Cooperative National Park Resources Studies Unit
University of Hawai'i at Manoa
Department of Botany
3190 Maile Way
Honolulu, Hawai'i 96822
(808) 956-8218

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Fire Effects In The Coastal Lowlands Hawai'i Volcanoes National Park

J.T. Tunison[1], J.A.K. Leialoha[2], R.L. Loh[1], L.W. Pratt[1], and P.K. Higashino[3]

[1]Hawai'i Volcanoes National Park
P.O. Box 52
Hawai'i National Park, Hawai'i 96718

[2]P.O. Box 803
Pahoa, Hawai'i 96778

[3]The Nature Conservancy of Hawai'i
P.O. Box 1716
Makawao, Maui 96768

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ABSTRACT

Since 1975 fire frequency has increased sharply in the coastal lowlands of Hawai'i Volcanoes National Park. This was due largely to increases in grass biomass following the removal of feral goats and/or the spread of fire-tolerant species. Fire effects were studied in 13 sites within five lava or lightning caused burns occurring between 1985 and 1989. The study sites were located in five major plant communities and two ecotones. Grasslands characterized the vegetation of the central coastal lowland sites, and lowland scrub with native shrub overstory and alien grass understory characterized the sites in the eastern lowlands. All of the coastal lowlands were severely impacted by Polynesian cultivation and burning practices, nineteenth century cattle grazing, and 150 years of feral goat browsing and grazing. Cover was determined by point-intercept methods along unreplicated transects established prior to the fire or by replicated burned and unburned pairs of transects. Density of shrubs was determined in plots along the paired transects. Frequency of resprouting of woody plants was determined by monitoring individual plants for one year. The results diff-ered from those observed by Hughes *et al.* (1991) and Smith and Parman (1981) in the lower submontane seasonal zone. Alien grass cover did not increase in most sites, and total native cover usually increased or remained the same. In the eastern coastal lowlands, fire characteristically stimulated the spread of the native subshrub *Waltheria indica*, bunchgrass *Heteropogon contortus*, and shrubs *Dodonaea viscosa* and *Osteomeles anthyllidifolia*. Fire however depleted the tall native shrub component by nearly eliminating *Wikstroemia sandwicensis*. *Waltheria* and *Heteropogon* generally were also stimulated in the central lowlands but not sufficiently to increase total native plant cover in most sites. These findings lead to the conclusions that the Park's policy of total fire suppression should continue to protect the native shrub component of the rare *Wikstroemia* shrubland, allow natural recolonization of the central grasslands by native trees and shrubs, and prevent the spread of the disruptive fire-stimulated *Melinis* and *Hyparrhenia*. However, a judicious use of prescribed burning, on an experimental basis, may be useful in establishing fuel breaks and stimulating the recovery of native species such as *Heteropogon* and *Dodonaea*.

INTRODUCTION

Fire frequency has increased markedly in the coastal lowlands of Hawai'i Volcanoes National Park (HAVO) since the mid-1970's. There were two documented fires prior to 1975. From 1975-1992 there have been 20 fires totalling 4200 ha (Tunison, unpublished data) Although some fires may be attributed to increased volcanic activity from 1983-1992, changes in fuels following the removal of feral goats (*Capra hircus*) and the spread of fire-tolerant introduced grasses largely account for greater fire frequency and size (Smith and Tunison, 1992).

The Park Service currently suppresses all fires in the coastal lowlands because of perceived but mostly unquantified damage to native vegetation. Fuel breaks have been established in HAVO, including the coastal lowlands, to reduce the spread of fire (NPS 1990).

The purpose of this report is to describe the short-term effects of fire on the major plant communities of the coastal lowland ecological zone in HAVO. The relative success of both native and alien vegetation, especially of introduced, fire-tolerant grasses and native woody plants will be emphasized. Recommendations about further research and the Park's fire management policy and strategies will be offered.

Studies of fire in the coastal lowlands were designed to address the following four hypotheses. These are based on published results of fire effects in the submontane seasonal zone, the ecological zone adjacent to the coastal lowlands which shares a summer-dry climate and many plant species (Hughes *et al.* 1991, Smith *et al.* 1980). Alien grasses invaded the submontane seasonal in the 1960's and allowed for fire spread (Hughes *et al.* 1991).

1. **Fire favors alien plant species, particularly grasses, and discourages native vegetation, particularly woody plants.** Alien plants are tolerant of fire, or even adapted to it, and quickly invade sites from which native plants are removed by fire. The main alien grasses in the coastal lowlands are *Andropogon virginicus* (broomsedge), *Schizachyrium condensatum* (beardgrass), *Melinis minutiflora* (molasses grass), *Hyparrhenia rufa* (thatchinggrass), and *Rhynchelytrum repens* (Natal redtop). Fire tolerance or adaptation is suggested by the fact that these species (especially first four species) tend to maintain high dead:live biomass ratios (80-90%) throughout the year, are capable of carrying fire at very high relative humidities (85-95%) and high fuel moistures (20-25%), and vegetatively regenerate rapidly and with increased vigor following fire (Hughes *et al.* 1991). Smith *et al.* (1980) found an increase in cover of the alien grasses *Schizachyrium* and *Andropogon* 18 months after a prescribed burn. Hughes *et al.* (1991) documented a sharp increase in *Melinis* 18 months after fire which persisted at high cover in a 17-year-old burn.

Mueller-Dombois (1981a) and Mueller-Dombois and Goldhammer (1990) found that fire in the wet tropics generally is deleterious to woody vegetation when grasses are stimulated by fire. Fire has reduced native woody plant cover in the Park's submontane seasonal zone. Smith *et al.* (1980) found a short term decrease in native plant cover. Hughes *et al.* (1991) demonstrated the long term loss of *Metrosideros polymorpha* ('ohi'a), *Styphelia tameiameiae* (pukiawe), and *Wikstroemia phillyreifolia* ('akia).

2. **Native plant species in the coastal lowlands are poorly adapted to fire.** Some upland native Hawaiian plant species, e.g., *Acacia koa* (koa) or *Sophora chrysophylla* (mamane) recover rapidly from fire, either by establishment from seed or by crown or root sprouts. One species in the lowlands, *Dodonaea viscosa* ('a'ali'i), is known to recover from fire through seedling recruitment (Hughes *et al.*, 1991). It is also known that *Heteropogon contortus* (pili) is tolerant of fire. This species was burned by early Hawaiians to stimulate its growth for thatching material (Mueller-Dombois 1981a). However, the response of other native plant species in the coastal lowlands is not known. From these patterns, a low percentage of resprouting and establishment from seed or sprouts is expected for coastal lowland native plants following fire.

The tolerance of coastal lowland native plant species could be predicted from the pre-human fire regime, which would determine the evolutionary importance of fire. Ecosystems characterized by abundant fine fuels, particularly grasses, would support frequent fires and fire-tolerant species. However, pre-Polynesian vegetation and fire regimes are not well understood. Cuddihy and Stone (1990) and Mueller-Dombois (1981a) feel that woody plants were much more abundant in the coastal lowlands, although grasses may have dominated in some areas.

3. **Damage to native plants and success of alien plants are related to fire intensity.** This hypothesis is not suggested by published data. However, If fire is not natural to native coastal lowland ecosystems (Mueller-Dombois 1981a), it follows that the higher fire intensities will result in greater damage to native vegetation. In weakening native competitors, more intense fires will result in more rapid or more abundant recovery of alien plants species, which are mostly tolerant of fire. The level of fire intensity, documented for all sites, varied from intense head fires to low intensity backing fires.

4. **Successive fires result in cumulative damage to native vegetation and increase the abundance of alien plants.** Hughes *et al.* (1991) found that a second fire further increased the cover of the alien grass *Melinis* and reduced the cover of native shrubs. This pattern of response will mean that successive fires will convert native woodlands and shrublands to alien savannas and grasslands. Two sites in the study area were burned twice.

STUDY SITES

Site Characteristics

The 13 sites studied are located on the southern flank of Kilauea volcano in the central and eastern coastal lowlands of HAVO between the Ka'aha Trail and the eastern Park boundary (Figs. 1 and 2). Site features are described in detail in Table 1. Mueller-Dombois (1976 and 1980) and Doty and Mueller-Dombois (1966) have described the coastal lowland environment. The following description of study sites is extracted from these accounts.

The coastal lowland environment consists of the area between the shoreline and the base of the major fault scarps which are typically located 1.4-5 km inland. Elevations range from near sea level to 450 m, although a majority of the study sites are located below 100 m. Eleven of the 13 sites are on pahoehoe with thin, discontinuous ash-derived soil, and two study sites are on deep soil formed from Pahala ash. At least a thin layer of ash is required to support sufficient grass biomass to carry fire.

The climate of the coastal lowlands is warm-tropical with mean annual temperatures of 22-24°C. and no cold period during the year. There is a distinct rainfall gradient from east to west reflecting the island windward-leeward gradient and the prevailing trade-wind weather patterns. Rainfall ranges from approximately 2000 mm at burn sites along the eastern Park boundary to approximately 500 mm at sites near Pu'u Kaone. All of the coastal lowlands have a summer dry climate, with this pattern more pronounced to the west.

The study sites in the central coastal lowlands occur in the grasslands that characterize this area: *Hyparrhenia* grassland, *Rhynchelytrum* grassland, *Hyparrhenia/Melinis*, and *Heteropogon* grassland (Mueller-Dombois 1980). *Hyparrhenia*, *Heteropogon*, and *Rhynchelytrum* grasslands are also described by Wagner *et al.* (1990). Study sites are also located in two ecotones: 1) a transition between *Melinis* and *Rhynchelytrum* grasslands, and 2) a transition among *Heteropogon*, *Rhynchelytrum*, and *Hyparrhenia* grasslands. The subshrubs (chamaephytes) *Chamaecrista nictitans* (patridge pea), *Waltheria indica* ('uhaloa) and *Indigofera suffruticosa* (indigo) are common in some sites in the central coastal lowlands.

The study sites in the eastern coastal lowland are located in open lowland scrub which characterizes the extensive pahoehoe flats of this area. This community is dominated by open stands of the shrubs *Dodonaea* and *Wikstroemia sandwicensis* ('akia). The prostrate form of *Osteomeles anthyllidifolia* ('u'ulei) is a common component of the shrub layer, and is, in some areas, the most abundant shrub. The subshrubs *Chamaecrista* and *Waltheria* are ubiquitous but contribute little cover. The native shrub/small tree *Canthium odoratum* ('alahe'e) and alien shrubs *Psidium guajava* (common guava) and *Schinus terebinthifolius* (Christmasberry) are widespread and locally common. Shrub densities, particularly the density of *Wikstroemia* and *Canthium*, tend to be higher to the east and closer to the coast. *Metrosideros* and *Disopyros sandwicensis* (lama) grow as a short-statured scattered tree in the eastern coastal lowlands, but were rare in the study sites. Williams (1985) concluded that most native and exotic woody plant species are regenerating well and woody species are increasing in density following the removal of non-native ungulates. Open lowland scrub is also described by Wagner *et al.* (1990) as

Wikstroemia shrubland. This community is characterized as rare and local in the state (Hawai'i Heritage Program 1990).

In the eastern coastal lowlands, grasses form a discontinuous matrix between and below the shrubs. *Andropogon virginicus* (broomsedge) and *Schizachyrium condensatum* (=*Andropogon glomeratus*) (beardgrass) are the dominants in the eastern sites. *Heteropogon* and *Rhynchelytrum* are more abundant to the west and closer to the shoreline. *Melinis* occurs in localized patches, usually above 70 m elevation, possibly in more well-watered sites.

The study sites were located in five burns which took place between 1985 and 1989 (Table 1). All burns resulted from natural ignition sources, four by lava flows and one by lightning. Fire intensities varied because of differences in fire spread behavior. Six sites experienced low intensity fire because fire passing through them was backing into the wind (backing fires). Four sites had high fire intensities because the fires that passed through them were pushed by strong winds (head fires). One area had moderate fire intensity because it was affected by a fire moving at right angles to the wind (flanking fire). One site contained a plot burned by a head fire and a plot burned by a backing fire (Table 1).

Recent Changes in Plant Communities, Fuels, and Fire Regimes

The dramatic increases in fire frequency and size in the last 20 years in the coastal lowlands is due largely to the increase in grass biomass. Increases in volcanic activity and park visitation may have also been factors. A noticeable increase in biomass and/or shift in species composition of grasses occurred throughout the coastal lowlands beginning in the 1960's and 1970's. Patterns of vegetation change and possibly the role of feral goat removal differ between the central and eastern coastal lowlands.

Grasslands in the central coastal lowlands shifted in the early 1970's from those dominated by annual and short-perennial grass to those dominated by tall and mid-sized, fire-tolerant, perennial grasses (Mueller-Dombois 1980). These patterns have been described through comparative mapping (Mueller-Dombois 1980) and exclosure studies (Mueller-Dombois and Spatz 1975). *Eragrostis tenella* (annual love grass), the low perennial grasses, *Chrysopogon aciculatus* (golden beardgrass) and *Cynodon dactylon* (Bermuda grass), and the indigenous *Heteropogon* were replaced by *Rhynchelytrum*, *Hyparrhenia*, and *Melinis*.

These successional patterns can be attributed to the removal of feral goats beginning in the early 1970's (Mueller-Dombois and Spatz 1975). Approximately 93% of the 14,000 goats inhabiting the Park in 1970 were removed between 1971-1975, with less than 200 goats remaining by 1980 (Katahira and Stone 1982). Some of the highest goat concentrations were in the central coastal lowlands (Baker and Reeser 1972). *Hyparrhenia* and *Melinis* continue to expand in the central coastal lowlands since last mapped by Mueller-Dombois in 1980 (Tunison, unpublished data). Pratt (unpublished data) has found an increase in native *Heteropogon*.

In the late 1960's, the eastern coastal lowlands underwent a noticeable increase in density of woody plants and a dramatic shift in grass composition and possibly biomass. Williams (1985) describes an increase in woody plant cover since the 1950's, especially *Canthium* and *Wikstroemia*. She attributes the increase in woody plants to goat removal, which was concluded in the Kalapana area in the late 1960's, prior to removal efforts in the central lowlands (Reeser, pers. comm., Baker and Reeser 1972).

Schizachyrium and *Andropogon* apparently invaded the eastern lowland scrub in the late 1960's. Stone (1959) did not find *Schizachyrium* or *Andropogon* in a botanical survey that included the eastern coastal lowlands, but Warshauer and Jacobi (1973) indicated that *Andropogon* and *Schizachyrium* were the understory dominants in the lowland scrub communities. The role of goat removal in the spread of *Andropogon* and *Schizachyrium* is not clear. *Schizachyrium* and *Andropogon* spread rapidly throughout most of the Park, including areas with considerable goat grazing pressure and areas with little or no goats. *Schizachyrium* and *Andropogon* are relatively unpalatable to goats, and not preferred to woody plants (Reeser, pers. comm.). The apparent abundance of shrubs in the eastern coastal lowlands during the 1960's suggests that grazing pressure on herbaceous plants was relatively low and may not have driven changes in grass species.

METHODS

Two distinct sampling designs were employed:

1. Replicated burned and unburned transects and associated plots in the eastern coastal lowlands, established after fire.

2. Unpaired, unreplicated, and preexisting transects in the central coastal lowlands. These transects were established by Mueller-Dombois in 1970 or by Pratt in 1978-1979.

In all cases, monitoring was initiated four to six weeks after the fire and repeated at six to 24 month intervals. The last monitoring was conducted between December, 1989 and July, 1990. Shrub mortality of marked individuals along transects was monitored for one year after the fire. Cover and density changes were monitored from two to five years. All sites were permanently marked and mapped for potential long-term study. Minor nuances of methodology among the 13 sites are described in Table 1.

Cover along all transects was determined by point-intercept methods using a 1.25 m tall point frame with five sharpened points per meter. Intercepted dried/dead foliage was recorded as if live if the foliage were attached to a live plant. This reduced differences due to seasonal fluctuations. Detached dried/dead vegetation was counted as litter. If the point did not encounter vegetation, a substrate type--rock, soil, litter, lichen, or moss--was recorded. Transects in the eastern coastal lowlands were 40 m long; transects established by Mueller-Dombois and Pratt varied in length but were usually 60 m long.

Density was monitored along paired burned and unburned transects. Woody plants were counted in three 3 X 10 m plots located systematically at 5, 15, and 25 m along and perpendicular to one side of each transect. Subshrubs were counted in four 2 × 2 m plots located systematically at 0, 10, 20, and 30 m along one side of the transect. Only those woody species with distinguishable individuals were counted. Clonal, root-sprouting shrubs such as *Osteomeles* were not counted.

Unburned controls were established in five of the 13 sites to evaluate the significance of vegetation changes in the burned area. They do not necessarily represent pre-burn vegetation because vegetation is changing throughout the coastal lowlands without the effects of fire (Mueller-Dombois 1980). Burned and unburned pairs were always located on burned and unburned sides of fire control lines rather than edges of the burn where fire was naturally extingushed. This minimized the possiblity of sampling across natural fuel/vegetation discontinuities.

