in 1985 and the entire unit had been systematically groundswept by work crews since 1993. The retreatment interval was initially at two years, but was pushed back to four years to accommodate demands on work crews to expand weed management to other rain forest SEAs. By 2008, the retreatment interval had been extended to five to six years. Similar to Koa unit, this SEA is a site for plantings of several endangered lobeliads, mint and other rare plants (Belfield et al. 2011) and supports natural populations of several rare plant species (Pratt and Abbott 1997).

Management recommendations: Continue current management of weeds in SEA. Consider reducing retreatment intervals to two years along the inside edge of the unit (e.g., 100 m in from the fence line) to address weed dispersal from surrounding areas.

Puauulu Buffer (weed control focused in 841 of 934 ha) - This ungulate-free unit surrounds Kīpuka Puauulu SEA and serves as a buffer area to reduce weed dispersal into the SEA. The area originally includes a 35-ha swath located outside the park in the Volcano Golf Course community. The vegetation communities are a mixture of seasonally dry ‘ōhi’a woodland and koa forest, and the primary invasive plants are faya tree, prickly Florida blackberry, firethorn, strawberry guava and common guava. Control (systematic groundsweeps by work crews) of these weeds was initially intended to be carried out throughout the 934 ha area, but was eventually reduced to 841 ha by omitting koa forest in the northeast corner of the unit where infestations of strawberry guava were too dense for crews to control. In 2008, weed control in the 35-ha area located outside the park was suspended and park staff re-allocated to focus on weed control in SEAs located inside the park.

Management recommendations: Continue current management of weeds in buffer unit. As funding becomes available, expand control to include koa forest in the northeast corner of the unit currently unmanaged, and re-initiate control along the park boundary in the Volcano Golf Course Community

Puhimau Hotspot (10 ha) - This ungulate free area is a hydrothermal spot that supports the largest remaining population of the endangered ‘īhi mākole (*Portulaca sclerocarpa*). The area is surrounded by ‘ōhi’a woodland infested by faya tree. The significant weeds in the hydrothermal area are alien broomsedge and a non-native *Portulaca (pilosa)*. The feasibility of successfully managing species species is low, and there are no plans to remove these weeds from the area. A recent study indicated that the number of endangered portulaca is declining in the area due to a number of factors including seed predation by mice (Pratt et al. 2011).

Management recommendations: Continue to monitor weeds and the rare plant population in the SEA.

Pu’u Huluhulu (1 ha) - This small ‘ōhi’a rain forest unit located at the top of a scenic point was selected for its interpretive value. A population of the locally rare *Clermontia hawaiiensis*, located in the central part of the crater, is used as a source population for seeds used in propagation and restoration efforts elsewhere in the park. Faya tree, strawberry guava, kāhili ginger and Himalayan raspberry are the major plant pests. Work crews groundswept the area to remove these target invasives in 1999 and in 2002. No retreatment has occurred since then and further control work in the unit was suspended in 2008 in order to focus work crews on higher priority units.

Management recommendations: Resume weed management as funding becomes available.

Thurston (263 ha) - The hiking trails at the Kīlauea summit are among the few places where park visitors can see native rain forest. Both hapu’u and ūluhe (*Dicranopteris linearis*) are common

understory elements with 'ōhi'a the dominant forest tree. The area has been ungulate free since the early 1980's. Intensive efforts by ground crews to systematically search and remove kāhili ginger, strawberry guava, faya tree, Himalayan raspberry and other invasive species was originally focused in the immediate vicinity of Thurston Lava Tube, a highly popular visitor attraction. From 1985 to 2007, control was gradually expanded to include 263 ha of rain forest in the summit area. Expansion was made possible following the discovery of Escort as an effective method of control kāhili ginger. Prior to 1989, plants had to be manually uprooted and rhizomes hauled out of the forest, which limited work crews to working close to roads and avoiding dense infestations. Retreatment intervals are typically two years, and are more frequent than in other rain forest units because of prolific seed dispersal of weeds from adjacent unmanaged areas. These unmanaged areas include forest where dense infestations of weeds have established and areas where earth cracks and steep cliffs make it difficult for work crews to navigate to weed infestations. Early experiments to control kāhili ginger using a bacterial wilt (*Ralstonia solanacearum*) conducted in the mid 1990s were initially promising, but poor dispersal characteristics of the bacterium limited its applicability as a landscape-level tool for controlling this weed (Anderson and Gardner 1999). In 2009, Thurston SEA has a natural population of *Trematolobelia wimmeri*, a Species of Concern, and was the focus of plantings of several rare and endangered species (e.g., *Clermontia peleana* subsp. *peleana*, *Cyanea tritomantha*, *Trematolobelia wimmeri*, *Phyllostegia vestita*).

Management recommendations: Expand weed management to adjacent rain forest in the Kīlauea summit and Devastation areas as funding becomes available.

