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FIRE EFFECTS IN THE SUBMONTANE SEASONAL ZONE HAWAI`I VOLCANOES NATIONAL PARK

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ABSTRACT

Alien grasses that promote fire invaded the submontane seasonal zone of Hawai`i Volcanoes National Park starting in the 1960s. These grasses recover rapidly from fire, maintain a high dead-to-live biomass ratio, and burn at high relative humidities. Since 1970, the invasion of fire-promoting grasses has increased fire frequency 10-fold and fire size over 1000-fold. We monitored plant cover and density after 11 fires in 16 sites throughout the range of the submontane seasonal zone. These fires occurred between 1972 and 1992, and were sampled 1-21 years after fire. Fire significantly reduced native vegetation, almost entirely represented in the submontane seasonal zone by native trees and shrubs. The monodominant tree species, `ohi`a (*Metrosideros polymorpha*), did not regenerate from seed in any burn. Fire killed on average 46% of `ohi`a, markedly thinning forests and woodlands. Native shrub cover declined 17-fold, with the near loss of the formerly dominant shrub pukiawe (*Styphelia tameiameiae*) from most burns. The fire tolerant native shrub `a`ali`i (*Dodonaea viscosa*) persisted in molasses grass sites and appeared to be capable of recovering to its former dominance in burns in which it was especially abundant prior to fire and molasses grass was absent. The loss of native trees and shrubs was greater in burns affected by high intensity fire. Alien grass cover and biomass increased in almost all burns, particularly where molasses grass (*Melinis minutiflora*) was present prior to fire. Fire enhanced the establishment of the aggressive alien invader faya tree (*Myrica faya*), especially in shrublands. The current park policy of suppressing all fires should be maintained because of the deleterious effects of fire on native plant communities. Research underway to revegetate fire damaged sites using mamane (*Sophora chrysophylla*), `a`ali`i, and other fire-tolerant native plants should be expanded.

INTRODUCTION

Fire-promoting alien grasses invaded the seasonally dry submontane `ohi`a (*Metrosideros polymorpha*) woodlands and forests of Hawai`i Volcanoes National Park in the early 1960s. Broomsedge (*Andropogon virginicus*) (from southeastern US) and beardgrass (*Schizachyrium condensatum*) (from tropical America) spread very rapidly and became dominant understory species in many plant communities in the submontane seasonal zone by the mid-1960s (Fosberg and Mueller-Dombois 1974). These grasses appear to have invaded plant communities in which grasses were largely absent (Mueller-Dombois 1976) or dominated by other alien grasses, e.g. redtop (*Rhynchelytrum repens*), which invaded portions of the submontane seasonal in the 1930s and 1940s (Fagerlund 1947). Molasses grass (*Melinis minutiflora*) (from East Africa) was present as early as the 1940s but was largely confined to roadways until the 1970s (Tunison *et al.*, in prep.). This grass is now an important component of submontane seasonal zone, especially at lower elevations.

Broomsedge, beardgrass, and molasses grass are fire-promoting grasses. They maintain high dead-to-live biomass ratios throughout the year, burn at high relative humidities (80-90%) (Tunison, unpublished data), and recover rapidly from seed and/or vegetatively following fire.

The spread of broomsedge, beardgrass, and molasses grass largely accounts for the dramatic increase in fire size and frequency in submontane seasonal zone in the last 25 years. From 1920-1970 there were 11 fires in the submontane seasonal zone averaging <1 ha in size (Tunison, unpublished data). From 1968-1992 there were 39 fires with an average size of 175 ha. The area burned per year increased almost 2000-fold, and the number of fires per year increased nearly 10-fold. Broomsedge and/or beardgrass were the fuels that carried fire in 10 of the 16 sites studied. Molasses grass was an important fuel in four other sites.

The spread of broomsedge, beardgrass, and molasses grass has established a grass/fire cycle. A grass invasion promotes fire, which in turn favors alien grass regeneration over native vegetation (Hughes *et al.*, 1991); more alien grass promotes subsequent fires. A grass/fire cycle has developed in other parts of the world when grasses become established by direct human disturbance in the form of clearing and/or burning (Mueller-Dombois and Goldhammer 1990) or by accidental invasion (D'Antonio and Vitousek 1992), as in Hawai`i. Grass invasions which alter fire regimes are becoming a significant threat to global biodiversity (D'Antonio and Vitousek 1992).

Early studies in the submontane seasonal zone indicate that fire is damaging to native plant communities, with limited recovery of native plants and vigorous spread of alien plants. Smith et al. (1980) found that 18 months after a prescribed burn, native shrub cover was reduced and little shrub regeneration was occurring. Pukiawe (*Styphelia tameiameiae*) was especially depleted. They also found that alien grass cover, particularly broomsedge, beardgrass, and to lesser degree, molasses grass, increased after fire.

Hughes *et al.* (1991) found that the invasion of beardgrass in never-burned `ohi`a (*Metrosideros polymorpha*) woodlands provided the fine fuels necessary to carry fire and establish the grass/fire cycle. Total grass cover increased 15 months after fire, and persisted at higher levels 18 years later. More importantly to native plant species, beardgrass was largely replaced by molasses grass. Molasses grass burns at higher intensity (Tunison, unpublished data) and forms thick mats capable of preventing the establishment of native plants. Hughes *et al.* (1991) found that a second fire further stimulated molasses grass. Few native shrubs survived fire and few were able to reestablish following fire, even after 18 years. `Ulei (*Osteomeles* *anthyllidifolia*), `akia (*Wikstroemia phillyraeifolia*), and pukiawe abundant in the unburned `ohi`a woodland, were largely eliminated by fire. `A`ali`i (*Dodonaea viscosa*) was the only native shrub found in significant numbers in the burned areas. Hughes and Vitousek (1993) found that the rapid reestablishment and long-term persistence of alien grasses following fire inhibits shrub colonization and growth by preempting resources such as light and nitrogen.

We investigated plant succession after 11 fires at 16 sites in the submontane seasonal zone. Our goal was to evaluate the response of vegetation to fire throughout the ecological range of the submontane seasonal zone. Other studies (Hughes *et al.*, 1991 and Smith *et al.*1980) studied fire effects in the submontane seasonal zone near Kipuka Nene. We evaluated fire response in drier sites to the west, wetter sites to the east, including vegetation transitional to rain forest, and in sites at higher elevations. We were particularly interested in differences in the interaction of alien grasses and the survival and regeneration of shrubs. We evaluated the vegetative recovery of native shrubs and `ohi`a, the dominant native tree, and the response of faya tree (*Myrica faya*), an alien tree rapidly invading the submontane seasonal zone. Finally, we determined if grass biomass or fuel loadings increased after fire, and we monitored the response of the major grass species to assess their patterns of regeneration.

STUDY AREA

The submontane seasonal zone is essentially the leeward section of HAVO between 300-1200 m elevation on the southern and southwestern flanks of Kilauea volcano (Fig. 1). This zone is transitional between the coastal lowlands and either rain forest or the montane seasonal zone. The submontane seasonal extends approximately from Kilauea Caldera at approximately 1200 m elevation and Chain of Craters Road south to the bases of Hilina, Poliokeawe, and Holei Pali at 100-300 m elevation. It has a largely summer-dry climate, with rainfall varying from approximately 2200 mm/yr at upper elevations and more windward locations to approximately 1000 mm in the southwestern part of the park.