Transects were located in a stratified-random or a random-systematic fashion. Three to six replicates were located in each identified stratum or vegetation type. In stratified-random sampling, all the replicates were located in the stratum with azimuths of transects located at random. In random-systematic sampling, a starting point for the first transect was established randomly and transect azimuths and distances to the next transect were fixed. Rejection criteria included the presence of pahoehoe tumuli, 'a'a patches, or lava tube openings. These substrates typically supported a lower cover of grass and higher densities of shrubs than surrounding areas. New random azimuths were selected if the first azimuths selected placed the transects in areas meeting the rejection criteria. If density plots were located on substrates with these rejection criteria, they were relocated to the opposite side of the transect or the next suitable location on the transect.

Additional transects and plots were established in early summer, 1990. Cover data were arc-sign transformed and density data were log-transformed. The significance of mean cover and density differences between burned and unburned controls within each site was tested with a t-test when variances were equal and a t' test when variances were unequal. Equality of variances was determined by an f-test. Only data from 1990 were statistically analyzed. Transects and plots consistently monitored from immediate post-fire to 1990 were evaluated qualitatively for successional trends. Pre-and post-burn conditions in the unreplicated transects in the central coastal lowlands were also tested statistically. Changes in the ratio of total cover of native vegetation to total cover of alien vegetation was tested with chi-square two x two contingency tables ($p<0.05$).

The capacity of woody plants to resprout after fire was monitored in the eastern coastal lowlands. Five to 15 individuals of each common tree or shrub species with partly or mostly scorched canopies were tagged when burn transects were first established prior to signs of recovery. The plants were tagged along 40 m transects utilized for cover measurements in five sites and along three 30 m long transects in two other sites set up solely to evaluate woody plant mortality. The transects were categorized as experiencing high intensity or low intensity fire based on a total of 382 native and 101 alien woody plants monitored. After one year, the presence of root crown or epicormic sprouts was noted. Two x two contigency tables ($p < 0.05$) were used to compare resprouting between low and high fire intensity sites.

RESULTS

Eastern Coastal Lowlands Sites

Fire effects in the eastern coastal lowlands were demonstrated by changes in cover and density in three sites in the Phase 30/Merrie Monarch Burns and two sites in the Paliuli Burn. They were also indicated by the resprouting of woody plants in the above sites and sites in the Access and Kapa'ahu Burns (Table 1).

Phase 30

The Phase 30 Fire occurred February, 1985 and was caused by the Phase 30 lava flow from Pu'u O'o. The eastern portion of the burn was affected by a low intensity fire, and this site is designated Low Intensity (Table 1). The western portion of the burn was affected by a flanking fire of relatively moderate intensity and is designated as Medium Intensity. A portion of the latter site was reburned 10 weeks later by the Merrie Monarch Fire with a high-intensity head fire, and this reburn is designated High Intensity-Reburn. A single unburned control (Unburned) for all three sites was established. Data from the three burned sites were compared because of their close proximity, common site features and unburned control, and the opportunity to compare the effects of different fire intensities.

All sites were located in coastal lowland scrub at approximately 70 m elevation and 2.5 km from the shoreline. *Osteomeles*, *Dodonaea*, and *Wikstroemia* were the most common shrubs and formed an open canopy. *Waltheria* and *Chamaecrista* were common subshrubs. *Andropogon* and *Schizachyrium* formed a matrix of alien grass beneath and among the shrubs.

After five years, the open lowland scrub of the Phase 30 site was physiogonomically altered by fire. The most perceptible change was the sharp reduction of tall shrubs. *Wikstroemia*, formerly the hallmark species of the coastal lowland scrub, was mostly eliminated and showed no signs of recovery, with cover and density of *Wikstroemia* significantly less in all burned sites (Tables 2 and 3). The shorter native shrubs, *Dodonaea* and *Osteomeles*, became more important in some sites. *Dodonaea* had significantly higher cover and densities in the High Intensity-Reburn but significantly lower cover in the Medium Intensity, compared to the Unburned. *Osteomeles* had significantly greater cover in the Low Intensity and Medium Intensity (densities were not determined for this clonal species). The scattered alien shrubs, *Lantana camara, Psidium guajava*, and the Polynesian introduction *Morinda citrifolia* (noni), did not appear to be affected by fire.

The subshrubs *Chamaecrista* and *Waltheria* achieved their greatest abundance one to three years after the burn, and thereafter appeared to decline (Fig. 3). Subshrubs dominated the first year of recovery in the High Intensity-Reburn site, relative to grass species. Even after five years the densities of *Waltheria* were greater in all burned sites, compared to the unburned, and cover of *Waltheria* was significantly greater in the High Intensity-Reburn site (Tables 2 and 4). *Chamaecrista* cover was greater in all burned sites compared to the Unburned.

The *Schizachyrium-Andropogon* grass matrix was largely maintained (Table 2). Andropogon and *Schizachyrium* achieved near pre-burn cover levels within nine months after fire in most sites (Fig. 4). *Andropogon* cover was not significantly different in any burn site from the control. Medium and High intensity cover were significantly different from each other. *Schizachyrium* had significantly lower cover only in the Medium Intensity site. *Heteropogon* became a significiant minor component in this vegetation layer in most areas. Its cover was significantly greater in the Low Intensity and High Intensity-Reburn sites than in the Unburned (Table 2).

Fire intensity was apparently an important factor in the recovery of species. High Intensity-Reburn and Medium Intensity sites were the most affected, as indicated by the fact that these treatments had the largest number of species significantly different in cover from other treatments (Table 2). The Low Intensity treatment had the fewest differences. Eight species in High Intensity-Reburn differed from the control. *Dodonaea*, *Waltheria*, *Heteropogon*, and *Chamaecrista* had significantly greater cover in the High Intensity-Reburn, whereas *Osteomeles*, *Wikstroemia*, *Cassytha filiformis* (kauna'oa), and *Andropogon* had significantly greater cover in the Unburned. Eight species in the Medium Intensity also differed from the Unburned. *Osteomeles*, *Chamaecrista*, *Andropogon*, *Schizachrium*, and *Phymatosorus scolopendrium* (laua'e fern) had greater cover in the Medium Intensity; *Dodonaea*, *Wikstroemia*, and *Cassytha* had less. Only three species in the Low Intensity area differed in cover from the Unburned. *Heteropogon* and *Osteomeles* had greater cover in the Low Intensity and *Wikstroemia* had less cover.

All burned sites had significantly greater aggregate cover of native vegetation (Table 2), with no significant differences among the three burned sites. Increases in total native cover in the Low Intensity were due to increases in cover of *Cassytha*, *Osteomeles*, and *Heteropogon*; in Medium Intensity to increases in cover of *Osteomeles* and *Heteropogon*; and in High Intensity-Reburn to increase in cover of *Dodonaea* and *Heteropogon*. Total alien cover was less in all burned sites relative to the unburned control, however significantly so only in the Low Intensity. Total alien cover did not differ significantly among the three burn treatments.

Paliuli Makai

The Paliuli Makai site is located at 90 m elevation, 1.5 km from the shoreline in the western edge of the open lowland scrub (Table 1). *Dodonaea* and *Osteomeles* were the most common shrubs, although *Wikstroemia* was locally common. The grass layer was dominated by *Andropogon* and *Heteropogon*, with *Schizachyrium* and *Rhynchelytrum* as minor components. Coastal lowland scrub differs in this drier location from that of the Phase 30 sites in the reduced importance of *Wikstroemia* and greater relative abundance of *Heteropogon* and *Rhynchelytrum*. It was burned at low intensity by the Paliuli Fire, a 325 ha fire caused by the Phase 48 lava flow of Pu'u O'o.

As in the Phase 30 Burn, the tall woody plant component of the lowland scrub was reduced, with the apparent elimination of *Wikstroemia*, already at very low densities prior to the burn (Table 5). *Lantana* was reduced in cover by the burn, but *Dodonaea* did not change significantly in cover or density, and *Osteomeles* was unchanged (Tables 5 and 6). The subshrubs *Chamaecrista* and *Waltheria* became established but showed signs of declining by four years (Fig. 5). Cover of both species was significantly greater in the burned area after four years.

There was a major shift in the composition of the grass matrix of the burned areas. *Heteropogon* and *Rhynchelytrum* increased sharply between six and 33 months (Fig. 6). After four years there was significantly greater cover of *Rhynchelytrum* and *Heteropogon* (Table 5). In contrast, *Andropogon* and *Schizachyrium*, which had significantly less cover in the burned area, recovered rapidly immediately post-burn but their rate of increase after six months was less than that of *Heteropogon* and *Rhynchelytrum* after six months (Fig. 6).

There was significantly greater total cover of native species in the burned area (Table 5). This was due chiefly to the increased abundance of *Heteropogon* and *Waltheria*. There was no significant difference in aggregate cover of alien species between the Burned and Unburned.

Paliuli Mauka

This site, located at 190 m elevation in the Paliuli Burn at the upper and western edge of the coastal lowland scrub, was burned by a high intensity fire. *Dodonaea* and *Osteomeles* were the most abundant native shrub components of unburned lowland scrub in this area, with *Wikstroemia* locally common. The Paliuli Mauka site had a locally high cover of *Melinis*. Transects were established primarily to monitor the effects of fire on this species in the coastal lowlands.

The most important change in this plant community after fire was the spread of *Melinis*. *Melinis* cover more than doubled in the burned area (Table 8), increasing rapidly during the first three years after fire (Fig. 7). There were no significant differences in the cover of the other grass species.

Total alien cover was significantly greater in the burned area because of the sharp increases in *Melinis*, even though the cover of three other alien species decreased after fire: the shrub *Lantana*, and the herbs *Desmodium sandwicensis* (Spanish clover) and *Stachytarpheta dichotoma*.

Total native plant cover was not significantly different between burned and unburned areas (Table 8) because there were no significant differences in cover of any of the four native plant species, *Dodonaea*, *Waltheria*, *Osteomeles*, and *Heteropogon*. *Osteomeles* was fairly abundant in the unburned area, but differences between the burned and unburned areas were not significant because of high variances and the low number of transects. However, there were significant differences in densities of the native woody plants. Densities of *Waltheria* were greater in the burn, whereas densities of *Wikstroemia* and *Dodonaea* were lower in the burn.

Resprouting of Shrubs in Eastern Coastal Lowlands

Resprouting of shrubs was monitored in the eastern coastal lowlands in four high intensity sites (Tables 11) and five low intensity sites (Table 12). *Schinus terebinthifolius* (Christmasberry), *Osteomeles*, and *Psidium* resprouted at relatively high frequencies in both high and low fire intensities (Tables 11 and 12). *Canthium odoratum* (alahe'e), *Dodonaea*, and *Lantana* resprouted moderately well in some low intensity sites. Syzygium cumini (Java plum), *Diospyros sandwicensis* (lama), and *Morinda citrifolia* (noni) resprouted consistently although sample sizes were very small. *Wikstroemia* was the poorest resprouter, with only 10% of the plants recovering in the low intensity sites and eight percent in the high intensity sites. All shrubs in the study, except *Psidium*, resprouted more frequently after low intensity than high intensity fire (Tables 11 and 12). However, when analyzed by chi square, these apparent differences were statistically significant ($p < .05$) only for *Canthium*, *Dodonaea*, *Lantana*, and *Morinda*.

The subshrubs *Waltheria* and *Chamaecrista* became established largely from seed after fire. Resprouting also occurred but was difficult to distinguish in all cases from seedling recruitment because the burned plants were small and often totally consumed by fire, and because both seedlings and resprouts grew rapidly. Resprouting was therefore not quantified for these species.

Central Coastal Lowland Sites

Fire effects in the central coastal lowlands were demonstrated by post-fire changes in vegetative cover at six sites in the Uila Burn of September, 1987. This 2700 ha lightning-caused fire burned through a feral goat exclosure built in 1970 at Kaone and through unreplicated 60 m transects established in 1978-1980 at Pu'u Kapukapu, Makahanau Pali, Keauhou Landing, and Halape Shelter 1978-1980 to monitor vegetation changes following the removal of feral goats. The transects have been read on a yearly or biannual basis since establishment. The last pre-burn reading was conducted in 1986, one year before the burn. Post-burn readings were made two months after the burn in 1987, in 1988 a year after the burn, and finally in late 1989 or early 1990 by the authors. No unburned controls are available for these four sites; so it is not possible to infer if all changes are the result of fire. A pair of transects was established inside and outside the burn near the Ka'aha Trail after the burn. Three of the six sites were exposed to high intensity fire and three to low intensity fire.

Some patterns are apparent for all or nearly all sites. Vegetative cover returned to preburn levels within two years. *Hyparrhenia* benefitted from fire more than any other grass species, increasing in cover in three sites, remaining the same in another, and declining in another. *Heteropogon* also benefitted from fire, increasing in cover or remaining the same in two sites and declining in another. *Rhynchelytrum* declined or remained the same in five of the six sites where present. Unlike the eastern coastal lowlands, *Melinis* declined in all sites where it was present before the burn. As in the eastern coastal lowlands, the subshrubs *Chamaecrista* and *Waltheria* typically increased in cover after fire, particularly in high intensity sites. They were often most abundant 1-2 years after fire, and typically declined slightly after two years.

The proportion of native to alien vegetative cover increased significantly in one of the three low intensity sites because of the increase in cover of *Heteropogon* but was unchanged in the two other sites. This ratio of native to alien plant cover was unchanged in one high intensity site, significantly higher in one site because of increased abundance of *Waltheria*, and signficantly lower in another because of elimination of the native vine *Canavalia Hawai'iensis* ('awikiwiki).

Keauhou Landing

The Keauhou Landing site is located at approximately 30 m elevation and 0.5 km from the shoreline in a *Rhynchelytrum* grassland with *Waltheria*, *Melinis*, *Chamaecrista*, *Hyparrhenia*, and *Desmodium* as minor components (Fig. 2). Fire intensity was low in this site (Tables 1 and 13).

Dominance patterns in the grasses changed by two years post-burn, with a substantial expansion of *Hyparrhenia* and a marked decline of *Rhynchelytrum* (Fig. 8, Table 13). *Melinis* cover changed little. *Heteropogon*, not present in the study site in 1986, had three percent cover by 1989. There was little net change in the cover of subshrubs *Chamaecrista* and *Indigofera* after two years. *Walteria* was more abundant one year after fire, but declined to lower than pre-burn values after two years. Total cover of aliens increased and total cover of native declined, mostly because of increases of *Hyparrhenia* and decreases in *Waltheria*. The change in proportion of native to aliens was not statistically significant.

Pu`u Kapukapu

This site is located at the summit of Pu`u Kapukapu at 320 m elevation, approximately 0.5 km from the shoreline (Fig. 2). It is located in a *Hyparrhenia* grassland, with *Canavalia*, *Heteropogon*, *Rhynchelytrum*, *Chrysopogon*, and the subshrubs *Waltheria* and *Chamaecrista* as minor components of the community. Fire intensity was high in this site (Tables 1 and 13).

Minor changes in alien vegetation and major changes in native vegetation occurred following the fire. *Hyparrhenia* recovered rapidly and resumed dominance of the site (Fig. 9, Table 13). However, this is the only site in which *Hyparrhenia* cover was less after two years relative to pre-burn levels. *Heteropogon* was present at less than one percent cover before the fire and was not intercepted in 1989. The most important changes were the apparent elimination of *Canavalia* and the stimulation of alien subshrubs (Fig. 9, Table 13). *Canavalia* is present in a few locations in the coastal lowlands, but probably owes its existence near the transect to a Park planting program during the 1970's. *Chamaecrista* increased cover dramatically by 1989 with copious recruitment from seed observed. Decreases in *Canavalia* and increases in *Chamaecrista* resulted in a significant decrease in the ratio of native to alien vegetation.

Makahanau Pali

The Makahanau Pali site, at approximately 450 m elevation and 2.5 km from the shoreline, is the highest elevation transect in the study area (Fig. 2). It is located just above the top of the pali in a *Melinis/Rhynchleytrum* transitional grassland with *Hyparrhenia*, *Chrysopogon*, and the subshrubs *Waltheria* and *Chamaecrista* as minor components. Fire intensity was high in this site (Table 1).

Melinis cover decreased, *Hyparrhenia* increased, amd *Rhynchelytrum* remained the same. The subshrubs *Chamaecrista, Indigofera, and Waltheria* increased substantially (Fig. 10, Table 13). Increases in *Waltheria* account for a significantly higher post-burn ratio of native to alien vegetation after fire.

Halape Shelter

This site was located near the Halape Shelter at approximately 15 m elevation and 0.25 km from the shoreline (Fig. 2). The vegetation is a mixed, probably ecotonal grassland with *Heteropogon*, *Rhynchelytrum*, and *Hyparrhenia* as codominants. The subshrubs *Waltheria*, *Chamaecrista*, and *Indigofera* occur as minor components. Fire intensity was low in this site (Tables 1 and 13).