Appendix B. Weed control work conducted or proposed post-2007 in Hawai'i Volcanoes National Park.

Devastation (34 ha) - The Devastation area was a former mesic 'ōhi'a forest located on the southeastern rim of Kīlauea caldera that was impacted by volcanic cinder fall associated with the 1959 Pu'u Pua'i eruption. The area offers a superb example of primary and secondary plant succession following a volcanic event (Smathers and Mueller-Dombois 2007) . Faya tree is the major invader followed by prickly Florida blackberry, and Himalayan raspberry and scattered individuals of kāhili ginger. Also, introduced knotweed is widespread across the cinder fields. The area is ungulate free and lies adjacent to Keanakāko'i and Thurston SEAs. Management of faya tree would remove an important source of weed dispersion into those SEAs, The area was proposed for a SEA in 2003, and funding was received in 2010 to implement weed control. By 2011, an initial search and removal of target weeds from the entire area was completed.

Kū'e'e (4,388 ha) - Establishment of this SEA would extend weed management of silk oak, faya tree and christmasberry beyond Kamaka'ia SEA to ~350 m elevation. The area has been managed to remove all fountain grass since the early 1990s and albizia (*Falcataria moluccana*) since 2000 when individuals were first spotted during aerial surveys in the area. The unit is a mosaic of dry 'ōhi'a woodland and alien grass kīpuka surrounded by sparsely vegetated lava flows. In some of the kīpuka are relictual stands of lama and habitat for several rare and federally listed species, including halapepe 'ōhai and kauila.

Kahuku East (6,498 ha) - The largest of the proposed SEAs in Kahuku, this area contains substantial subalpine shrubland that provides habitat for the endangered laukāhi kuahiwi (*Plantago hawaiiensis*) in addition to other rare and endangered species (e.g., makou (*Ranunculus hawaiiensis*), mau`u lā`ili (*Sisyrinchim acre*), `ōhelo papa (*Fragaria chiloensis* subsp. *sandwicensis*) and nēnē. Montane mesic koa and 'ōhi'a forest contains the endangered honeycreepers `akiapōlā `au (*Hemignathus munroi*), `ākepa (*Loxops coccineus* subsp. *coccineus*), Hawaiian creeper (*Oreomystis mana*), and endangered and rare plants (`ākala (*Rubus macraei*), Hawaiian catchfly, hō`awa (*Pittosporum hawaiiense*), and `ōhā (*Clermontia lindseyana*). Recovery efforts for rare plants are focused inside a small fenced exclosures (< 10 ha). Boundary fencing to exclude ungulates began in 2009 and ungulate removal is expected to be completed by 2017. Plant communities are native dominated. Faya tree is the primary threat to native ecosystems. Several individuals have been located and removed but additional searches are needed to locate all individuals and determine the extent of the infestation, and sites prioritized for treatment.

Kahuku Mauka (3,466 ha) - Spanning montane mesic koa and 'ōhi'a forest to subalpine mesic shrubland (1,500 m to 2,100 m) this area contains the largest remaining population of the endangered Ka'ū silversword, and is the focus of intensive recovery efforts for this species as well as several other endangered and rare plant species that previously occurred or occur in low numbers (`ākala, Hawaiian catchfly, hō`awa, makou, mau`u lā`ili, `ōhelo papa, and `ōhā. The mesic forest provides habitat for endangered honey creepers `ākepa, and Hawaiian creeper. Shrublands provide important forage for nēnē during the nonbreeding months (April through September). Plant communities are native dominated. Boundary fencing to exclude ungulates began in 2009 and is expected to be completed in 2016 followed by completion of ungulate removal in 2017. A planting of Monterey pine (*Pinus radiata*) by the previous landowners located near an administrative cabin was removed by park staff to prevent seedlings from spreading. Follow-up is needed to treat new seedlings that may establish. Faya tree is the primary threat to native ecosystems. Several individuals have been located and removed but additional searches are needed to locate all individuals and determine the extent of the infestation, and sites prioritized for treatment.

Kahuku Pu`u `Akihi (12 ha) - This is the largest remnant of lowland wet forest in Kahuku, situated in a narrow ravine surrounded by former cattle pasture at 900 m elevation. The steep topography of the ravine prevented cattle from entering and damaging the forest. The locations close

proximity to the main road has allowed for ranger led hikes that offer visitors a rare glimpse of wet lowland native forest. Within this site is one of the three populations of the shrub *Cyrtandra menziesii*, a Species of Concern (SOC), as well as the endangered hō`awa, the only Kahuku populations of hame and alani (*Melicope radiata*), and the only individual of olonā (*Touchardia latifolia*). Although domestic cattle have been removed, threats to plants include feral pigs and wild mouflon sheep, and invasive strawberry guava, christmasberry, and kāhili ginger. If protected and restored, this area would serve as a site for reintroduction of missing rare plant species previously documented at Kahuku but apparently no longer present.