Fire is not capable of spreading in the most common vegetation type of the submontane seasonal zone, `ohi`a scrub, because of the young ages of the substrates, paucity of soil, and sparseness of grasses in this vegetation type. Fires have spread on older pahoehoe flows with sufficient ash soil to support continuous grass cover. The main communities affected by fire are open `ohi`a forest or woodland, `ohi`a savanna, and native shrubland. The understories of the forests and woodlands tend to be dominated by open pukiawe, `a`ali`i, `ulei (*Osteomeles anthyllidifolia*), and a mostly continuous layer of alien grasses, chiefly beardgrass, but also broomsedge and molasses grass. The introduced, nitrogen-fixing faya tree is now abundant or even codominant with `ohi`a in many areas of `ohi`a forest and woodland.

Twelve of the 16 sites sampled were in `ohi`a woodland (Table 1). One `ohi`a woodland sampled was transitional to uluhe (*Dicranopteris linearis*)-dominated rain forest. Fire was carried by the main understory species, introduced swordfern (*Nephrolepis multiflora*). Alien grasses were a minor constituent of the understory. `Ohi`a savannas are characterized by very widely spread `ohi`a in broomsedge and beardgrass grasslands, often with patches of molasses grass and scattered native shrubs. The two sampling sites located in `ohi`a savanna burned in the early 1970s, and fire may have been responsible for reduced densities of `ohi`a (Hughes et al. 1991). Two distinct native shrublands were sampled: An `a`ali`i shrubland with a swordfern understory and a pukiawe-`a`ali`i shrubland with an alien grass understory.

METHODS

To examine successional changes after fire, we sampled nine burns occurring from 1985-1992 and two burns occurring in the early 1970s. Sixteen sites were sampled, with the mix of vegetation features evaluated varying considerably by site (Table 1). Recent burns were generally sampled 1-3 months after the fire and at 1-3 year intervals thereafter. The results of the final sampling are presented. Older burns were sampled once. Both low intensity burns and high intensity burns were sampled. Low intensity burns resulted from backing fires in which the flaming front spreads against the wind. High intensity fires resulted from head fires in which the flaming front was pushed by the wind.

Plant cover was determined along 3-5, 40 m transects located within a burn site. An arbitrary starting point was selected and the location of the first transect was randomly determined. To facilitate relocation, other transects were selected at a fixed distance from the first transect. Compass bearings of the transects were also randomly selected. Potential transect locations were rejected if they occurred on anomalous microtopography such as pahoehoe tumuli or cracks. An equal number of unburned control transects were established per site. Unburned controls were established as close as possible to burn transects and on the opposite side of fire control lines or along the edge of the burn where the fire was observed to stop because of changing weather patterns. Controls were not established where fires were extinguished due to a discontinuity of fuels and vegetation. Controls were located in areas with similar soil depth and `ohi`a size and density, as determined by visual inspection.

We determined cover by point-intercept using a 1.25m tall point frame with five points per meter and 200 points per transect. The tallest vegetation intercepted by the rod was counted. Shrubs were counted in three 3 X 10 m plots located at 5, 15, and 25 m and at right angles to the transect using the following height classes: 0-10 cm, 10-50 cm, 50-100 cm, and 100-200 cm. The subshrubs partridge pea (*Chamaecrista nictitans*) and `uhaloa (*Waltheria indica*) were counted by height classes in four 2 X 2 m plots located at 0, 10, 20, and 30 m along the transects.

Cover and shrub density in the Napau Burn sites (Table 1, Fig. 2) were determined by a standardized National Park Serivce methodology for fire effects monitoring (National Park service 1990). In the forested site, four 20 X 50 m plots were established in the burn with an equal number in the unburned control. The diameter at breast height (dbh) (1.4 m from ground) of trees was measured throughout the plot. Cover was determined by point-intercept. All plant species intercepting a pole, 6.5 mm diameter and two meters tall, set vertically at 30 cm intervals along 50 m transects were counted. Shrubs were counted by height classes in a 1 m wide belt centered on the transect. In the shrubland site, 50 m transects were established for cover with a 1 m wide belt for shrub density, segmented at 5 m intervals. Subshrubs were also counted in 1 x 1 m plots set at each 5 m interval.

We monitored the vegetative recovery of shrubs in five sites by tagging recently burned shrubs along the cover transects or all shrubs within two 5 m x 30 m wide belts established at right angles to the cover transect. Shrubs were evaluated for resprouting after 12-18 months.

The vegetative recovery of burned `ohi`a was monitored in six burns. Trees without signs of fire damage were not evaluated, even if located within study plots. `Ohi`a were tagged within 1-3 months after each burn. Height, dbh, number of boles, height of char on the bole, and percent of canopy scorched were recorded at that time. Residual live foliage, epicormic sprouts (from buds along boles and stems), or crown sprouts (from the root collar) were monitored for 18-36 months. The vegetative recovery of `ohi`a in the 14 year old Namakani Paio burn was determined by locating burned boles, many of which had shoots resulting from crown sprouting.

The vegetative recovery of faya tree was investigated in two small burns in `ohi`a woodland along Hilina Pali Road, both burned at low intensity by backing fire (fire backing into the wind). The percent of the canopy scorched, tree height and basal diameter, percent residual foliage, and the presence of epicormic and crown sprouts were recorded. Faya tree seedling recruitment after fire was monitored in four sites. The three woodland sites, burned at low intensity, were monitored once at 1, 2, and 6 years after fire. The shrubland site, burned at high intensity, was monitored at 6 years. The number of faya tree 0-10 cm, 1-5 cm, 5-10 cm, and >10 cm basal diameter were counted in each site and adjacent unburned controls. The one and two year old sites were located in small burns which limited sampling to one large plot/burn, 18 X 18 m in the one year old burn and 25-50 m in the two year old burn. The larger sizes of the six year old sites allowed us to count and measure faya tree in belt transects of 15 or 16 contiguous 30 X 30 m plots. Because of the small numbers of pre-burn faya trees and the difficulty of distinguishing resprouting trees in the six year old burn, all faya trees present were included in the analysis.

We compared the above-ground biomass of grasses in three burns and in their unburned controls. Grasses (including dead foliage) were clipped at ground level and grass litter was collected in approximately 30 x 30 cm quadrats (1 ft^2) placed along the cover transects at regular intervals. Extensive rocky areas were not sampled. The grasses were dried at 70^0 C for 4 days and then weighed.

The regeneration patterns of the major alien grass species were quantified in 108, 1 x 1 m plots three times over a 20 month period after fire in the Pepeiau Burn (Site 12, Fig. 2). These plots were arranged in a single 6 X 9 m plot dominated by molasses grass in one site and in three 3 X 6 m plots dominated by broomsedge and beardgrass in another site. Redtop (*Rhynchelytrum repens*) occurred in both sets of plots in very low numbers. The three broomsedge/beardgrass plots were pooled for the sake of analysis. All plots burned at low fire intensity. Grass seedlings and resprouting individuals were counted. Resprouting individuals were flagged to distinguish resprouting plants from seedlings and counted.

Differences in recovery of woody plants were tested with a *chi* square test. All other differences were statistically tested transforming data and conducting an *f*-test. A *t*-test was conducted unless variances were unequal. If variances were unequal, a t^1-test was used. Significance was determined at the 5% level for all statistical tests. Only statistically significant changes in vegetation are reported below.