The greatest vegetation change was a sharp increase in *Heteropogon* cover (Fig. 11, Table 13). *Hyparrhenia* cover was unchanged and *Rhynchelytrum* cover declined. *Waltheria* and *Chamaecrista* increased slightly and *Indigofera* decreased (Fig. 12, Table 13). Increases in the cover of *Heteropogon* and *Waltheria* account for a significant increase in the ratio of native to alien plants.

Pu`u Kaone

This site is located at 290 m elevation on Pu`u Kaone, approximately 1 km from the shoreline. The vegetation was dominated by *Hyparrhenia*, with *Melinis*, *Indigofera*, *Rhynchelytrum*, and *Chamaecrista* as minor components. Fire intensity was high in this site (Tables 1 and 13). Pu'u Kaone burned in both 1980 and 1987.

Hyparrhenia clearly retained its dominance of the site (Fig. 13, Table 13). *Melinis* cover declined, while *Rhynchelytrum* was apparently eliminated. *Chamaecrista* increased dramatically in the first year after the burn but declined to approximately twice pre-burn levels after two years. Changes in ratios of total cover of native to total cover of aliens were not significant.

Ka`aha Trail

This site is located at 70 m elevation north of the Ka`aha shelter, 0.5 km from the shoreline, and near the Ka`aha Trail (Fig. 2). Pre-burn vegetation was a *Heteropogon* grassland with minor amounts of *Rhynchelytrum* and *Chamaecrista*. The Ka`aha Trail site burned at low intensity. Sampling design in this site differed from that of other central coastal lowland sites in that transects were established after the fire and were paired, burned and unburned along the western edge of the Uila Burn (Tables 1 and 13).

Differences in cover between burned and unburned after three years were minor (Fig. 15 and Table 13). Both *Heteropogon* and *Rhynchelytrum* had similar cover in both the burned and unburned areas. *Chamaecrista* was more abundant in the burned area. There were no significant differences in total native and alien cover between burned and unburned areas.

DISCUSSION

The results of the studies in the coastal lowlands burns are discussed below in terms of the four hypotheses proposed in the Introduction.

Hypothesis 1. Fire favors alien plant species, particularly grasses, and discourages native vegetation, particularly woody plants. This hypothesis can be quantified and statistically tested for the eastern coastal lowlands by assessing differences in the aggregate cover of alien and native plants in the burn and alien plants or native in the unburned control. It can be assessed in single transects in the central coastal lowlands by statistically testing changes in the ratio of native to alien vegetation pre-burn and post-burn.

Hypothesis 1 is not supported by short term fire effects in the eastern coastal lowlands. Native vegetation typically increased in cover and alien vegetation rarely increased. Total native cover was significantly greater in the burned areas in the Phase 30-Low Intensity, Phase 30-High Intensity/Reburn, and Paliuli Makai sites. It was unchanged in the Phase 30-Medium Intensity site and declined only in the Paliuli Mauka site. Greater abundance of *Heteropogon*, *Waltheria*, and to a lesser extent *Osteomeles* and *Dodonaea*, account for much of the increase in native plant cover.

In contrast to the lower submontane seasonal zone of HAVO (Hughes *et al.*, 1991), native woody plant cover did not decline. The total cover of native woody plants did not change in any burn sites in the eastern lowland scrub, even though the cover of *Osteomeles* and *Waltheria* increased in three of the six sites and *Wikstroemia* declined in three sites. *Furthermore*, the total recruitment of native woody plant seedlings was unchanged except in the Phase 30-High Intensity/Reburn, where the density of *Dodonaea* increased, and in Paliuli Mauka, where the density of *Dodonaea* declined.

Even though fire may increase the total cover of native plants in the short-term, it perceptibly simplifys the native shrub overstory of the coastal scrub. This occurs primarily because of the sensitivity of *Wikstroemia* to fire and its lack of seedling recruitment after fire. *Wikstroemia* is consistently reduced to low population levels by fire. Fire also reduces *Canthium* and *Diospyros* in those sites vulnerable to fire in which these species are components of the coastal lowland scrub (Takeuchi, 1991). *Dodonaea, Osteomeles, and Waltheria*, at least in early stages, dominate the native shrub layer of the lowland scrub. Hotter fires and reburns favor *Dodonaea* and *Waltheria*, and take a greater toll on *Diospyros*, *Wikstroemia*, and *Canthium*, and *Osteomeles*. The native shrub component is eliminated where *Melinis* is important prior to the fire, except perhaps for some recovery *Dodonaea*. Hughes *et al.* (1991) found a similar relationship between the spread of *Melinis* and the loss of native shrubs after fire in the submontane seasonal zone of HAVO.

Alien plant cover did not increase in burned sites in the eastern coastal lowlands, except in one site. Alien grasses are responsible for almost all alien plant cover. Total alien plant cover declined in the Phase 30-Low Intensity and Paliuli Makai sites. It was unchanged in the Phase 30-Medium Intensity and Phase 30-High Intensity/Reburn. Total alien plant cover increased significantly in the Paliuli Mauka site, because of the spread of *Melinis*.

In the central coastal lowlands, there was not a clear trend toward increases in cover of native plants after fire. The ratio of native to alien plants increased in the Halape Shelter and Makahanau sites, declined in the Pu'u Kapukapu site, and did not change in the Keauhou Landing, Pu'u Kaone, and Ka'aha Trail sites.

Heteropogon and *Waltheria* were considered to be native plant species in the analysis above, even though there is not a concensus about their status. *Wagner et al.* (1990) considered *Heteropogon* to be indigenous or a Polynesian introduction. St. John (1973) considered it to be indigenous. Fosberg (1972) thought it might be either a Polynesian introduction or indigenous, its widespread distribution and use by Polynesians an argument for the former. Nagata (1985) did not list it as a Polynesian introduction, and Cuddihy and Stone (1990) characterized it as probably native. Records of early botanists do not help determine the status of *Heteropogon*, which was abundant in coastal areas, stimulated by Polynesians for thatching by the use of fire (Cuddihy and Stone 1990). *Waltheria* is considered by Wagner *et al.* (1990) to be apparently indigenous. St. John (1973) considered it to be such, but characterized it later (without explanation) as a weed introduced by Polynesians (St. John 1979). Other accidental Polynesian introductions are found in wet landscapes cultivated by Polynesians, but *Waltheria* grows in dry sites. Without a pollen analysis from pre-Polynesian substrates, the preponderance of circumstantial evidence supports the contention that these species are indigenous. Both are pantropical and readily dispersed by birds and therefore could have arrived on their own.

Native shrub cover changed little in the central lowland grasslands, in spite of the stimulation of *Waltheria* in some sites. The ratio of native shrub cover to total vegetative cover was significantly greater only in one of the six sites.

Fire typically did not change total alien grass cover in the eastern lowland scrub. Total alien grass cover was reduced slightly in four of the five sites (Paliuli Makai, Phase 30-Medium Intensity, Phase 30-High Intensity/Reburn, Phase 30-Low Intensity and Paliuli, although significantly so only in the last site. It increased significantly only in one site (Paliuli Mauka) where *Melinis*, a codominant prior to the fire, spread rapidly after the burn. In the grasslands of the central lowlands, total alien grass cover was unchanged two years after fire. There were no significant differences in the proportion of alien grasses to total vegetative cover prior to the fire and after two years.

The lack of change in total grass cover represents trends only in the two to five year time frame of the study. Curves of total grass cover indicate continued small increases in most sites, and total alien grass cover may eventually become significantly greater in a few years. The potential for a further increase of alien grass cover exists after future fires with the current gradual spread of *Melinis* and *Hyparrhenia* without the benefit of fire. These two species appear to be favored by fire, *Melinis* particularly in the eastern lowlands and *Hyparrhenia* in the central lowlands. The largest gains in total alien grass cover observed were due to the intensification of these species.

Hypothesis 2. Native plant species in the coastal lowlands are poorly adapted to fire. Some native plant species in the study sites appear to be well-adapted to fire, as demonstrated by their ability to recover by resprouting or from seed. *Osteomeles* resprouts at a high rate, and *Canthium* resprouts moderately well, at least under low fire intensities. *Waltheria* and *Heteropogon*, in fact, appear to be fire-stimulated. *Waltheria* reproduces from seed prolifically and *Heteropogon* intensifies after fire. Seed germination in *Waltheria* may be fire-stimulated, an adaptation for fire (Gill 1981). Although the recovery mechanisms of *Heteropogon* were not quantitatively documented, rapid vegetative recovery and numerous seedlings were observed. Burned *Heteropogon* was noted to synchronously resprout and flower within six to ten weeks after a fire. Fire-stimulated flowering is considered to be an adaptation to fire (Gill 1981). *Dodonaea*, although a weak resprouter, becomes established from seed, with prolific seedling recruitment after hotter fires or reburns. Seed germination may be fire-stimulated. *Dodonaea* can be considered to be a fire-stimulated species, but perhaps to a lesser degree than *Waltheria* and *Heteropogon*.

Although tolerant of fire, the native plants in the coastal lowlands do not constitute a fire flora. Only *Heteropogon* appears to be especially flammable, flammability being an adaptation to fire (Mutch 1972). Similar to fire-tolerant alien grasses in the lowlands, *Heteropogon* retains considerable amounts of dead foliage which increase fuel loadings and provide a fuel bed for successful ignitions and more intense fires. No native woody species appeared to require fire to regenerate. All species were reproducing well without fire (Williams 1985). The absence of seedling recruitment in resprouting woody species such as *Canthium* and *Osteomeles* and the lack of resprouting in species such as *Dodonaea* do not indicate a lack of adaptation to fire. Fire-tolerant shrubs tend to regenerate after fire by one mechanism or the other (Keely 1981).

Hypothesis 3. Damage to native plants and success of alien plants are related to fire intensity. In other words, the higher the fire intensity, the less native vegetation recovers and the more alien vegetation is intensified.

The three Phase 30 sites provide an opportunity to assess fire effects along a gradient of fire intensity, although results from the high intensity site are confounded by the fact that this site was reburned. Broad patterns of response of native plants in these sites are not consistent; thus the hypothesis is only partly supported. The highest native plant cover and the greatest reduction of alien cover are in the site with the lowest fire intensity. This is consistent with the hypothesis. However, the highest alien cover and the lowest native plant cover are in the Medium Intensity site, rather than the High Intensity/Reburn. Fire-stimulated species such as *Waltheria*, *Dodonaea*, and *Heteropogon* reach their highest recover and density in the High Intensity/ Reburn. Alien grasses do their best in the Medium Intensity and have nearly equal and lower cover in the Low Intensity and High Intensity/Reburn.

There are also no clear patterns between fire intensity and effects on the few native plants found in the central coastal lowlands. Three sites were burned at high intensity and three at low intensity (Tables 1 and 13). *Waltheria* increased in cover in two low intensity sites and decreased in another; it increased in one high intensity and was unchanged in the others. *Heteropogon*, on the other hand, may be favored by low intensity fire. It increased in the two low intensity sites where it was present and decreased in the one high intensity site where it was present.

Hypothesis 4. Successive fires result in cumulative damage to native vegetation and intensification of alien plants. In the eastern coastal lowlands, one site was reburned, the High Intensity-Reburn site in the Phase 30 sites. The total cover of native vegetation was significantly greater in the reburned site than the other sites, primarily because of the high seedling recruitment of *Waltheria*, *Dodonaea*, and the stimulation of *Heteropogon*. The total cover of alien vegetation was reduced, particularly that of alien grasses, but not significantly so. Interpretation of differences in this site is confounded by the fact that this is the only site burned at high intensity. The Pu'u Kaone site in the central lowlands was burned in 1980 and 1987. However, sampling problems preclude a comparative analysis between that site and similar once burned areas.

RECOMMENDATIONS FOR MANAGEMENT AND RESEARCH

Fire Management Policy

Fire is not as harmful to native vegetation in the coastal lowlands as previously assumed (National Park Service 1990). Fire certainly is not as damaging here as in the submontane seasonal (Hughes *et al.* 1991). However, the fire effects documented in this study indicate that the current policy of comprehensive fire suppression in the coastal lowlands is needed to preclude the spread of fire into the submontane seasonal zone, the depletion of fire-sensitive native shrubs, and the expansion of disruptive alien grasses. All burn sites studied were affected by lava-or lightning-caused fire. Therefore, a total suppression policy includes not only human-caused fire but also fire from natural ignition source.

The likelihood of fire escaping from the coastal lowlands to the submontane seasonal zone, where fire effects are decidely deleterious, is considerable. This was demonstrated by the 1992 Napau Fire which started in the coastal lowlands and readily moved into the submontane seasonal. There are no natural barriers to fire spread between the coastal lowlands and the lower submontane seasonal along Holei Pali and much of Poliokeawe Pali.

In the eastern coastal lowlands, fires deplete the native shrub component of the lowland scrub, and converts an increasingly rare plant community, *Wikstroemia* scrub, to *Dodonaea* scrub, a much more common community in the Park and and the state. Lava flows in late 1992 and early 1993 at Kamoamoa have greatly reduced the aerial extent of *Wikstroemia* scrub in HAVO. Fires in the central coastal grasslands would probably preclude the eventual recovery of the woody plant component of this area. *Dodonaea*, *Canthium*, *Styphelia tameiameiae*, *Waltheria*, and *Wikstroemia* are the most likely candidates to recolonize the central coastal lowlands, long depleted of native shrubs by 150 years of feral goat activity. Of these, only *Dodonaea* might be successful after fire.

Fires will also enhance the spread of *Melinis* and *Hyparrhenia* which are now spreading into the eastern coastal lowlands. Fire effects were more unfavorable to native vegetation in sites dominated by these two grasses, especially *Melinis*, than other alien grasses. *Melinis* and *Hyparrhenia* accumulate high fuel loadings, and burn with higher fire intensity (Fujioka and Fujii 1980; NPS 1990). These factors will reduce the resprouting of native shrubs.

The effects of successive fires were not addressed adequately enough to predict succession in reburned communities. The question of successive fires is now more important because of lava flows in late 1992 and early 1993 which ignited fires that burned much of the coastal scrub, some of which burned in the 1980's. Repeated fires may eventually eliminate lowland scrub and its native plant components or stimulate highly undesirable aliens. Finally, there are some questions about whether *Heteropogon* and *Waltheria* are native species. Statistical increases in cover of these species are responsible for the apparent success of native vegetation after fire in the coastal lowlands. This may represent an artificial value. A prudent approach in the face of these unknowns is to exclude fire.

Fuel Breaks and Prescribed Burning

Prescribed burning to create fuel breaks is undertaken in HAVO as a presuppression action when there is imminent threat of fires ignited by lava. These fuel breaks are characteristically 15-25 m wide, generally wide enough to stop head fires. Prescribed burning may also be useful in the establishment and maintenance of permanent fuel breaks, regardless of threat of lava flow ignitions. High intensity fire should be used in the eastern coastal lowlands because it reduces grass cover and stimulates recovery of relatively non-flammable subshrubs during the first year of recovery. Prescribed burning stimulates *Rhynchelytrum* in most sites in the eastern lowlands and near the shoreline in the central lowlands. This is probably an ideal grass species for fuel breaks because it appears to carry fire only when relative humidities are low (Tunison, unpublished data). In most areas, fire will also stimulate *Heteropogon*. This grass produces less litter than *Andropogon* and *Schizachyrium*, and is preferred for that reason.

The major shortcoming of using fire to create and maintain fuel breaks, aside from the possiblity of escaped fire, is the removal of native shrubs such as *Canthium* and *Wikstroemia* and the potential stimulation of *Melinis*. Prescribed burning in *Wikstroemia* scrub should be carried out only as an emergency measure, in disturbed areas, or where these native species are absent. Fire should not be used to make fuel breaks in areas with *Melinis* because of the potential of stimulating this species.

Restoration Research

Experimental prescribed burning should also be considered to stimulate native species such as *Heteropogon and Dodonaea* in selected areas of the coastal lowlands. *Heteropogon* was stimulated by fire in the western part of the eastern coastal lowlands and in most communities of the central lowlands, where it was a minor component or codominant prior to fire. *Heteropogon* tended to replace *Schizachyrium* and *Andropogon* in the lowland scrub. *Dodonaea* is stimulated by fire, if a sufficient seed bank is present. Prescribed burning might be useful in restoring *Dodonaea* to the central lowlands, if *Dodonaea* were first planted or seeds were sown before fire to create a seed bank. Care should be taken not to exacerbate *Melinis* or *Hyparrhenia* in attempting to encourage establishment of native plants.