Kahuku West (1,538 ha) - This montane elevation habitat (1,500 m to 2,100 m) contains mesic koa and `ōhi`a forest and woodland, examples of early plant colonization on young lava flows and habitat for the candidate endangered makou, and the Species of Concern mau`u lā`ili. Although degraded by koa logging and pasture grasses, koa trees along with some māmane, nāio and tree `ā`ali`i, are rapidly recovering since construction of boundary fences and ungulate reduction to to remnant numbers. Recovery of rare plants thru propagation and planting has begun in three restoration sites. Faya tree is at an early stage of invasion with 170 individuals encountered during surveys in 2005 that were subsequently treated, with additional individuals (2 adults and 65 seedlings) discovered and removed in 2006. This is considered a discrete population likely established by seed dispersal via birds from distal trees located in the state Ka`ū Forest Reserve. Other invasive species present on young lava flow communities are mullein and pink knotweed.

Mauna Loa Lower (641 ha) - This area lies between Mauna Loa Upper and Kīpuka Kī SEA and its establishment as an SEA would provide contiguous weed management of montane koa forest from 1,200 m to 2,200 m in the park. Fenced and ungulate free since the early 1980's, concentrations of prickly Florida blackberry and the widespread presence of meadowrice and Kikuyu grasses are the primary threats to the forest. Small patches of Jerusalem cherry are also present in the understory. Beneath the koa canopy there is little remaining of the native understory with regards to both species and structure. Park staff began experiments to restore the native understory through removal of grasses and planting of native species in several locations beginning in 1999. There are several small koa kīpuka isolated by historic a`ā flows that contain remnants of the native understory that were identified for restoration in 2006 and work begun in 2009. In 2005, biannual control of banana poka (*Passiflora tarminiana*) by ground crews began shortly after several plants were discovered along the upper boundary of this proposed unit. Searches were confined to a 9-ha area that straddled this area and the adjacent Mauna Loa Upper SEA after staff mapped the boundaries of the Infestation. Also in 2005, a patch of lupine (*Lupinus angustifolius*) was discovered and treated along the jeep road that demarcated the upper boundary of this proposed unit.

`Ōla`a-Ag Unit (162 ha) - This area lies between `Ōla`a-Koa and `Ōla`a-Pu`u units. Establishment of this fenced unit as an SEA would provide a 8-km contiguous strip of protected rain forest in `Ōla`a tract. In addition, weed management in Ag unit would remove a significant source of weed dispersion into Pu`u and Koa units. Infestations of Himalayan raspberry, banana poka, kāhili ginger Andean raspberry, and strawberry guava are scattered throughout the unit. The area was fenced and ungulate-free by 1986. The `ōhi`a/hāpu`u rain forest provides habitat for several rare plants including the federally listed ha`iwale (*Cyrtandra giffardii*), and one of only a handful of known naturally occurring population of the Species of Concern *Schiedea diffusa* on the island of Hawai`i. This area was originally proposed for a SEA in 2003 and funding was received in 2008 to implement weed control. By 2009, an initial search and removal of target weeds from the entire fenced unit was completed.

`Ōla`a-New Unit (764 ha) - This area was fenced in 1999 units and pigs are reduced to remnant numbers. Infestations of Himalayan raspberry, banana poka, kāhili ginger, palm grass (*Setaria palmifolia*) and strawberry guava are present throughout the unit. The `ōhi`a/hāpu`u rain forest provides habitat for several rare and federally listed plants. Weed management would remove a significant source of weed dispersion into Pu`u and Koa units and would support weed control in the nearby state Pu`u Maka`ala Natural Area Reserve. However, the more remote location, large

size, and small number of pigs remaining in the unit makes this a lower priority for weed management compared to the other proposed 'Ōla'a units.

Upper Mauna Ulu (2,718 ha) - The 1969-1974 Mauna Ulu lava flows offer an example of primary succession on young lava flows stretching across dry to mesic and wet environments. At higher elevations that receive more moisture, 'ōhi'a trees, 'ōhelo (*Vaccinium reticulatum*), and other native shrubs, and sedges are slowly establishing. The sparsely-vegetated environment serves as a natural barrier to weed dispersal into adjacent SEAs (Kīpuka Kahali'i, Pu'u Huluhulu, and East Rift). Above 800 m elevation, several small kīpuka located inside the lava flows harbor rare plants such as nēnēleau (*Rhus sandwicensis*) and 'iliahi. However most of these kīpuka are invaded by faya tree. Also knotweed is establishing on the northwest end of the lava flows. Establishment of an SEA in the upper portion of the lava flows would perpetuate the area as a natural buffer zone for adjacent SEAs, and protect a unique ecological system.