RESULTS

COVER AND DENSITY

Namakani Paio Burn, 1977

The human-caused Namakani Paio Fire burned through an upper submontane seasonal site at approximately 1200 m elevation (Table 1). The vegetation was `ohi`a woodland with an open shrub layer dominated by pukiawe and `a`ali`i. Broomsedge and beardgrass formed a relatively continuous fuel bed. Unlike lower submontane seasonal sites, molasses grass was absent. The site bordered on the lower reaches of the montane seasonal zone, and plant species such as koa (*Acacia koa*) and the native bunch grass, *Deschampsia nubigena*, characteristic of this zone were present in low numbers. We compared a site burned at high fire intensity with a site burned at low intensity.

Twelve years after the fire, total native plant cover was reduced by one-third in the low intensity burn site and two-thirds in the high intensity burn site, relative to the unburned site (Table 2). These differences were due primarily to the loss of native shrubs, particularly pukiawe. There was a four-fold reduction of pukiawe cover in the low intensity and a 10-fold reduction in the high intensity site. Ohelo (*Vaccinium reticulatum*) and `a`ali`i increased cover in the low intensity site. Alien grass cover increased >1.5 times in both burned sites due largely to a three-fold increase in beardgrass. Native herbaceous plants, present at low cover before the burn, were unchanged, except for *Gahnia gahniiformis*, which decreased in the burned sites. Native grasses, alien herbs, and alien woody plants were unchanged.

The total density of native shrubs declined 1.5 times in the low intensity site and nearly four-fold in the high intensity site, relative to the unburned sites, due to five-fold decrease in pukiawe density (Table 3). The density of na`ena`e (*Dubautia ciliolata*) and ohelo increased in the low intensity site.

Lucky Eddie Burn, 1985

The Lucky Eddie Fire of 1985 occurred in `ohi`a woodland surrounded by `ohi`a scrub of the upper Ka`u Desert at approximately 1100 m elevation (Table 1). Native shrubs were open (25-60% cover) to scattered (<25% cover). Molasses grass was present in small, scattered patches prior to the fire.

Native plant cover declined by nearly an order of magnitude due to a 25-fold decrease in pukiawe cover (Table 4). Alien plant cover was relatively unchanged in spite of a 10-fold increase in cover of molasses grass, which replaced beardgrass as the dominant grass. The density of taller pukiawe and `a`ali`i declined by two-thirds and one-third, respectively (Table 5).

Kealakomo Burn, 1986

The Kealakomo Fire was a prescribed burn conducted at 600 m elevation in an `ohi`a savanna with an understory of open `a`ali`i, and a mix of alien grasses dominated by broomsedge and beardgrass (Table 1). This site was previously burned during the Mauna Ulu eruptions, 1969-1974. Only the portion of the prescribed burn affected by a low intensity backing fire was sampled.

After four years, native plant cover decreased by an order of magnitude, largely because of reduced cover of `a`ali`i (Table 6). Prolific seedling recruitment, however, occured in this species such that densities of the smaller size classes were significantly greater in the burn compared to the unburned (Table 7). Alien plant cover increased because of a five-fold increase in red top and an increase in cover of broomsedge (Table 6). Beardgrass cover declined two-fold and swordfern cover declined by an order of magnitude.

Shackleton Burn, 1986

The low intensity, human-caused Shackleton Fire affected upper elevation (1200 m) submontane seasonal `ohi`a woodland similar to that burned by the Namakani Paio Fire (Table 1). Four years after the fire, native plant cover was 2.5 times lower than in the adjacent unburned woodland, and alien plant cover was nearly twice as high (Table 8). A 10-fold decrease in the cover of pukiawe accounted for most of the loss of native plant cover. Increases in cover of alien herbaceous plants (e.g., *Lotus uliginosus* and gosmore (*Hypochoeris radicata*) and alien grasses (broomsedge and sweet vernal grass (*Anthoxanthum odoratum*) account for increase in cover of alien plants after fire.

The density of pukiawe and older `a`ali`i declined nearly 4-fold (Table 9). The overall densities of younger `a`ali`i were unchanged because of recruitment in the small size classes. Similar to the Namakani Paio low intensity site, ohelo increased in density, largely by root sprouting.

Kipuka Nene Burn, 1987

The Kipuka Nene Fire burned 'ohi'a savanna and woodland (Table 1). After 6 years, native plant cover in the low intensity 'ohi'a savanna site was an order of magnitude lower than in the control, largely because of the loss of pukiawe (Table 10) and larger 'a'ali'i (Table 11). There was, however, no net change in the density of 'a'li'i because of seedling recruitment. Alien species cover increased 1.5 times, primarily because molasses grass cover doubled (Table 10).

Native plant cover in the high intensity 'ohi'a savanna site also declined by an order of magnitude because of the loss of pukiawe (Tables 12 and 13). Similar to the low intensity site, molasses grass nearly doubled in cover, increasing the cover of alien vegetation by one-third.

Uila Burn, 1987

The Uila Fire burned in a shrubland dominated by pukiawe and 'a'ali'i with a nearly continuous matrix of beardgrass and molasses grass and in an 'ohi'a woodland with an understory of native shrubs, beardgrass, and molasses grass (Table 1). Six years after the burn in the shrubland, native plant cover was reduced 20-fold relative to the unburned controls. This was due to a one to two order of magnitude decline of 'a'ali'i and pukiawe (Table 14). The density of individuals of both these species and also 'ulei declined (Table 15). Alien plant cover increased 1.5 times because of an increase in introduced grasses, primarily molasses grass.

Similar but less extreme patterns prevailed in the 'ohi'a woodland site. Native plant cover declined approximately 12-fold because of losses of pukiawe and 'a'ali'i (Table 16). There were declines in the number of larger individuals of pukiawe and 'a'ali'i (Table 17). Alien plant cover increased over 1.5 times because of increased cover of molasses grass and broomsedge (Table 16).

Napau Burn, 1992

Both a woodland and shrubland site were studied in the Napau Burn (Table 1). Both sites occur on the wet margin of the submontane seasonal zone and have alien swordfern as the dominant understory species rather than introduced grasses. Both sites were burned by the 1972 Naulu Fire. Portions of the shrubland site may also have been burned by a 1980 fire, the perimeter of which is uncertain. Scattered 'ohi'a snags and logs suggest that this species may have been more abundant in both sites prior to the fire.

Eighteen months after fire in the shrubland site, total plant cover was less in the early stages of recovery than in the control, burned 20 years previously (Table 18). Native plant cover in the burn was approximately one-half of that of the control. Loss of 'a'ali'i and kauna'oa vine (*Cassytha filiformis*) account for the loss. However, smaller 'a'ali'i plants were much more abundant in the 1992 burn than in the 1972 burn (Table 19). 'Uhaloa cover increased by an order of magnitude (Table 18) because of increases in smaller individuals (Table 20). Total alien plant cover in the 1992 burn was about one-third the alien plant cover of the 1972 burn because the cover of alien grasses was lower (Table 18). Swordfern, the single most abundant herbaceous species in the site, recovered well by sprouting after fire and had the same cover after both the 1972 and 1992 fires.