Fire Effects Research

Research on fire effects should continue. Recovery in all study sites should be monitored at five to ten year intervals. The current study addresses only short-term successional patterns, and it is possible that, with longer intervals between fires, native species may recover, or alien grasses may eventually become more abundant. Replication of sites is needed in the central coastal lowlands to test competition among *Heteropogon*, *Rhynchelytrum*, *Hyparrhenia*, and *Melinis*. Additional sites are needed to determine the effects of repeated fires. This is especially important in the lowland scrub. Most sites burned in the 1980's re-burned in the 1992-1993 lava flows at Kamoamoa.

Descriptive successional studies by National Park Service personnel are probably sufficient to guide management policy. Studies by university or independent researchers which investigate life histories of species, demography, nutrient cycling, and physiological ecology to indicate what factors drive succession are important. Studies of these kinds are now being conducted in the submontane seasonal zone by Carla D'Antonio, Peter Vitousek, and their students. The coastal lowlands, which offer a different set of plant responses to fire, also provide a valuable study site for ecological studies.

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Table 1. Site and sampling design factors in coastal lowlands fire effects studies, Hawai'i Volcanoes National Park. Locations of burn sites are indicated by number in Fig. 2.

Burn Site	Burn Name (Cause)	Burn Date	Site # (Fig. 1)	Fire Intensity	Fire History	Preburn Vegetation	Sampling Design/ Methods
Phase 30-Low Intensity	Phase 30 (lava)	2/85	1	Low	First Recorded Fire	Wikstroemia, Dodonaea shrubland with Andropogon-Schizachyrium understory	4 transects in burn and 8 transects in unburned; Phase 30-Low Intensity area to be compared with Phase 30-Medium Intensity and Phase 30-High Intensity/ Reburn; All areas equivalent in terms of pre-burn vegetation and other site factors.
Phase 30-Medium Intensity	Phase 30 (lava)	2/85	2	Moderate	First Recorded Fire	Wikstroemia, Dodonaea shrubland with Andropogon-Schizachyrium understory	4 transects in burn and 8 in unburned
Phase 30-High Intensity/ Reburn	Merrie Monarch (lava)	4/85	3	High	This area first burned in Phase 30 Fire, 2/85; Reburned 4/85	Wikstroemia, Dodonaea shrubland with Andropogon-Schizachyrium understory	4 transects in burn and 8 in unburned
Paliuli Makai	Paliuli (lava)	7/86	4	Low	First Recorded Fire	Dodonaea, Wikstroemia shrubland with Andropogon-Schizachyrium Heteropogon understory	6 pairs of burned and unburned transects
Paliuli Mauka	Paliuli (lava)	7/86	5	High	First Recorded Fire	Dodonaea, Wikstroemia shrubland with Andropogon-Melinis understory	2 pairs of burned and unburned transects

Table 1. (continued)

Burn Site	Burn Name (Cause)	Burn Date	Site # (Fig. 1)	Fire Intensity	Fire History	Preburn Vegetation	Sampling Design/ Methods
Kapa`ahu	Kapa`ahu (lava)	4/87	6	Low	First Recorded Fire	Wikstroemia, Dodonaea shrubland with Andropogon-Schizachyrium understory	Tagged trees and shrubs monitored 1 year; No cover transects
Keauhou Landing	Uila (lightning)	9/87	7	Low	First Recorded Fire	Rhynchelytrum grassland	One transect with pre-burn data available
Pu`u Kapukapu	Uila (lightning)	9/87	8	High	First Recorded Fire	Hyparrhenia grassland	One transect with pre-burn data available
Makahanau Pali	Uila (lightning)	9/87	9	High	First Recorded Fire	Melinis-Rhynchelytrum transitional grassland	One transect with pre-burn data available
Halape	Uila (lightning)	9/87	10	Low	First Recorded Fire	Heteropogon-Hyparrhenia-Rhynchelytrum transitional grassland	One transect with pre-burn data available
Pu`u Kaone	Uila (lightning)	9/87	11	High	Burned also in 1980	Hyparrhenia grassland	10 transects in a goat exclosure; pre-burn data available
Ka`aha Trail	Uila (lightning)	9/87	12	Low	First Recorded Fire	Heteropogon grassland	1 pair, burned and unburned transects established after burn
Access	Access (lava)	6/89	13	Low/High	First Recorded Fire	Wikstroemia, Dodonaea shrubland with Andropogon-Schizachyrium understory	Low and high intensity burned areas compared; Tagged trees and shrubs monitored one year; no cover transects.

Table 2. Percent cover of plants in the Phase 30 sites. Means that do not share a common superscript differ significantly ($P<0.05$).

	Unburned Control n=8		Low Intensity n=4		Medium Intensity n=4		High Intensity/ Reburn n=4	
	Mean	S.E.*	Mean	S.E.	Mean	S.E.	Mean	S.E.
Native Woody Plants								
Dodonaea viscosa	2.1^{a}	0.6	1.0^{ab}	0.7	0.0^{b}	0.0	4.0^{c}	0.6
Osteomeles anthyllidifolia	7.6^{a}	0.9	13.1^{b}	1.8	11.8^{b}	0.4	2.2^{c}	0.8
Waltheria indica	1.2^{a}	0.2	1.2^{a}	0.4	1.0^{a}	0.5	4.1^{b}	0.9
Wikstroemia sandwicensis	1.4^{a}	0.6	0.0^{b}	0.0	0.0^{b}	0.0	0.0^{b}	0.0
Subtotal	12.5^{a}	0.3	15.4^{a}	2.5	12.8^{a}	0.4	10.4^{a}	1.3
Native Herbs, Ferns & Sedges								
Cassytha filiformis	2.6^{a}	0.4	5.1^{a}	2.1	0.0^{b}	0.0	0.1^{b}	0.1
Subtotal	2.6^{a}	0.4	5.1^{a}	2.1	0.0^{b}	0.0	0.1^{b}	0.1
Native Grasses								
Heteropogon contortus	3.2^{a}	1.0	7.9^{bc}	2.2	6.2^{ac}	1.8	12.0^{bc}	2.7
Subtotal	3.2^{a}	1.0	7.9^{bc}	2.2	6.2^{ac}	1.8	11.9^{bc}	2.8
Alien Woody Plants								
Chamaecrista nictitans	0.7^{a}	0.3	1.9^{b}	0.3	1.6^{b}	0.4	4.5^{b}	1.9
Psidium guajava	0.4^{a}	0.2	0.2^{a}	0.1	0.0^{a}	0.0	0.0^{a}	0.0
Subtotal	1.1^{a}	0.3	2.1^{ac}	0.4	1.6^{a}	0.4	4.5^{a}	1.9
Alien Herbs, Ferns & Sedges								
Arundina graminifolia	1.0^{ab}	0.5	0.1^{b}	0.1	0.9^{a}	0.2	1.4^{a}	0.4
Desmodium sandwicense	0.1^{a}	0.1	0.0^{a}	0.0	0.0^{a}	0.0	0.1^{a}	0.1
Nephrolepis multiflora	0.0^{a}	0.0	0.1^{a}	0.1	0.1^{a}	0.1	0.0^{a}	0.0
Phymatosorus scolopendrium	0.3^{a}	0.2	0.2^{ab}	0.2	0.0^{b}	0.0	0.0^{b}	0.0
Stachytarpheta dichotoma	0.1^{a}	0.1	0.1^{a}	0.1	0.0^{a}	0.0	0.0^{a}	0.0
Subtotal	1.4^{a}	0.4	0.5^{b}	0.2	1.0^{a}	0.2	1.5^{a}	0.4
Alien Grasses								
Andropogon virginicus	22.3^{abc}	2.6	20.9^{abc}	4.7	27.5^{b}	0.5	14.5^{c}	3.3
Chrysopogon aciculatus	0.1^{a}	0.1	0.0^{a}	0.0	0.1^{a}	0.1	0.0^{a}	0.0
Rhynchelytrum repens	0.1^{a}	0.1	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0
Schizachyrium condensatum	35.5^{a}	1.7	28.6^{ab}	4.3	28.6^{b}	2.5	35.4^{ab}	4.4
Subtotal	59.1^{a}	2.6	49.6^{b}	2.5	56.1^{ab}	2.5	49.9^{b}	5.1
Total native species cover	**15.6^{a}**	**0.9**	**22.1^{b}**	**2.0**	**19.1^{ab}**	**1.8**	**22.4^{b}**	**2.3**
Total alien species cover	**60.5^{a}**	**2.7**	**52.4^{b}**	**2.8**	**58.8^{ab}**	**2.2**	**55.9^{ab}**	**3.7**

* standard error

Table 3. Densities of shrubs in the Phase 30 sites (individuals/30 m²). Means that do not share a common superscript differ significantly ($P<0.05$).

Species and Height Class	Unburned Control n=21 Mean	S.E.*	Low Intensity n=12 Mean	S.E.	Medium Intensity n=12 Mean	S.E.	High Intensity/ Reburn n=12 Mean	S.E.
Native Shrubs								
Dodonaea viscosa								
<10 cm	0.3^{a}	0.2	0.8^{a}	0.4	0.7^{a}	0.2	6.7^{b}	2.6
10-50 cm	1.0^{a}	0.3	1.4^{a}	1.0	7.4^{b}	2.4	60.2^{c}	19.3
50-100 cm	1.8^{a}	0.4	1.8^{a}	1.0	1.5^{a}	0.5	8.8^{b}	4.0
>100 cm	1.8^{a}	0.5	0.8^{c}	0.8	0.0^{bc}	0.0	0.2^{bc}	0.2
subtotal	4.9^{ab}	1.0	4.8^{b}	3.2	9.6^{a}	2.8	75.9^{c}	22.7
Wikstroemia sandwicensis								
<10 cm	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0
10-50 cm	0.1^{a}	0.1	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0
50-100 cm	0.4^{a}	0.1	0.0^{b}	0.0	0.0^{b}	0.0	0.0^{b}	0.0
>100 cm	0.9^{a}	0.3	0.1^{b}	0.1	0.0^{b}	0.0	0.0^{b}	0.0
subtotal	1.3^{a}	0.4	0.1^{b}	0.1	0.0^{b}	0.0	0.0^{b}	0.0
Total	**6.2^{ab}**	**1.3**	**4.9^{a}**	**3.2**	**9.6^{b}**	**2.8**	**75.9^{c}**	**22.7**
Alien Shrubs								
Lantana camara								
<10 cm	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0
10-50 cm	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0
50-100 cm	0.1^{a}	0.1	0.0^{a}	0.0	0.0^{a}	0.0	0.1^{a}	0.1
>100 cm	0.1^{a}	0.1	0.0^{a}	0.0	0.1^{a}	0.1	0.0^{a}	0.0
subtotal	0.1^{a}	0.1	0.0^{a}	0.0	0.1^{a}	0.1	0.1^{a}	0.0
Psidium guajava								
<10 cm	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0
10-50 cm	0.2^{a}	0.1	0.2^{a}	0.1	0.2^{a}	0.2	0.1^{a}	0.1
50-100 cm	0.3^{a}	0.1	0.2^{a}	0.1	0.0^{a}	0.0	0.0^{a}	0.0
>100 cm	0.1^{a}	0.1	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0
subtotal	0.6^{a}	0.2	0.4^{a}	0.1	0.2^{a}	0.2	0.0^{a}	0.0
Total	**0.7^{a}**	**0.2**	**0.4^{a}**	**0.1**	**0.3^{a}**	**0.2**	**0.0^{a}**	**0.0**
Polynesian Introduced Shrubs								
Morinda citrifolia								
<10 cm	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0
10-50 cm	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0
50-100 cm	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0
>100 cm	0.1^{a}	0.1	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0
Total	**0.1^{a}**	**0.1**	**0.0^{a}**	**0.0**	**0.0^{a}**	**0.0**	**0.0^{a}**	**0.0**

* standard error

Table 4. Densities of shrubs in the Phase 30 sites (individuals/4 m^2). Means that do not share a common superscript differ significantly ($P<0.05$).

Species and Height Class	Unburned Control n=31 Mean	S.E.*	Low Intensity n=16 Mean	S.E.	Medium Intensity n=16 Mean	S.E.	High Intensity/ Reburn n=16 Mean	S.E.
Native subshrubs								
Waltheria indica								
<10 cm	1.2^{a}	0.5	0.3^{bc}	0.1	0.4^{ac}	0.2	0.3^{ac}	0.1
10-50 cm	2.7^{a}	0.6	4.3^{b}	0.6	6.1^{bc}	1.0	7.3^{c}	1.2
50-100 cm	0.3^{a}	0.1	2.4^{b}	0.6	1.4^{b}	0.4	2.0^{b}	0.8
>100 cm	0.1^{a}	0.1	0.4^{bc}	0.2	0.1^{ac}	0.1	0.4^{ac}	0.3
subtotal	4.3^{a}	0.9	7.4^{b}	1.0	8.0^{b}	1.4	10.0^{b}	1.8
Total	**4.3^{a}**	**0.9**	**7.4^{b}**	**1.0**	**8.0^{b}**	**1.4**	**10.0^{b}**	**1.8**
Alien subshrubs								
Chamaecrista nictitans								
<10 cm	0.4^{a}	0.2	0.6^{ac}	0.4	0.2^{a}	0.2	1.8^{bc}	0.7
10-50 cm	1.7^{a}	0.5	5.1^{b}	1.3	8.4^{bc}	2.5	13.2^{c}	3.0
50-100 cm	0.2^{a}	0.1	6.6^{b}	2.2	3.2^{b}	1.4	3.7^{b}	1.2
>100 cm	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0	0.0^{a}	0.0
subtotal	2.2^{a}	0.5	12.4^{b}	3.1	12.0^{b}	3.3	18.6^{b}	4.1
Total	**2.2^{a}**	**0.5**	**5.7^{b}**	**1.0**	**12.0^{bc}**	**3.3**	**18.0^{c}**	**4.1**

* standard error

Table 5. Percent cover of plants in the Paliuli Makai site.

	Unburn n=6 Mean	S.E.*	Burn n=6 Mean	S.E.	p<0.05
Native Woody Plants					
Dodonaea viscosa	0.5	0.5	0.3	0.2	ns
Osteomeles anthyllidifolia	2.5	1.1	0.3	0.3	ns
Waltheria indica	0.8	0.3	5.2	0.9	sig
Wikstroemia sandwicensis	1.0	0.9	0.0	0.0	ns
Subtotal	4.8	1.5	5.8	1.0	ns
Native Grasses					
Heteropogon contortus	14.8	2.2	27.0	3.5	sig
Subtotal	14.8	2.2	27.0	3.5	sig
Alien Woody Plants					
Chamaecrista nictitans	2.1	0.6	4.6	1.1	sig
Lantana camara	2.1	0.7	0.4	0.2	sig
Psidium guajava	0.7	0.3	0.2	0.1	ns
Subtotal	4.8	1.0	5.2	1.0	ns
Alien Herbs, Ferns & Sedges					
Arundina graminifolia	0.2	0.1	0.1	0.1	ns
Desmodium sandwicense	0.2	0.2	0.0	0.0	ns
Desmodium triflorum	0.0	0.0	0.1	0.1	ns
Nephrolepis multiflora	1.3	0.5	0.0	0.0	sig
Phymatosorus scolopendrium	0.2	0.2	0.0	0.0	ns
Subtotal	1.8	0.4	0.2	0.1	sig
Alien Grasses					
Andropogon virginicus	28.8	3.4	10.9	2.1	sig
Chrysopogon aciculatus	0.7	0.3	0.4	0.2	ns
Melinis minutiflora	0.2	0.2	0.0	0.0	ns
Rhynchelytrum repens	6.0	1.8	28.3	3.4	sig
Schizachyrium condensatum	9.4	2.9	2.5	1.0	sig
Subtotal	44.9	4.4	41.8	2.4	ns
Total native species cover	**19.6**	**2.6**	**32.8**	**3.0**	**sig**
Total alien species	**51.7**	**3.6**	**47.2**	**1.9**	**ns**

* standard error

Table 6. Density of shrubs in the Paliuli Makai site (individuals/30 m²).

Species and Height Class	Unburn n=6 Mean	S.E.*	Burn n=6 Mean	S.E.	p<0.05
Native Shrubs					
Dodonaea viscosa					
<10 cm	0.3	0.3	2.2	2.0	ns
10-50 cm	0.7	0.3	1.7	0.6	ns
50-100 cm	0.2	0.1	0.7	0.5	ns
>100 cm	0.1	0.1	0.1	0.1	ns
subtotal	1.4	0.6	4.6	2.6	ns
Total	**1.4**	**0.6**	**4.6**	**2.6**	**ns**
Alien Shrubs					
Lantana camara					
<10 cm	0.6	0.3	0.0	0.0	sig
10-50 cm	2.4	0.7	1.4	0.6	ns
50-100 cm	3.1	0.8	1.7	0.5	ns
>100 cm	1.5	0.5	0.9	0.3	ns
subtotal	7.6	1.7	4.0	1.0	sig
Psidium guajava					
<10 cm	0.0	0.0	0.2	0.1	ns
10-50 cm	2.4	0.5	1.7	0.4	ns
50-100 cm	3.6	0.9	1.0	0.2	sig
>100 cm	0.3	0.2	0.6	0.2	ns
subtotal	6.4	1.2	3.4	0.7	sig
Total	**14.0**	**2.1**	**7.3**	**1.2**	**sig**
Polynesian Introduced Shrubs					
Morinda citrifolia					
<10 cm	0.0	0.0	0.0	0.0	ns
10-50 cm	0.0	0.0	0.0	0.0	ns
50-100 cm	0.0	0.0	0.0	0.0	ns
>100 cm	0.2	0.2	0.0	0.0	ns
subtotal	0.2	0.2	0.0	0.0	ns
Total	**0.1**	**0.2**	**0.0**	**0.0**	**ns**

* standard error

Table 7. Density of subshrubs in Paliuli Makai site (individuals/4 m^2)

Species and Height Class	Unburn n=24 Mean	Unburn n=24 S.E.*	Burn n=24 Mean	Burn n=24 S.E.	p<0.05
Native Subshrubs					
Waltheria indica					
<10 cm	1.4	0.5	1.2	0.4	ns
10-50 cm	3.5	0.7	12.2	1.9	sig
50-100 cm	0.8	0.2	3.5	0.7	sig
>100 cm	0.0	0.0	0.2	0.1	sig
subtotal	5.7	0.9	17.1	2.2	sig
Total	**5.7**	**0.9**	**17.1**	**2.2**	**sig**
Alien Subshrubs					
Chamaecrista nictitans					
<10 cm	1.2	0.4	6.7	2.1	sig
10-50 cm	10.6	2.5	22.9	4.1	ns
50-100 cm	1.0	0.2	6.2	2.5	sig
>100 cm	0.0	0.0	0.0	0.0	ns
subtotal	12.8	2.6	35.8	6.7	sig
Total	**12.8**	**2.6**	**35.8**	**6.7**	**sig**

* standard error

Table 8. Percent cover of plants in Paliuli Mauka site.

	Unburn n=2 Mean		Burn n=2 S.E.*		p<0.05 Mean S.E.
Native Woody Plants					
Dodonaea viscosa	4.9	3.1	0.0	0.0	ns
Osteomeles anthyllidifolia	11.7	7.3	2.5	1.8	ns
Waltheria indica	0.0	0.0	1.8	0.9	ns
Subtotal	16.6	4.2	4.3	2.6	ns
Native Grasses					
Heteropogon contortus	2.0	1.4	0.0	0.0	ns
Subtotal	2.0	1.4	0.0	0.0	ns
Alien Woody Plants					
Chamaecrista nictitans	0.9	0.3	1.0	0.3	ns
Lantana camara	1.4	0.1	0.3	0.2	sig
Psidium guajava	1.2	0.5	0.5	0.4	ns
Subtotal	3.6	0.8	1.8	0.5	ns
Alien Herbs, Ferns & Sedges					
Desmodium sandwicense	16.6	2.9	4.5	2.8	ns
Nephrolepis multiflora	1.3	0.5	0.0	0.0	sig
Stachytarpheta dichotoma	0.3	0.2	0.0	0.0	ns
Subtotal	18.2	2.6	4.5	2.8	ns
Alien Grasses					
Andropogon virginicus	6.5	3.9	1.0	0.3	ns
Chrysopogon aciculatus	0.5	0.4	0.0	0.0	ns
Melinis minutiflora	40.6	2.8	87.0	6.4	sig
Rhynchelytrum repens	3.5	2.5	0.0	0.0	ns
Subtotal	51.1	1.4	88.0	6.0	sig
Total Native Cover	**18.6**	**5.6**	**4.3**	**2.6**	**ns**
Total Alien cover	**73.2**	**1.9**	**96.9**	**1.0**	**sig**

* standard error

Table 9. Density of subshrubs in Paliuli Mauka site (individuals/4 m^2)

Species and Height Class	Unburn n=8 Mean	S.E.*	Burn n=8 Mean	S.E.	p<0.05
Native Subshrubs					
Waltheria indica					
<10 cm	0.0	0.0	0.0	0.0	ns
10-50 cm	0.1	0.1	2.6	0.7	sig
50-100 cm	0.1	0.1	0.8	0.4	ns
>100 cm	0.1	0.1	0.0	0.0	ns
subtotal	0.2	0.2	3.4	1.0	sig
Total	**0.2**	**0.2**	**3.4**	**1.0**	**sig**
Alien Subshrubs					
Chamaecrista nictitans					
<10 cm	0.2	0.2	0.1	0.1	ns
10-50 cm	2.0	0.6	4.1	1.4	ns
50-100 cm	0.5	0.5	1.2	1.2	ns
>100 cm	0.0	0.0	0.0	0.0	ns
subtotal	2.8	0.9	5.5	1.5	ns
Total	**2.8**	**0.9**	**5.5**	**1.5**	**ns**

* standard error

Table 10. Density of shrubs in the Paliuli Mauka site (individuals/30 m^2).

Species and Height Class	Unburn n=6 Mean	Unburn n=6 S.E.*	Burn n=6 Mean	Burn n=6 S.E.	p<0.05
Native Shrubs					
Canthium odoratum					
<10 cm	0.0	0.0	0.0	0.0	ns
10-50 cm	0.0	0.0	0.0	0.0	ns
50-100 cm	0.0	0.0	0.0	0.0	ns
>100 cm	0.3	0.2	0.0	0.0	ns
subtotal	0.3	0.2	0.0	0.0	ns
Dodonaea viscosa					
<10 cm	0.0	0.0	1.5	0.9	ns
10-50 cm	1.7	1.3	0.3	0.3	ns
50-100 cm	8.2	2.4	0.0	0.0	sig
>100 cm	0.7	0.3	0.0	0.0	sig
subtotal	10.5	2.9	1.8	1.1	sig
Wikstroemia sandwicensis					
<10 cm	0.0	0.0	0.0	0.0	ns
10-50 cm	0.0	0.0	0.0	0.0	ns
50-100 cm	0.7	0.4	0.0	0.0	ns
>100 cm	1.0	0.6	0.0	0.0	ns
subtotal	1.7	0.9	0.0	0.0	sig
Total	**12.5**	**3.0**	**1.8**	**1.1**	**sig**
Alien Shrubs					
Lantana camara					
<10 cm	0.0	0.0	0.0	0.0	ns
10-50 cm	0.5	0.3	1.2	1.1	ns
50-100 cm	0.7	0.3	0.5	0.3	ns
>100 cm	0.2	0.2	0.0	0.0	ns
subtotal	1.3	0.6	1.7	1.3	ns
Psidium guajava					
<10 cm	0.0	0.0	0.0	0.0	ns
10-50 cm	0.8	0.6	0.8	0.4	ns
50-100 cm	1.2	0.5	0.7	0.4	ns
>100 cm	0.3	0.2	0.0	0.0	ns
subtotal	2.3	0.9	1.5	0.7	ns
Total	**3.6**	**2.0**	**3.2**	**1.4**	**ns**

* standard error

Table 11. Shrub recovery in five high intensity burn sites in the eastern coastal lowlands.

Burn Site	Number of Individuals	Number of Resprouting Individuals	Percent Recovery
Access			
Canthium odoratum	16	3	18.8
Lantana camara	12	0	0.0
Osteomeles anthyllidifolia	16	10	62.5
Psidium guajava	7	4	57.1
Schinus terebinthifolius	7	5	71.4
Wikstroemia sandwicensis	34	0	0.0
Kapa`ahu			
Canthium odoratum	14	1	7.2
Morinda citrifolia	2	0	0.0
Osteomeles anthyllidifolia	8	0	0.0
Wikstroemia sandwicensis	14	2	14.3
Phase 30-Medium Intensity			
Dodonaea viscosa	10	1	10.0
Wikstroemia sandwicensis	10	1	10.0
Phase 30-High Intensity/Reburn			
Dodonaea viscosa	10	1	10.0
Osteomeles anthyllidifolia	10	6	60.0
Wikstroemia sandwicensis	10	1	10.0
Paliuli Mauka			
Canthium odoratum	12	9	75.0
Dodonaea viscosa	1	0	0.0
Lantana camara	3	1	33.3
Osteomeles anthyllidifolia	5	5	100.0
Psidium guajava	6	4	66.7
Wikstroemia sandwicensis	15	3	20.0
Total			
Canthium odoratum	42	13	31.0
Dodonaea viscosa	21	2	9.5
Lantana camara	15	1	6.7
Morinda citrifolia	2	0	0.0
Osteomeles anthyllidifolia	39	21	53.8
Psidium guajava	13	8	61.5
Schinus terebinthifolius	7	5	71.4
Wikstroemia sandwicensis	83	7	8.4

Table 12. Shrub recovery in four low intensity burn sites in the eastern coastal lowlands.

Burn Site	Number of Individuals	Number of Resprouting Individuals	Percent Recovery
Access			
Canthium odoratum	12	6	50.0
Lantana camara	10	8	80.0
Osteomeles anthyllidifolia	29	17	58.6
Psidium guajava	5	3	60.0
Schinus terebinthifolius	21	18	85.7
Wikstroemia sandwicensis	55	5	9.1
Kapa`ahu			
Canthium odoratum	14	8	57.1
Diospyros sandwicensis	2	2	100.0
Morinda citrifolia	2	2	100.0
Osteomeles anthyllidifolia	8	8	100.0
Wikstroemia sandwicensis	14	4	28.6
Paliuli Makai			
Lantana camara	18	6	33.3
Osteomeles anthyllidifolia	3	0	0.0
Psidium guajava	10	3	30.0
Syzygium cumini	3	2	66.7
Wikstroemia sandwicensis	12	0	0.0
Phase 30-Low Intensity			
Dodonaea viscosa	10	5	50.0
Osteomeles anthyllidifolia	15	15	100.0
Psidium guajava	5	3	60.0
Wikstroemia sandwicensis	20	1	5.0
Total			
Canthium odoratum	26	14	53.8
Dodonaea viscosa	10	5	50.0
Diospyros sandwicensis	2	2	100.0
Lantana camara	22	14	63.6
Morinda citrifolia	2	2	100.0
Osteomeles anthyllidifolia	55	40	72.7
Psidium guajava	20	9	45.0
Schinus terebinthifolius	21	18	85.7
Syzygium cumini	3	2	66.7
Wikstroemia sandwicensis	101	10	9.9

Table 13. Cover of plant species in six sites in the central coastal lowlands.

Fire Intensity	Keauhou Landing 1986	1989	Pu`u Kapukapu 1986	1989	Makahanau Pali 1986	1989	Halape Shelter 1986	1989	Pu`u Kaone 1986	1989	Ka`aha Trail (1989) Unburn.	Burn.
	Low		High		High		Low		High		Low	
Native Woody Plants												
Waltheria indica	7.7	4.0	0.0	0.0	0.1	4.6	0.4	6.3	0.0	0.0	0.0	3.0
Subtotal	7.7	4.0	0.0	0.0	0.1	4.6	0.4	6.3	0.0	0.0	0.0	3.0
Native herbs												
Canavalia hawaiiensis	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtotal	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Native Grasses												
Heteropogon contortus	0.0	2.7	0.3	0.0	0.0	0.0	19.3	31.3	0.0	0.0	25.0	24.0
Subtotal	0.0	2.7	0.3	0.0	0.0	0.0	19.3	31.3	0.0	0.0	25.0	24.0
Alien Woody Plants												
Chamaecrista nictitans	6.3	6.3	1.0	18.0	1.3	5.3	0.3	2.0	2.8	4.8	5.5	13.5
Indigofera suffruticosa	0.3	0.0	0.0	0.0	0.3	9.7	0.0	0.3	3.4	0.0	0.0	0.0
Subtotal	6.9	6.3	1.0	18.0	1.6	15.0	0.3	2.3	6.2	4.8	5.5	13.5
Alien Herbs												
Bulbostylis capillaris	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Desmodium triflorum	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.5
Subtotal	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0
Alien Grasses												
Hyparrhenia rufa	0.3	25.3	74.7	64.0	5.0	11.0	21.0	21.6	75.5	80.3	0.0	0.0
Melinis minutiflora	5.0	4.3	0.0	0.0	52.7	40.3	0.0	0.0	1.7	0.5	0.0	0.0
Rhynchelytrum repens	41.0	25.0	0.0	0.0	18.7	18.7	19.3	10.3	0.5	0.0	3.5	4.5
Subtotal	46.3	54.6	74.7	64.0	76.4	70.0	40.3	31.9	77.7	80.8	3.5	4.5
Total Native	**7.7**	**6.7**	**8.6**	**0.0**	**0.1**	**4.6**	**19.7**	**37.6**	**0.0**	**0.0**	**35.0**	**27.0**
Total Alien	**53.2**	**60.9**	**75.7**	**85.0**	**78.0**	**85.0**	**40.6**	**33.2**	**83.9**	**85.6**	**10.0**	**19.0**