In the woodland site, cover of both alien and native plants was less after the 1992 fire in the early stages of recovery (12 months post-fire) than after the 1972 fire (Table 21). Native plant cover was lower largely because of reduced cover of 'a'ali'i, which had fewer individuals in all size classes in the 1992 burn (Table 22). Alien plant cover was approximately 1.5 times less in the 1992 burn. This was largely due to lower cover of swordfern, which forms a nearly continuous understory in the 1972 burn. Unlike the shrubland, there were no differences in densities of the subshrubs `uhaloa and partridge pea (Table 23).

SEEDLING RECRUITMENT AND VEGETATIVE RECOVERY

Shrubs

Vegetative recovery of five species of shrubs/small trees was monitored in the Uila, Kipuka Nene, and Pepeiau burns by level of fire intensity. Common guava (*Psidium guajava*), an uncommon alien small tree, and `ulei, a native shrub, recovered more consistently than any other woody species monitored (Table 24). Mamane (*Sophora chrysophylla*) also recovered relatively well after fire, with more than half of the individuals resprouting. Both `ulei and mamane may have recovered at higher rates after low intensity fire, but sample sizes were too small for statistical evaluation. Pukiawe resprouted more often than not in low intensity burns, but less than one plant in five reprouted in the high intensity sites. The high frequency of resprouting in the Pepeiau Burn occurred in an area with very low fire intensity due to wet fuels. Fewer than 10% of the `a`ali`i plants resprouted after fire.

Grasses

Grass biomass was significantly greater in the burned areas than in the unburned controls for the Namakani Paio, Lucky Eddie, and Uila Burns (Table 25). Broomsedge and beardgrass were the most abundant grasses in the Namakani Paio Burn prior to fire. Molasses grass was not present. The grass biomass of the burned area was nearly 2.5 times that of the unburned control 17 years after the fire. Beardgrass was the dominant grass in the low intensity Lucky Eddie Burn prior to fire; molasses grass was dominant after fire. After five years, the biomass of grasses in the burn was nearly 2-fold greater than in the unburned control. Beardgrass and molasses grass were codominant in the unburned control of the Uila shrubland site; molasses grass was dominant after fire. Six years post-burn the biomass of grasses in the burned area was nearly three times greater than in the unburned control.

After fire, molasses grass, beardgrass, broomsedge, and redtop regenerated vegetatively by sprouts from basal meristems and by seeds (Figs. 3 and 4). The cover of all species increased over the monitoring period (Fig. 3). Vegetative recovery accounted for approximately 90% of the cover 20 months after the burn. The cover of molasses grass originating from sprouts nearly doubled in the plot it dominated over the monitoring period. The cover of beardgrass and broomsedge originating from sprouts more than doubled in the plots they dominated. Molasses grass seedling density reached a peak at four months, and beardgrass seedlings were prominent in the plot dominated by molasses grass starting at three months. Both beardgrass and broomsedge were very abundant in all plots 20 months after the burn.

`Ohi`a

No `ohi`a seedlings were observed in the more recent burns (<7 years old). On average, 46% of `ohi`a were killed by fire, with higher mortality and less resprouting after the higher intensity fires. Typically, surviving `ohi`a with much or most of the canopy killed by fire recover by resprouting along the boles or stems (epicormic sprouts) or from the root collar (crown sprouts). Epicormic or crown sprouts may not develop if an affected `ohi`a is only lightly burned. Percent scorch is the percentage of foliage in the canopy killed by fire and is determined 2-3 months after fire by the extent of browning of the foliage and leaf loss. Bole char is the height of burned bark or wood along the tree bole.

Fire intensity was the overriding factor determining `ohi`a survival in the Uila Fire. In this fire, `ohi`a recovery was compared between a site burned by a backing fire (low intensity) and a site burned by a head fire (high intensity). Greater than 80% survived in a low intensity site, whereas 50% survived in the high intensity site (Table 26). Survival was evaluated in the low intensity site relative to char height, number of stems/tree, percent canopy scorch, and diameter. Percent canopy scorch was negatively associated with survival for tree >5 cm dbh. Nearly all `ohi`a >5 cm dbh survived if they had <75% canopy scorch. The high intensity site was sampled one year after the burn, so percent scorch could not be determined. `Ohi`a with >1 bole/tree survived at higher rates than those with a single bole.

Percent canopy scorched and diameter determined recovery in the Napau fire. All trees with ≤75% percent scorch, regardless of diameter, survived (Table 27). Trees with <100% scorch survived several times more frequently than trees which were entirely scorched. Trees ≤5 cm dbh survived more frequently than larger trees, regardless of percent scorch.

Tree diameter was also important in the Namakani Paio Burn (Table 28). In both the low and high intensity burn sites, trees <=10 cm dbh were more likely to survive than larger trees. Data on scorch, char, and other features are not available for this burn because it was evaluated 12 years after the fire.

All trees died in the Kipuka Nene Burn, even those with <100% scorch (Table 29). Higher char heights indicate a high intensity fire, but the absence of any surviving trees precludes statistical analysis. The Pepeiau fire was generally a backing fire, but some trees burned at high intensity because of localized concentrations of molasses grass. Only trees with <100% scorch were selected for monitoring to assess association with percent char height (Table 29). No association was found between char height and mortality. Tree diameter, the only factor measured, was not important in the Lucky Eddie Fire in terms of mortality.

`Ohi`a mortality increased in two burns over the monitoring period and resprouting trees increased slightly in another (Table 30). Surviving `ohi`a declined over three-fold in the Lucky Eddie Burn and one-third in the Napau Fire in a two year period. Essentially all of these had crown sprouts which subsequently died after initially flushing after the burn. Resprouting `ohi`a increased slightly over a two year period in the Uila Fire because of increased incidence of crown sprouting.

Faya Tree

Faya tree resprouts at very high frequency after low intensity fire. Only one out of 75 partially to completely scorched trees >1 cm basal diameter did not resprout in two `ohi`a woodland sites, burned one to two years prior to monitoring.

Establishment from seed after fire differed among woodland sites over time and between woodland and shrubland sites. Seedling recruitment was similar to burned areas in the first two years after a fire (Figs. 5 and 6).

Seedling recruitment was significantly greater after six years in burned woodlands and shrublands. It is difficult to distinguish pre-burn and post-burn individuals in the six year old sites because signs of fire (scorch and char) are no longer present on rapidly recovering burned individuals. Judging from the size of trees resprouting after fire, we considered faya trees <5 cm diameter to have become established after the burn; individuals >10 cm were established before the burn. Individuals in the 5-10 cm class could be either pre- or post-burn. Six years after fire in the `ohi`a woodland and shrubland, there were very few seedlings (0-1 cm basal diameter) in the burn or control (Figs. 7 and 8). There were significantly greater numbers of individuals established after fire (in the 1-5 cm class), three times as many in the woodland and 10 times as many in the burned shrubland, versus the unburned controls.

DISCUSSION

Fire was detrimental to native vegetation throughout the submontane seasonal zone, often converting `ohi`a woodlands and forests to savannas dominated by alien grasses. `Ohi`a declined sharply, with the complete loss of seedling recruitment. Fire killed, on average, nearly one-half of `ohi`a in the submontane seasonal zone, noticeably thinning `ohi`a stands. `Ohi`a were nearly eliminated in some burns. Native shrub cover declined 17-fold on average. Pukiawe, the dominant or codominant shrub in much of this zone, was the most affected by fire, declining on average an order of magnitude in cover and three-fold in density. `Ulei cover declined 2-fold and molasses grass appeared to be overtopping `ulei in burns where it persisted.

`A`ali`i, codominant with pukiawe in many unburned sites, had a more favorable response to fire than pukiawe. Although mature plants were killed by fire and cover declined two-fold, seedling establishment accounted for a three-fold increase in density. The abundance of seedlings and scattered young plants suggests that `a`ali`i will at least persist in sites dominated by molasses grass (Hughes et al. 1991) or even return to pre-burn levels.

There was greater recovery of native shrubs in burns in which molasses grass did not become abundant. Pukiawe was able to regenerate from seed to a limited degree. Ohelo, where present, increased in cover or density by root sprouting. In addition, `a`ali`i recovered rapidly in burns in which it was abundant prior to fire. Prolific seedling recruitment and the abundance of young plants in these burns suggest a return to pre-burn dominance. The recovery of native shrubs in sites without molasses grass distinguishes our results from earlier studies (Hughes et al., 1991) centered on molasses grass-dominated sites in the lower submontane seasonal. Greater native shrub recovery in sites without molasses grass indicates that fire in the submontane seasonal zone is more detrimental to native vegetation if molasses grass becomes abundant after fire.

Fire intensity appears to be a factor in the survival and recovery of native vegetation. Survival or resprouting of `ohi`a depends strongly on fire intensity. This relationship is demonstrated by higher mortality rates in high intensity burns. The importance of fire intensity is also suggested, in part, by the relationship of scorch and mortality. Trees with <75% scorch are very likely to survive or resprout. However, greater degrees of scorch are inconsistent predictors of mortality, possibly because of the response of smaller trees which are readily scorched. On the one hand, smaller trees may tend to resprout, regardless of percentage scorch, due to greater vigor. On the other hand, smaller trees may be thorougly scorched, yet receive insufficient heat at the root crown to kill them. Smith et al. (1980) found that multi-stemmed `ohi`a resprouted more frequently than trees with one bole, possibly because of the insulating effects of multiple boles on the meristematic tissue of the root crown. We found this to be the case in only one burn.

Fire intensity also affected survival and recruitment of native shrubs. Pukiawe, in particular, resprouted more frequently after low intensity fire. Native shrub cover was greater after low intensity fire than high intensity fire in the one burn (Namakani Paio) in which this comparison could be made.

Our results confirm that fire increases both the cover and biomass of alien grass, enhancing fine fuel loadings and thus perpetuating the grass/fire cycle. Alien grass cover increased on average by one-third, with significantly greater cover in eight of 11 sites in which grass cover was measured. Grass biomass increased two to three-fold after fire, regardless of composition or sampling period (5-17 years after fire). Molasses grass was responsible for much of the increase in alien grass cover and biomass. Molasses grass became abundant only in burns in which it was present prior to fire, mainly in sites in the lower submontane seasonal zone below 900 m elevation.

Greater grass cover and biomass in burned areas of the submontane seasonal zone, along with loss of forest cover, increase the likelihood of faster spreading hence larger fires and more intense fires in the submontane seasonal zone. This positive feedback response has been verified in a site in the submontane seasonal zone in HAVO (Freifelder et al., in prep.). These investigators input fuel bed measurements, environmental inputs from microclimatic data, and fuel moisture data from a fire-created savanna and an adjacent unburned woodland into BEHAVE (Andrews and Chase 1990) to calculate fire behavior outputs. Greater wind speeds in the grassland accounted for a 10-fold greater rate of fire spread and a 50-fold increase in area burned after one hour. Predicted fire intensity was approximately 3-fold greater in the grassland than woodland site.

Fire promoted the establishment of the alien faya tree in the submontane seasonal zone, especially in shrublands. Although fire did not appear to stimulate seedling recruitment in the first one to two years, seedlings became established between two and six years and significantly increased the number of small trees in burned areas. In the beginning stages of invasion in forest and woodland areas, faya tree becomes established almost exclusively beneath `ohi`a. Recruiting faya tree in the shrubland after fire were not associated with `ohi`a, which was virtually absent.

Patterns of vegetation recovery in the submontane seasonal zone differed from those of the coastal lowlands (Tunison *et al.* 1994). Native plant cover sharply declined in the submontane seasonal zone with the loss of native shrubs. Native plant cover maintained itself or even increased with the recovery of native shrubs and the spread of native grasses in the coastal lowlands. Alien grass cover did not increase in the coastal lowlands, except where molasses grass was present. Alien grass cover increased in almost all submontane seasonal zone primarily because of the spread of molasses grass. The thinning of `ohi`a stands in the submontane seasonal zone was not a factor in the coastal lowlands because of the paucity of `ohi`a in this zone. However, fire in the coastal lowlands depleted tall native shrubs, which were replaced by short native shrubs. The sampling period (five years since fire) was not sufficient to determine if low shrubs would achieve the same cover as tall shrubs.

RECOMMENDATIONS FOR MANAGEMENT AND RESEARCH

1) The current Park policy of suppressing all fires in the submontane seasonal zone should be continued. This applies to fires ignited not only by humans but also by natural sources such as lightning or lava flows. Fire in the submontane seasonal zone is detrimental to native vegetation, increases fuel loadings of alien grasses, perpetuates the grass/fire cycle, and accelerates the invasion of faya tree. Higher grass fuel loadings, combined with a more open canopy, create a fire environment with greater potential for more rapidly spreading and intense fires.

2) Fire suppression and prevention measures should emphasize protecting the remaining unburned submontane seasonal `ohi`a forests. These remnants are located largely east of Hilina Pali Road and west of the Mauna Ulu flows above 800 m elevation and contain two Special Ecological Areas (SEAs) (Tunison and Stone 1992). The SEAs

are the most floristically rich areas of the submontane seasonal zone and contain a number of rare plant species.

3) Revegetation of severely degraded burned areas with native plants should be undertaken on an experimental basis in the submontane seasonal zone. These studies should emphasize fire-tolerant native plants such as mamane, `a`ali`i (D`Antonio and Tunison, 1993), sandalwood (*Santalum paniculatum*), koko`olau (*Bidens hawaiiensis*), and ilima (*Sida fallax*). Restoration of the pre-burn plant community dominated by fire-sensitive species such as `ohi`a and pukiawe is problematic because of the rapid post-burn recovery of alien grasses and the slow growth of native trees and shrubs. Attempts to revegetate with fire-sensitive species would also be futile since subsequent fires are probably inevitable. Successful revegetation of fire-tolerant native plant species will result in new plant communities ideally with the potential to maintain themselves in the presence of alien grasses and fire. Prescribed burning is a potential tool for revegetating burned areas because it removes the alien grass canopy and may stimulate seedling recruitment of fire-tolerant species.

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Table 1. Fire history and intensity, pre-burn vegetation, and features sampled in 16 sites in the submontane seasonal zone, Hawaii volcanoes National Park. The locations of these sites are indicated by number in Fig. 2.