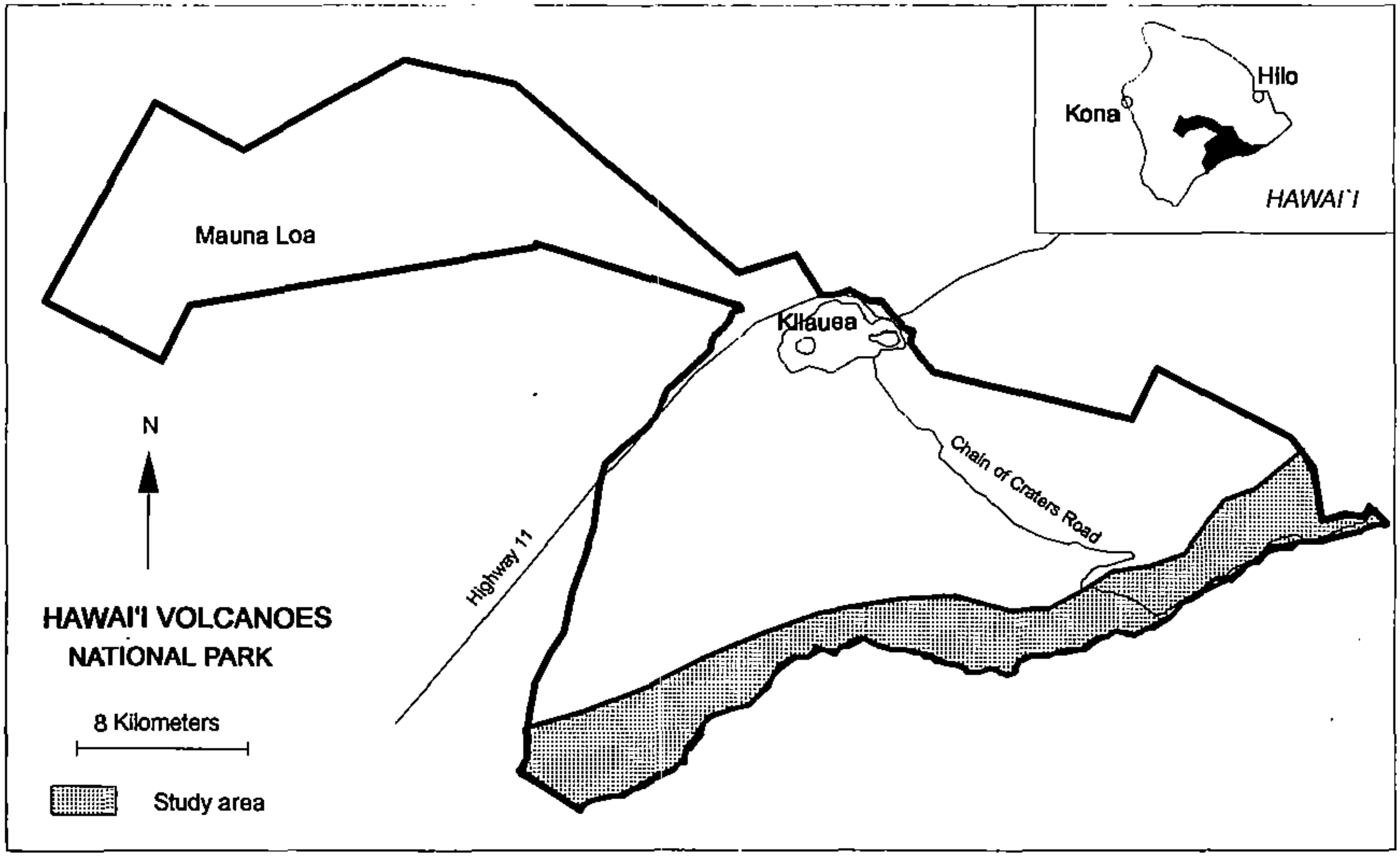

Figure 1. Location of submontane study site in Hawai`i Volcanoes National Park

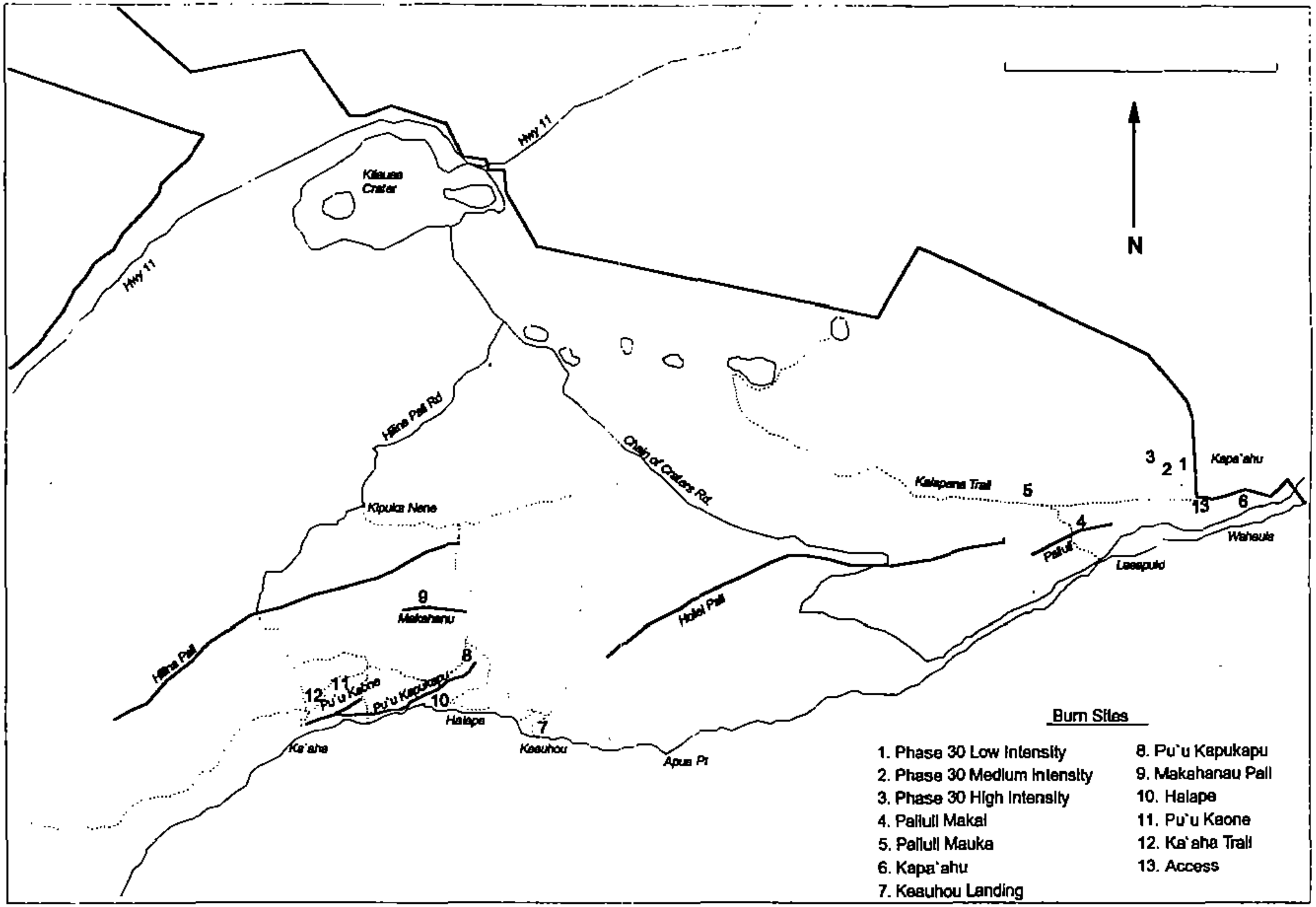

Figure 2. Location of study sites in the central and eastern coastal lowlands of Hawai`i Volcanoes National Park.

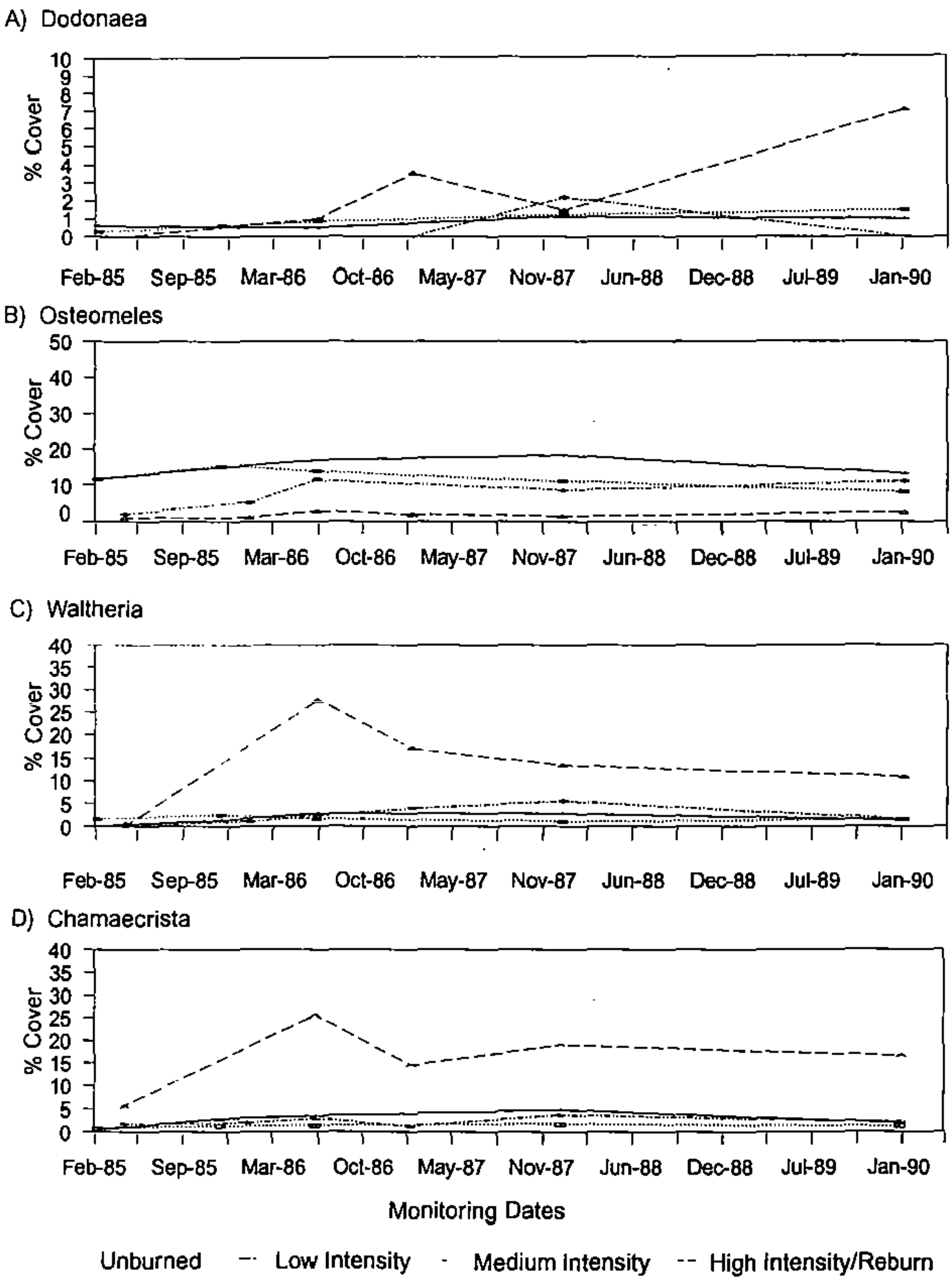

Fig. 3. Changes in percent cover of woody plants in the Phase 30 sites.

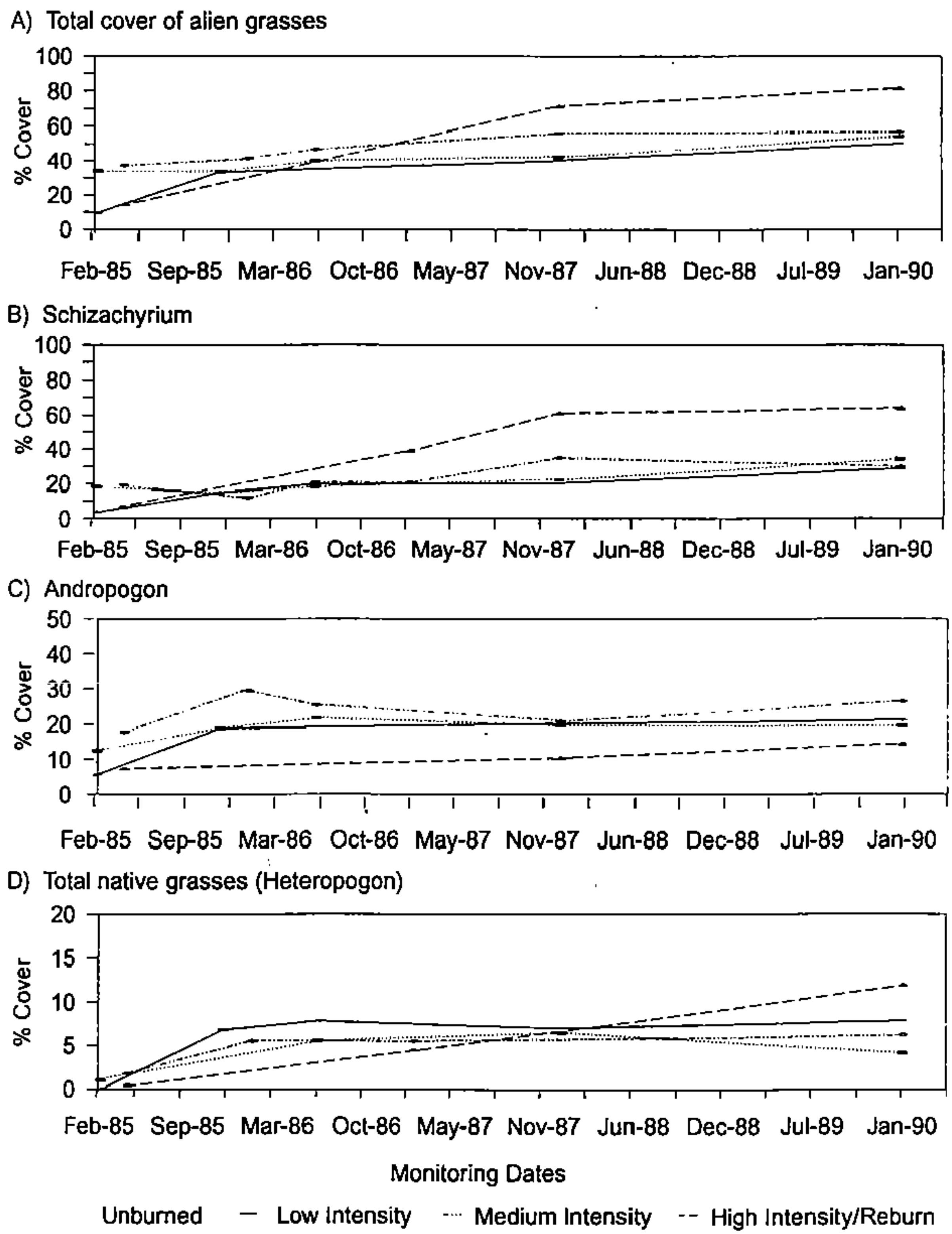

Fig. 4. Changes in percent cover of grasses in the Phase 30 sites.

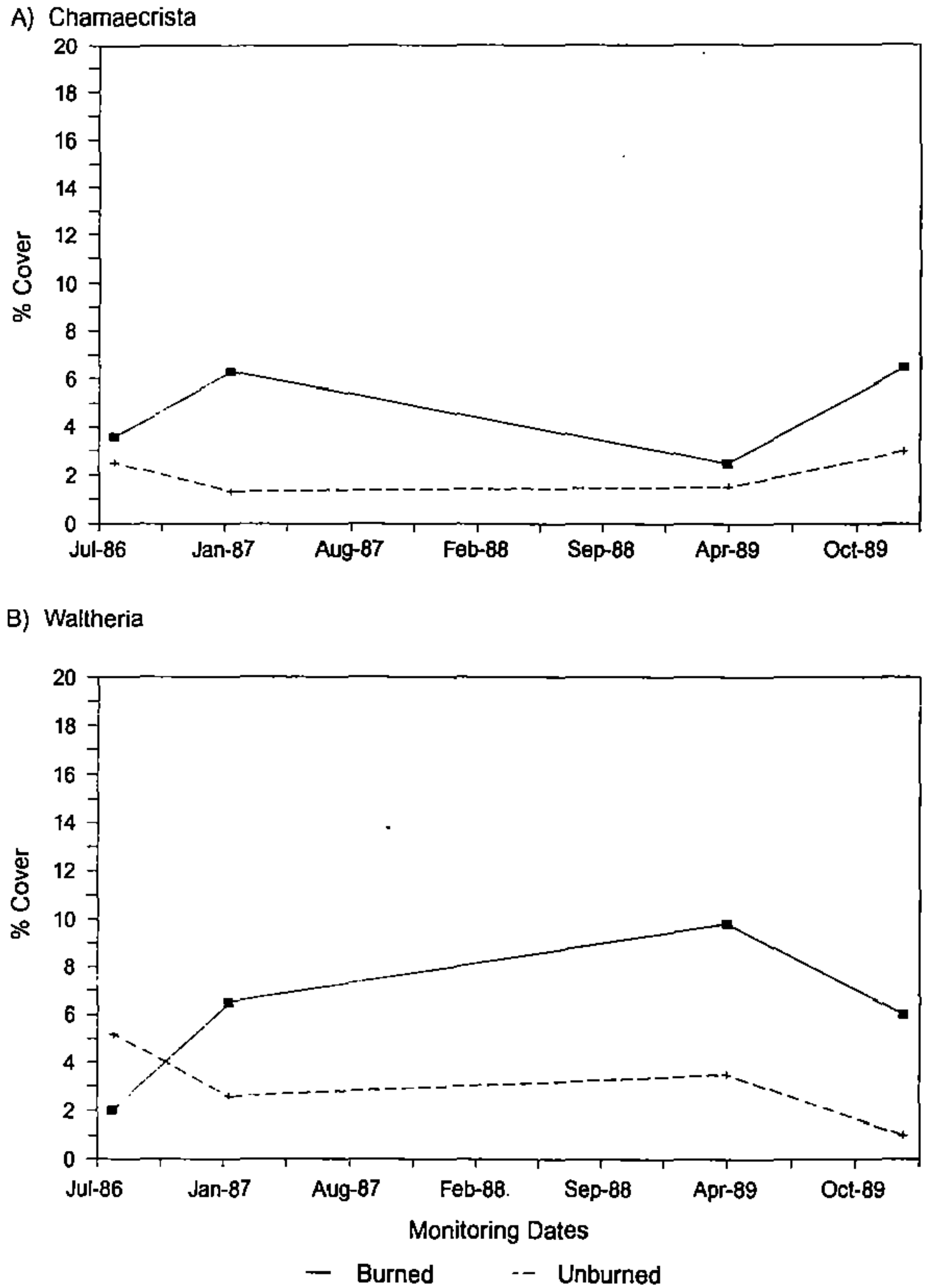

Fig. 5. Changes in percent cover of subshrubs in Paliuli Makai site.