BURN	CAUSE	SAMPLING* PERIOD (YRS)	SITE NO	FIRE INTENSITY	FIRE HISTORY	PRE-BURN HISTORY	FEATURES SAMPLED
Napau/Naulu	Human	1/21	1	High	Burned in 1972	`Ohi`a woodland, transitional to rain forest	Cover and density `Ohi`a recovery Controls burned in 1972
			2	High	Burned in 1972	`A`ali`i shrubland	Cover and density
Honeybee	Human	1	3	Low	First recorded fire	`Ohi`a woodland	Faya tree recruitment
Pepeiau	Lightning?	1	4	Low	First recorded fire	`Ohi`a woodland	Shrub recovery `Ohi`a recovery Grass biomass
Pali Junction	Human	2	5	Low	Previously burned?	`Ohi`a woodland	Faya tree recruitment
Kealakomo	Prescribed	4	6	Low	Burned 1969-74	`Ohi`a savanna	Cover and density
Shackleton	Human	4	7	Low	First recorded fire	`Ohi`a woodland	Cover and density
Lucky Eddie	Human	5 9	8	Low	First recorded fire	`Ohi`a woodland	Cover and density Ohi`a recovery Grass biomass
Kipuka Nene	Human	6	9	Low	Burned in 1970	`Ohi`a savanna	Cover and density Shrub recovery
			10	High	First recorded fire	`Ohi`a savanna	Cover and density Shrub recovery
			11	High	First recorded fire	`Ohi`a woodland	`Ohi`a recovery
Uila	Lightning	6	12	Low	First recorded fire	`Ohi`a woodland	Cover and density `Ohi`a recovery Shrub recovery
		6 7	13	High	First recorded fire	Pukiawe/`a`ali`i Shrubland	Cover and density Shrub recovery Faya tree recruitment Grass biomass
			14	High	First recorded fire	`Ohi`a woodland	`Ohi`a recovery
Namakani Paio	Human	12	15	Low	First recorded fire	`Ohi`a woodland	Cover and density `Ohi`a recovery
			16	High	First recorded fire	`Ohi`a woodland	Cover and density `Ohi`a recovery Grass biomass

* Sampling periods is number of years between occurrence of fire and sampling for cover and density; shrub recovery determined 1 year after burn, `ohi`a recovery 1-2 years after fire.

Table 2. Percent cover of plant species (means and their standard errors) in the Namakani Paio Burn, Hawai'i Volcanoes National Park. Means that share the same superscript do not differ significantly (P<0.05).

	Control n=6 Mean	Control n=6 S.E.	Low Intensity Burn n=3 Mean	Low Intensity Burn n=3 S.E.	High Intensity Burn n=3 Mean	High Intensity Burn n=3 S.E.
Native Woody Plants						
Dodonaea viscosa	4.2 a	1.2	6.5 b	0.3	5.5ab	1.4
Dubautia ciliolata	0.3 a	0.3	0.7 a	0.4	0.0 a	0.0
Metrosideros polymorpha	2.3 a	0.8	2.2ab	0.9	0.3 b	0.2
Sophora chrysophylla	0.1 a	0.1	0.0 a	0.0	0.0 a	0.0
Styphelia tameiameiae	23.4 a	1.4	5.9 b	0.1	2.2 b	0.8
Vaccinium reticulatum	0.4 a	0.2	3.9 b	1.3	0.1 a	0.1
Subtotal	30.6 a	2.0	19.1 b	0.7	8.1 c	0.5
Native Herbs, Ferns & Sedges						
Gahnia gahniiformis	1.2 a	0.3	0.1 b	0.1	0.2 b	0.1
Luzula hawaiiensis	0.0 a	0.0	0.0 a	0.0	0.0 a	0.0
Lycopodium cernuum	0.0 a	0.0	0.0 a	0.0	0.0 a	0.0
Pteridium aquilinum	0.7 a	0.4	2.1 a	1.7	1.9 a	1.1
Subtotal	2.0 a	0.7	2.2 a	1.6	2.0 a	1.0
Native Grasses						
Deschampsia nubigena	0.6 a	0.3	0.0 a	0.0	0.3 a	0.1
Subtotal	0.6 a	0.3	0.0 a	0.0	0.3 a	0.1
Alien Woody Plants						
Myrica faya	0.0 a	0.0	0.1 a	0.1	0.0 a	0.0
Subtotal	0.0 a	0.0	0.1 a	0.1	0.0 a	0.0
Alien Herbs, Ferns & Sedges						
Arundina graminifolia	0.0 a	0.0	0.2 a	0.1	0.0 a	0.0
Bulbostylis capillaris	0.0 a	0.0	0.0 a	0.0	0.0 a	0.0
Hypochoeris radicata	0.1 a	0.1	0.0 a	0.0	0.0 a	0.0
Kyllinga brevifolia	0.0 a	0.0	0.0 a	0.0	0.0 a	0.0
Subtotal	0.1 a	0.1	0.3 a	0.1	0.0 a	0.0
Exotic Grasses						
Andropogon virginicus	16.9 a	2.3	20.8 a	1.5	23.9 a	2.8
Anthoxanthum odoratum	6.4 a	1.7	2.6 a	1.0	6.6 a	2.0
Holcus lanatus	0.7 a	0.4	0.4 a	0.2	0.0 a	0.0
Melinis multiflora	0.0 a	0.0	0.0 a	0.0	0.2 a	0.1
Schizachyrium condensatum	8.2 a	0.7	25.5 b	4.2	27.8 b	3.4
Sporobolus africanus	0.6ab	0.4	0.0 a	0.0	0.8 b	0.3
Subtotal	32.9 a	3.7	49.2 b	3.2	59.3 b	0.6
Total Native Species	33.0 a	1.7	21.3 b	1.0	10.4 c	1.4
Total Exotic Species	33.0 a	3.7	49.6 b	3.1	52.3 b	0.6

Table 3. Woody plant densities (individuals/30 m. sq.) in thr Namakani Paio Burn, Hawai'i Volcanoes National Park. Means that share the same superscript do not differ significantly (P>0.05).

Species and Height Class	Control n=17		Low Intensity Burn n=9		High Intensity Burn n=9	
	Mean	S.E.	Mean	S.E.	Mean	S.E.
Native Shrubs						
Dodonaea viscosa						
<10 cm	3.9 a	0.9	3.3 a	0.6	2.2 a	0.7
10-50 cm	10.8 a	1.9	3.4 b	0.9	3.9 b	0.6
50-100 cm	3.5 a	0.8	7.0 b	1.6	3.4ab	0.5
>100 cm	0.6 a	0.2	2.4 b	0.9	1.6 b	0.4
subtotal	18.7 a	2.8	16.2 a	3.0	11.1 a	0.8
Dubautia ciliolata						
<10 cm	0.2 a	0.2	2.7 b	1.2	0.0 a	0.0
10-50 cm	0.5 a	0.3	1.3 b	0.5	0.4ab	0.3
50-100 cm	0.2 a	0.1	1.1 b	0.3	0.1 a	0.1
>100 cm	0.0 a	0.0	0.4 b	0.2	0.0 a	0.0
subtotal	0.9 a	0.6	5.6 b	1.9	0.6 a	0.4
Styphelia tameiameiae						
<10 cm	24.9 a	6.8	4.1 b	2.4	1.9 b	1.6
10-50 cm	30.4 a	4.6	4.4 b	1.0	5.9 b	2.3
50-100 cm	8.3 a	1.0	5.7 b	1.6	3.1 b	1.4
>100 cm	2.5 a	0.4	0.9 b	0.2	0.6 b	0.3
subtotal	66.1 a	9.7	15.1 b	2.4	11.4 c	5.0
Vaccinium reticulatum						
<10 cm	3.2 a	1.5	2.8 a	1.3	1.8 a	0.8
10-50 cm	13.8 a	4.2	16.3 1	6.2	2.6 b	1.2
50-100 cm	0.2 a	0.1	7.7 b	2.1	0.1 a	0.1
>100 cm	0.0 a	0.0	0.1 a	0.1	0.0 a	0.0
subtotal	117.2 a	4.9	26.9 a	8.0	4.4 b	1.6
Total	102.9 a	11.6	63.8 b	10.4	27.6 c	5.9

Table 4. Percent cover of plant species (means and their standard errors) in the Lucky Eddie Burn, Hawai`i Volcanoes National Park.

	Control n=3		Burn n=5		
	Mean	S.E.	Mean	S.E.	P<0.05
Native Woody Plants &					
Dodonaea viscosa	2.2	0.8	2.0	0.7	ns
Dubautia ciliolata	0.2	0.1	0.2	0.1	ns
Metrosideros polymorpha	0.0	0.0	0.3	0.2	ns
Osteomeles anthyllidifolia	1.3	0.7	0.1	0.1	sig
Styphelia tameiameiae	25.8	2.4	1.0	0.6	sig
Subtotal	26.6	2.2	8.4	2.0	sig
Native Herbs, Ferns & Sedges					
Gahnia gahniiformis	1.3	0.5	0.0	0.0	sig
Pycreus polystachos	0.0	0.0	0.1	0.1	ns
Subtotal	1.3	0.5	0.1	0.1	sig
Native Grasses					
Agrostis avenacea	0.7	0.3	0.0	0.0	ns
Eragrostis variabilis	0.3	0.3	0.0	0.0	ns
Subtotal	1.0	0.4	0.0	0.0	ns
Exotic Woody Plants					
Chamacrista nictitans	0.0	0.0	1.2	0.6	ns
Subtotal	0.0	0.0	1.2	0.6	ns
Exotic Herbs, Ferns & Sedges					
Bulbostylis capillaris	2.2	0.6	2.4	1.0	ns
Desmodium sandwicense	0.0	0.0	1.9	0.7	sig
Erechtites valerianifolia	0.0	0.0	0.2	0.1	ns
Erigeron canadense	0.0	0.0	0.1	0.1	ns
Erigeron pusillus	0.2	0.2	0.0	0.0	ns
Hypochoeris radicata	0.2	0.1	0.5	0.1	ns
Subtotal	2.5	1.0	5.1	1.0	ns
Exotic Grasses					
Andropogon virginicus	2.5	1.2	2.8	0.6	ns
Digitaria violascens	0.2	0.1	0.5	0.3	ns
Holcus lanatus	0.3	0.3	0.0	0.0	ns
Melinis multiflora	3.7	0.3	27.8	6.3	sig
Rhynchelytrum repens	0.0	0.0	0.5	0.4	ns
Schizachyrium condensatum	31.5	7.2	16.5	1.7	sig
Setaria gracilis	0.0	0.0	0.4	0.2	ns
Subtotal	38.2	8.2	48.5	6.1	ns
Total Native Species	31.8	1.0	3.7	1.4	sig
Total Exotic Species	40.7	5.1	54.8	8.4	ns

Table 5. Woody plant densities (individuals/30 m. sq.) in the Lucky Eddie Burn, Hawai'i Volcanoes National Park.

Species and Height Class	Control n=9 Mean	S.E.	Burn n=9 Mean	S.E.	P<0.05
Native Shrubs					
Dodonaea viscosa					
<10 cm	0.8	0.4	1.5	0.6	ns
10-50 cm	2.0	0.7	3.0	0.8	ns
50-100 cm	5.1	1.0	1.5	0.6	sig
>100 cm	1.8	0.5	0.8	0.4	ns
subtotal	9.7	0.9	6.7	1.5	sig
Dubautia ciliolata					
<10 cm	0.0	0.0	0.8	0.5	sig
10-50 cm	0.4	0.4	1.5	0.9	ns
50-100 cm	0.1	0.1	0.4	0.2	ns
>100 cm	0.0	0.0	0.1	0.1	ns
subtotal	0.6	0.5	2.8	1.5	ns
Metrosideros polymorpha					
<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	1.2	0.7	0.2	0.1	ns
subtotal	1.2	0.7	0.2	0.1	ns
Osteomeles anthyllidifolia					
<10 cm	0.0	0.0	0.0	0.0	ns
10-50 cm	0.0	0.0	0.1	0.1	ns
50-100 cm	0.1	0.1	0.0	0.0	ns
>100 cm	0.4	0.3	0.2	0.1	ns
subtotal	0.6	0.4	0.3	0.1	ns
Styphelia tameiameiae					
<10 cm	2.8	1.2	1.3	0.4	ns
10-50 cm	6.4	2.0	4.3	1.1	ns
50-100 cm	10.4	2.8	1.6	0.6	sig
>100 cm	4.4	1.1	0.9	0.5	sig
subtotal	24.1	6.1	8.0	1.8	sig
Wikstroemia phillyreifolia					
<10 cm	0.0	0.0	0.1	0.1	ns
10-50 cm	0.1	0.1	0.1	0.1	ns
50-100 cm	0.2	0.1	0.0	0.0	ns
>100 cm	0.1	0.1	0.0	0.0	ns
subtotal	0.4	0.2	0.1	0.1	ns
Total	36.6	6.7	18.2	3.4	sig

Table 6. Percent cover of plant species (means and their standard errors) in the Kealakomo Burn, Hawai'i Volcanoes National Park.

	Control n=3		Burn n=3		
	Mean	S.E.	Mean	S.E.	P<0.05
Native Woody Plants					
Dodonaea viscosa	28.0	3.3	3.0	0.7	sig
Styphelia tameiameiae	2.0	1.6	0.0	0.0	ns
Subtotal	30.0	4.3	3.0	0.7	sig
Native Grasses					
Heteropogon contortus	0.0	0.0	0.0	0.0	ns
Subtotal	0.0	0.0	0.0	0.0	ns
Exotic Woody Plants					
Chamaecrista nictitans	1.5	0.0	0.1	0.1	sig
Indigofera suffruticosa	0.0	0.0	0.1	0.1	ns
Lantana camara	0.0	0.0	1.0	0.8	ns
Subtotal	1.5	0.0	1.2	0.9	ns
Exotic Herbs, Ferns & Sedges					
Bulbostylis capillaris	0.0	0.0	0.5	0.3	ns
Nephrolepis multiflora	4.8	0.7	0.5	0.4	sig
Subtotal	4.8	0.7	1.0	0.5	sig
Exotic Grasses					
Andropogon virginicus	20.7	1.7	32.0	4.0	sig
Digitaria violascens	0.2	0.1	0.0	0.0	ns
Melinis multiflora	0.0	0.0	0.2	0.2	ns
Rhynchelytrum repens	2.7	1.4	15.4	2.6	sig
Schizachyrium condensatum	20.3	1.4	7.1	2.8	sig
Setaria gracilis	0.5	0.4	4.2	3.7	ns
Sporobolus africanus	0.0	0.0	0.4	0.3	ns
Subtotal	44.3	2.1	59.2	4.4	sig
Total Native Species	30.0	4.3	3.0	0.7	sig
Total Exotic Species	50.7	1.6	61.5	3.8	sig

Table 7. Woody plant densities (individuals/30 m. sq.) in the Kealakomo Burn, Hawai'i Volcanoes National Park.