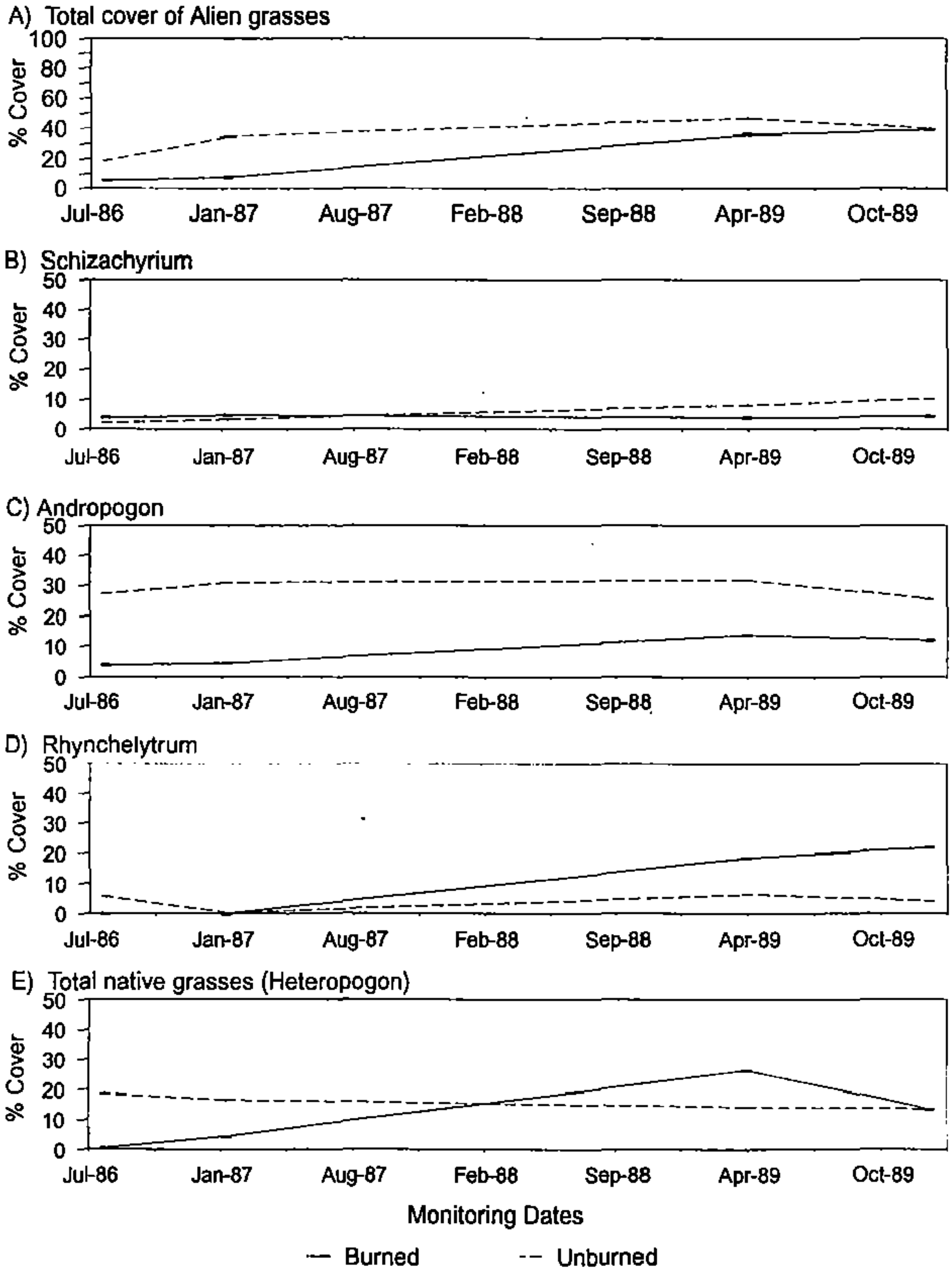

Fig. 6. Changes in percent cover of grasses in the Paliuli Makai site.

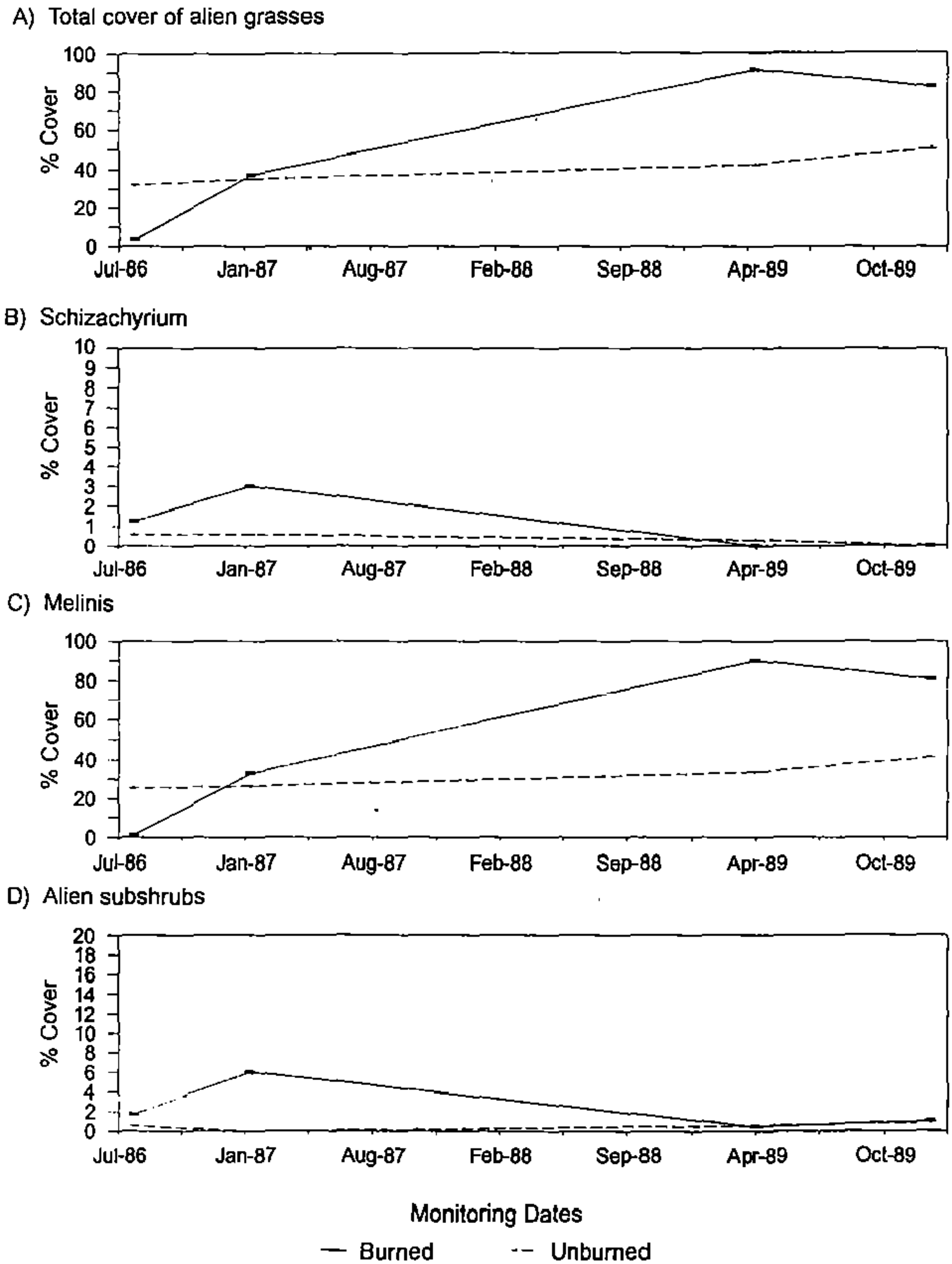

Fig. 7. Changes in percent cover of grasses and subshrubs in the Paliuli Mauka site.

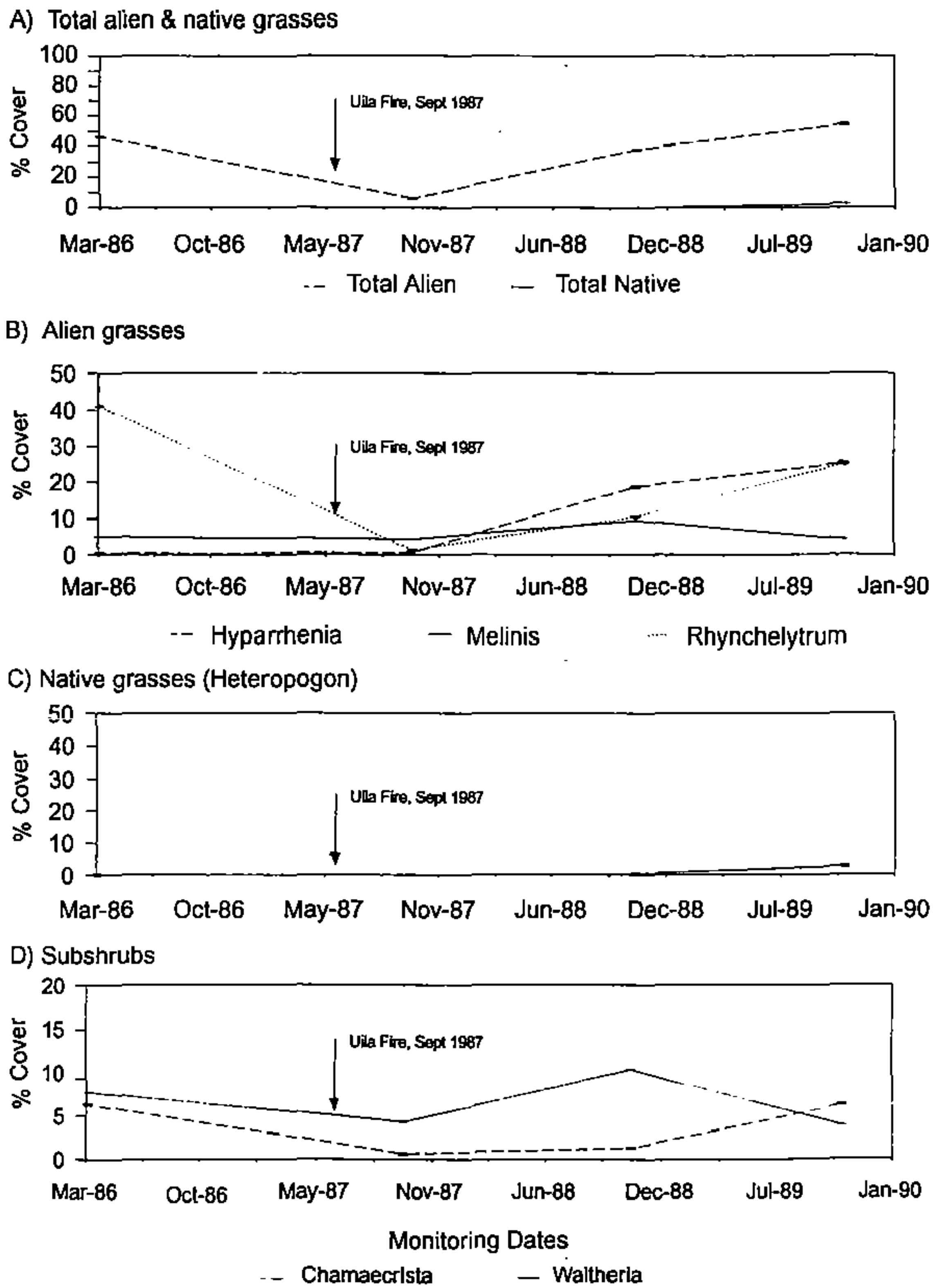

Fig. 8. Changes in percent cover of grasses and subshrubs in the Keauhou Landing site.

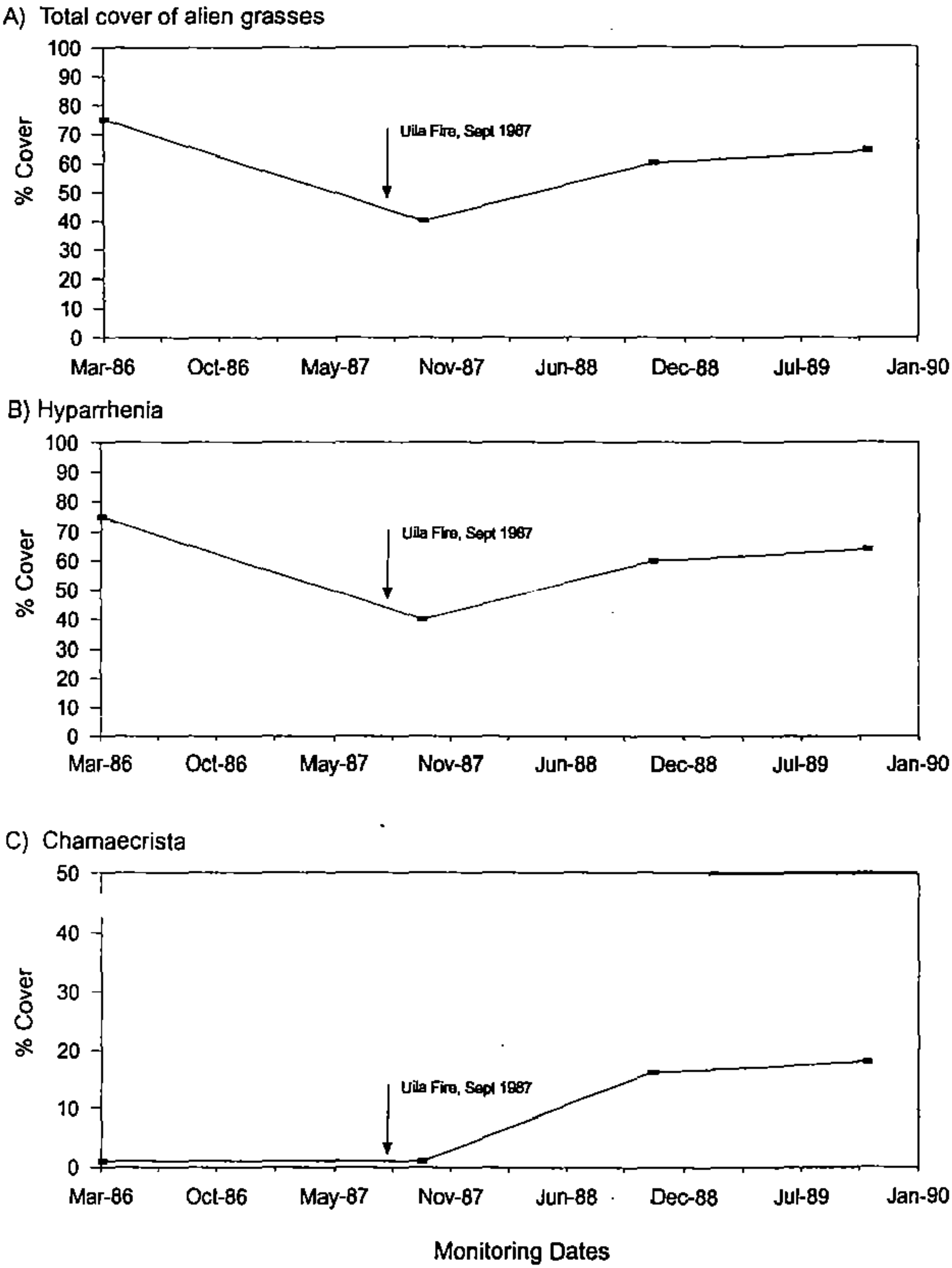

Fig. 9. Changes in percent cover of grasses and subshrubs in the Pu`u Kapukapu site.

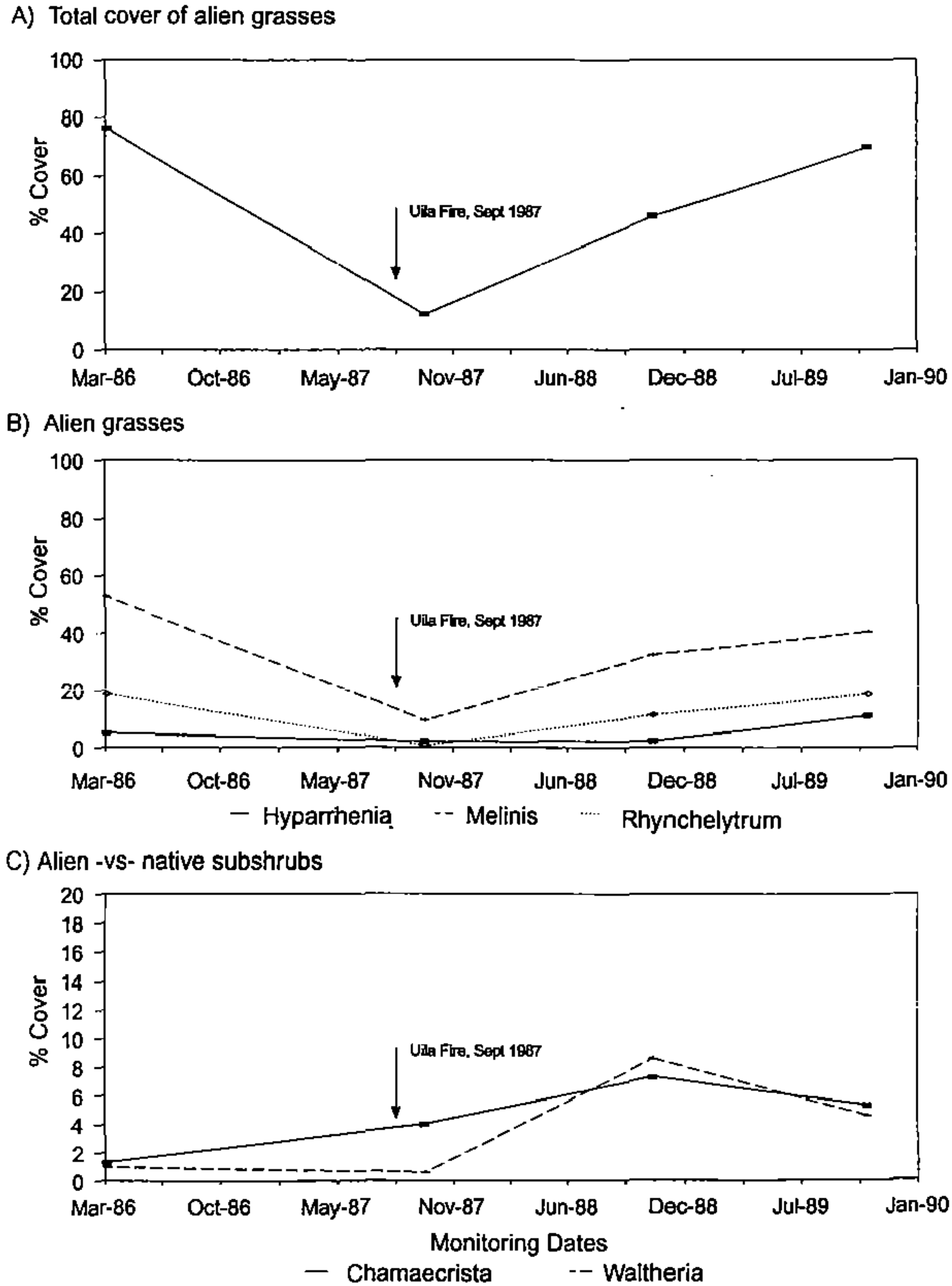

Fig. 10. Changes in percent cover of grasses and subshrubs in the Makahanau site.

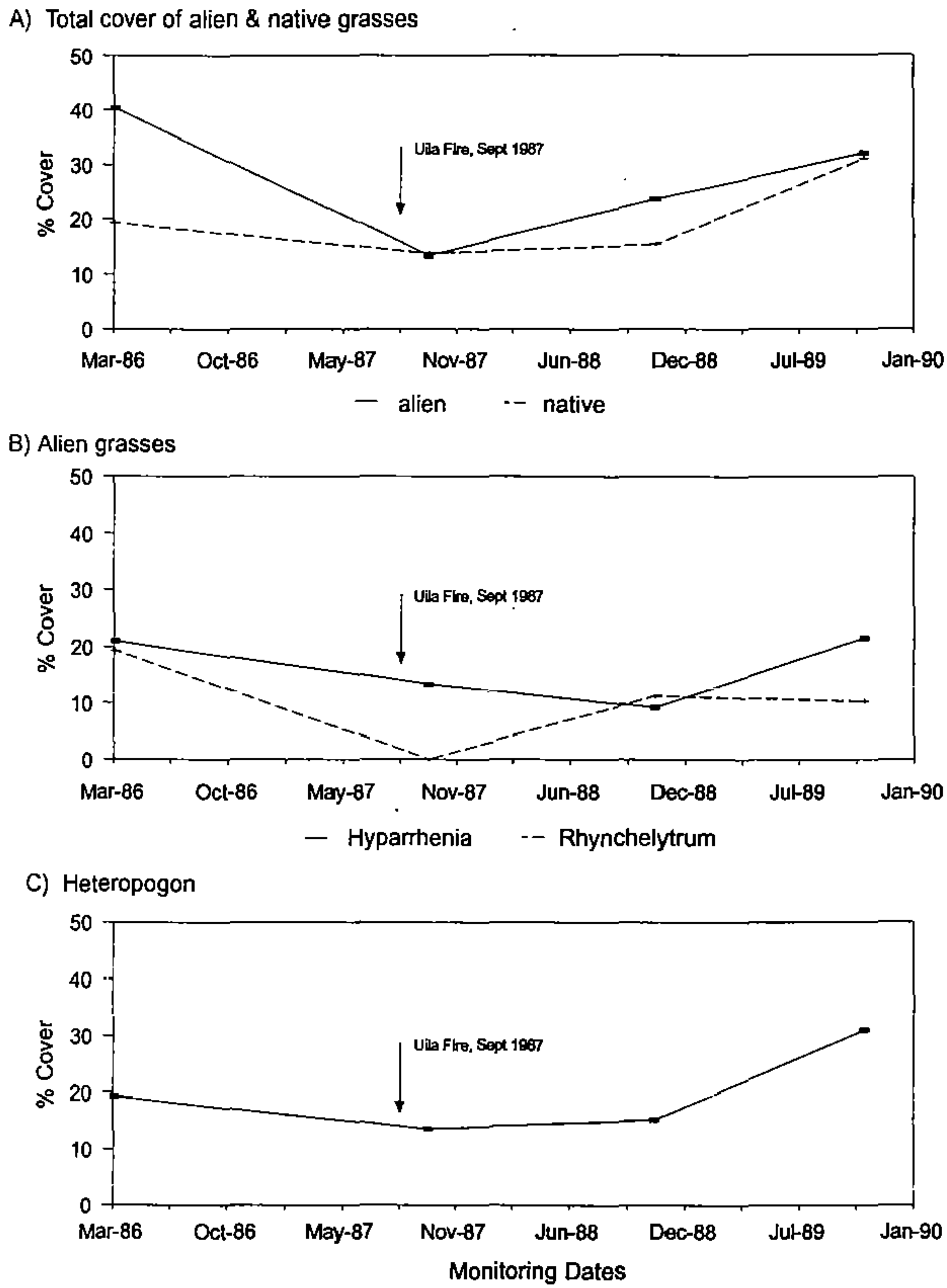

Fig. 11. Changes in percent cover of grasses in the Halape site.

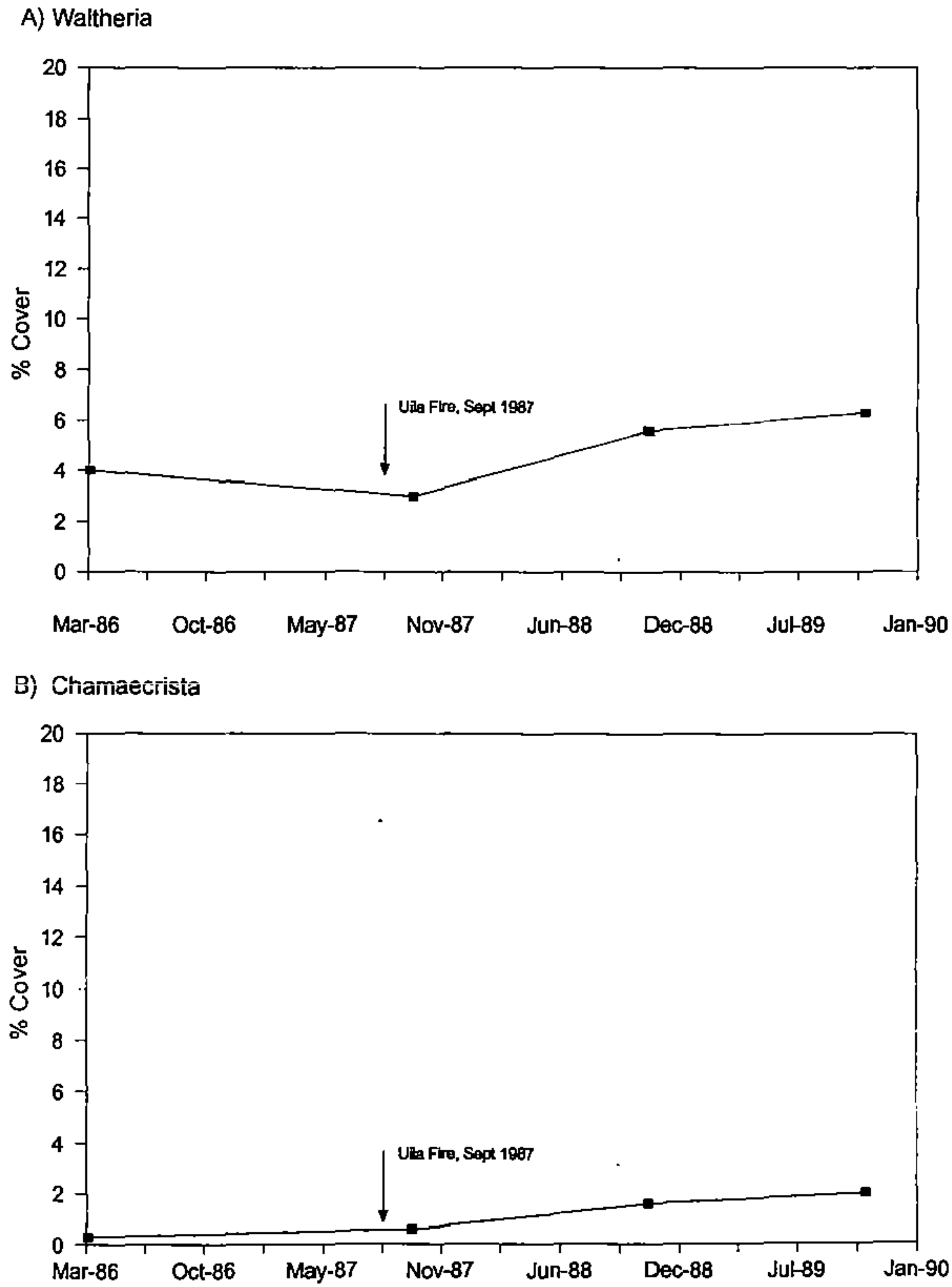

Fig. 12. Changes in percent cover of subshrubs in the Halape site.

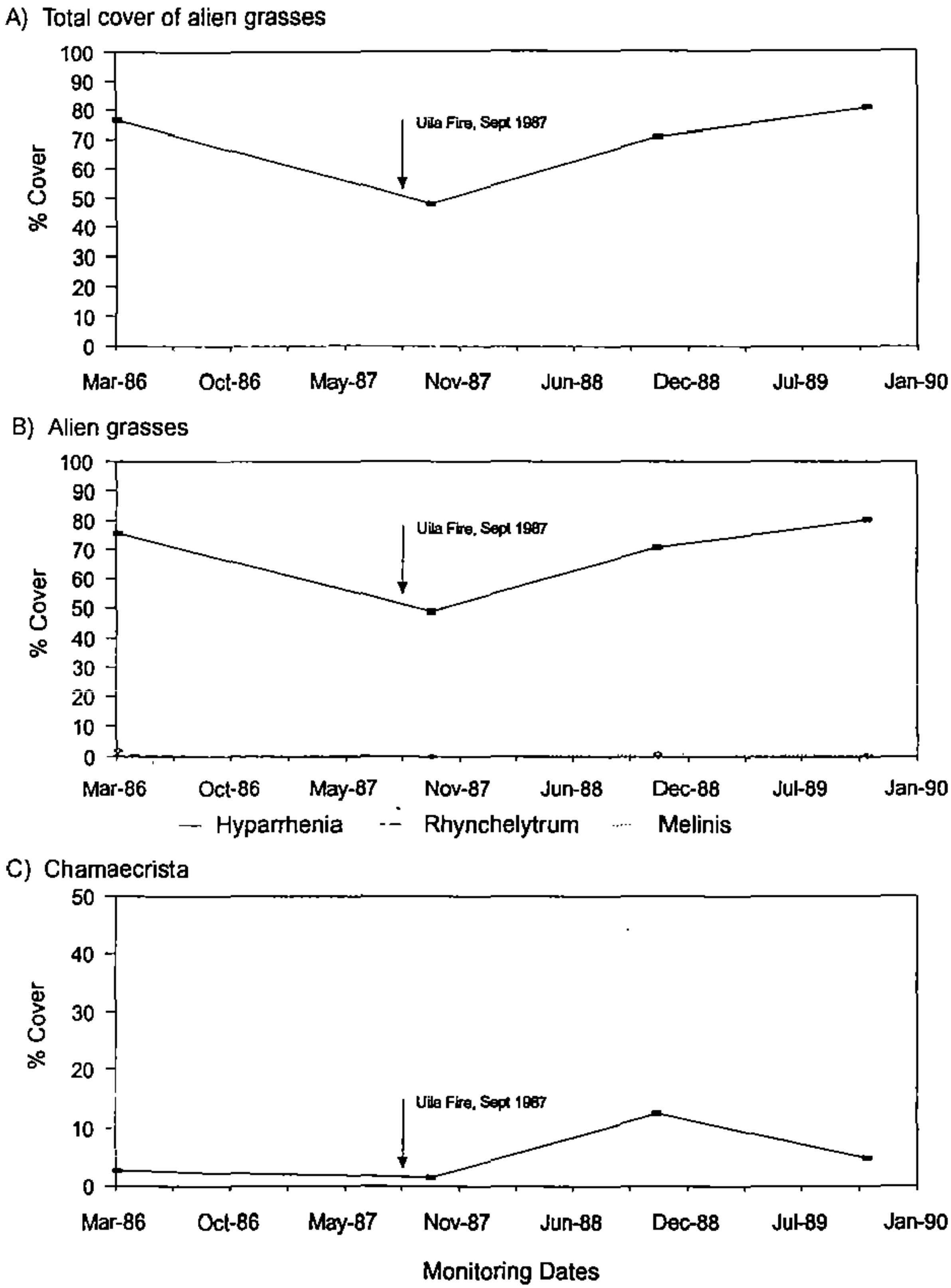

Fig. 13. Changes in percent cover of grasses and subshrubs in the Pu`u Kaone site.

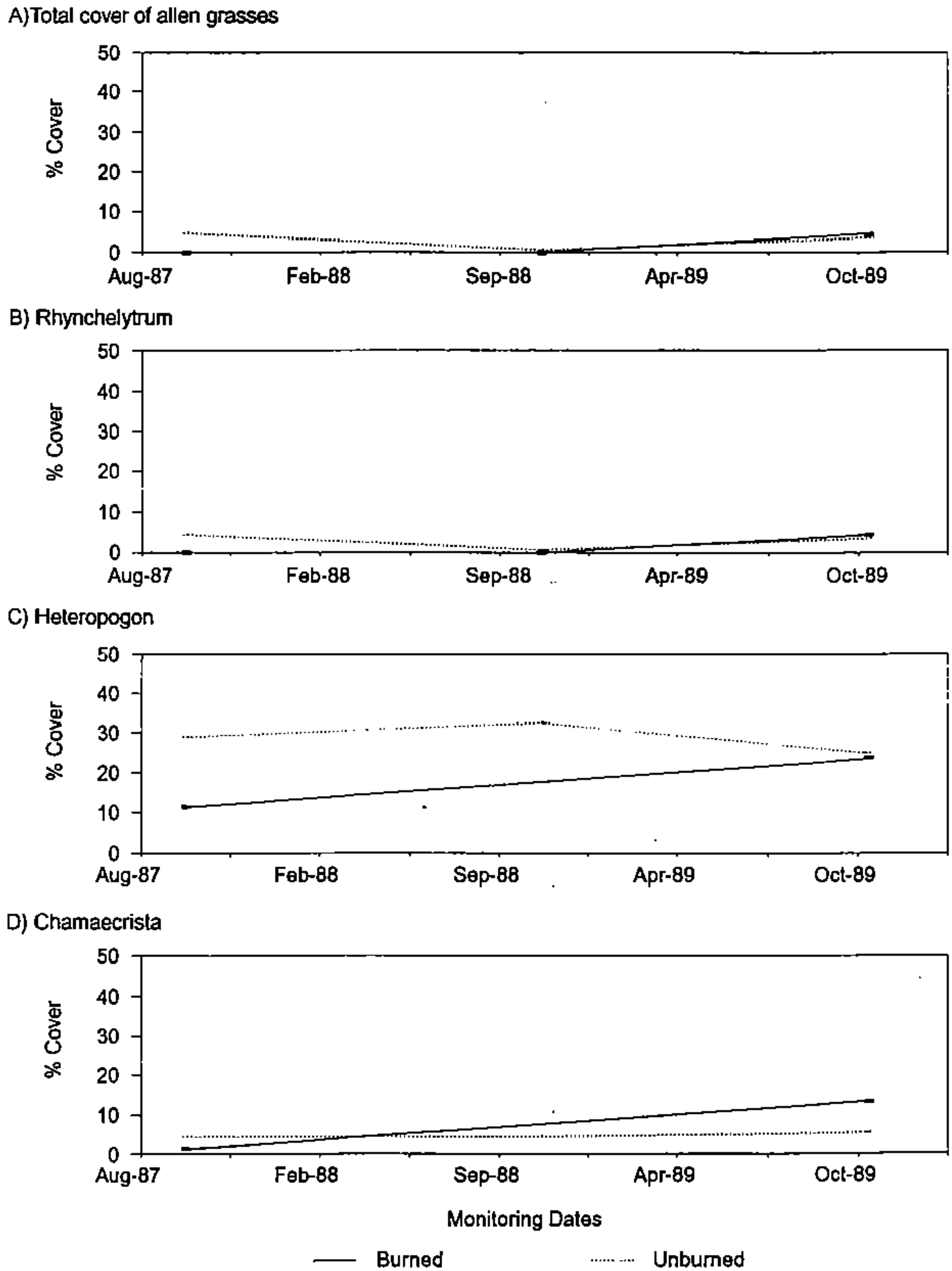

Fig. 14. Changes in cover of grasses and subshrubs in one burned site and one unburned control at Ka`aha.