Species and Height Class	Control n=9 Mean	Control n=9 S.E.	Burn n=12 Mean	Burn n=12 S.E.	P<0.05
Native Shrubs					
Dodonaea viscosa					
<10 cm	7.9	2.0	74.8	10.0	sig
10-50 cm	19.1	2.5	65.0	10.2	sig
50-100 cm	14.6	2.0	5.8	1.3	sig
>100 cm	1.0	0.4	0.2	0.2	sig
subtotal	42.6	3.2	145.8	18.9	sig
Alien Shrubs					
Lantana camara					
<10 cm	0.1	0.1	0.1	0.1	ns
10-50 cm	0.2	0.1	0.1	0.1	ns
50-100 cm	0.1	0.1	0.2	0.1	ns
>100 cm	0.1	0.1	0.1	0.1	ns
subtotal	0.6	0.3	0.4	0.2	ns

Table 8. Percent cover of plant species (means and their standard errors) in the Shackleton Burn, Hawai'i Volcanoes National Park.

	Control n=9		Burn n=9		
	Mean	S.E.	Mean	S.E.	P<0.05
Native Woody Plants & Tree Ferns					
Dodonaea viscosa	3.3	0.9	2.2	1.0	ns
Metrosideros polymorpha	2.9	1.0	2.0	0.5	ns
Sadleria sp.	0.2	0.1	0.0	0.0	ns
Styphelia tameiameiae	19.0	1.5	2.9	1.2	sig
Vaccinium reticulatum	1.3	0.3	1.3	0.2	ns
Subtotal	26.6	2.2	8.4	2.0	sig
Native Herbs, Ferns & Sedges					
Gahnia gahniiformis	1.3	0.4	0.0	0.0	sig
Luzula hawaiiensis	0.1	0.1	0.0	0.0	ns
Machaerina angustifolia	0.1	0.1	0.0	0.0	ns
Pteridium aquilinum	0.0	0.0	3.1	1.4	sig
Subtotal	1.4	0.5	3.1	1.4	ns
Native Grasses					
Deschampsia nubigena	3.0	0.6	0.6	0.3	sig
Subtotal	3.0	0.6	0.6	0.3	sig
Exotic Herbs, Ferns & Sedges					
Bulbostylis capillaris	0.9	0.3	1.5	0.4	ns
Erigeron canadense	0.0	0.0	0.1	0.1	ns
Erigeron pusillus	0.0	0.0	1.2	0.7	ns
Hypochoeris radicata	0.3	0.2	1.7	0.7	sig
Kyllinga brevifolia	0.2	0.1	0.4	0.3	ns
Lotus sp	0.2	0.1	2.8	0.6	sig
Subtotal	1.6	0.3	7.7	1.2	sig
Exotic Grasses					
Andropogon virginicus	24.3	2.0	32.7	3.0	sig
Anthoxanthum odoratum	1.0	0.3	6.4	1.1	sig
Digitaria violascens	0.0	0.0	0.2	0.1	ns
Holcus lanatus	1.6	0.7	4.4	0.5	sig
Melinis multiflora	0.0	0.0	0.3	0.3	ns
Schizachyrium condensatum	1.3	2.5	3.0	1.0	ns
Subtotal	28.2	2.5	47.0	4.0	sig
Total Native Species	31.0	2.3	12.1	2.8	sig
Total Exotic Species	29.8	2.5	54.7	4.1	sig

Table 9. Woody plant densities (individuals/30 m. sq.) in the Shackleton Burn, Hawai'i Volcanoes National Park.

Species and Height Class	Control n=12		Burn n=12		
	Mean	S.E.	Mean	S.E.	P<0.05
Native Shrubs					
Dodonaea viscosa					
<10 cm	1.3	0.4	1.8	0.5	ns
10-50 cm	6.1	1.8	7.5	2.9	ns
50-100 cm	1.9	0.6	0.6	0.4	sig
>100 cm	0.4	0.2	0.1	0.1	ns
subtotal	9.8	2.3	10.0	3.5	ns
Dubautia ciliolata					
<10 cm	0.0	0.0	0.1	0.1	ns
10-50 cm	0.1	0.1	0.8	0.4	ns
50-100 cm	0.2	0.1	0.2	0.2	ns
>100 cm	0.0	0.0	0.0	0.0	ns
subtotal	0.3	0.2	1.1	0.5	ns
Santalum ellipticum					
<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	0.2	0.2	ns
>100 cm	0.0	0.0	0.1	0.1	ns
subtotal	0.0	0.0	0.4	0.2	ns
Styphelia tameiameiae					
<10 cm	5.9	1.2	5.1	2.6	ns
10-50 cm	45.7	4.9	8.8	2.1	sig
50-100 cm	4.1	0.8	0.6	0.5	sig
>100 cm	0.0	0.0	0.0	0.0	ns
subtotal	55.7	5.5	14.5	2.7	sig
Vaccinium reticulatum					
<10 cm	1.4	0.5	10.5	3.8	ns
10-50 cm	16.3	2.7	42.8	6.9	sig
50-100 cm	1.1	0.6	1.6	1.0	ns
>100 cm	0.0	0.0	0.0	0.0	ns
subtotal	18.9	2.9	54.9	10.1	sig
Wikstroemia phyllreifolia					
<10 cm	0.0	0.0	0.0	0.0	ns
10-50 cm	0.6	0.3	0.0	0.0	sig
50-100 cm	0.2	0.2	0.0	0.0	ns
>100 cm	0.0	0.0	0.0	0.0	ns
subtotal	0.8	0.4	0.0	0.0	sig
Total	85.4	6.9	80.9	10.5	ns

Table 10. Percent cover of plant species (means and their standard errors) in the Kipuka Nene Burn (low intensity site), Hawai`i Volcanoes National Park.

	Control n=3		Burn n=3		
	Mean	S.E.	Mean	S.E.	P<0.05
Native Woody Plants					
Dodonaea viscosa	11.2	1.5	1.8	0.4	sig
Sophora chrysopylla	0.0	0.0	0.0	0.0	ns
Styphelia tameiameiae	9.7	2.1	0.2	0.1	sig
Subtotal	20.8	3.6	2.0	0.5	sig
Native Herbs, Ferns & Sedges					
Cocculus ferrandianus	0.0	0.0	0.3	0.3	ns
Pteridium aquilinum	0.2	0.1	0.0	0.0	ns
Subtotal	0.2	0.1	0.3	0.3	ns
Exotic Woody Plants					
Lantana camara	0.3	0.3	0.0	0.0	ns
Myrica faya	0.0	0.0	3.8	3.1	ns
Subtotal	0.3	0.3	3.8	3.1	ns
Exotic Herbs, Ferns & Sedges					
Bulbostylis capillaris	0.0	0.0	0.0	0.0	ns
Desmodium sandwicense	0.0	0.0	0.0	0.0	ns
Subtotal	0.0	0.0	0.0	0.0	ns
Exotic Grasses					
Andropogon virginicus	6.5	1.9	2.0	1.0	ns
Melinis multiflora	23.2	3.0	54.8	2.6	sig
Paspalum urvilliae	0.0	0.0	0.2	0.1	ns
Rhynchelytrum repens	0.0	0.0	1.2	0.5	ns
Schizachyrium condensatum	30.3	1.8	24.8	2.2	ns
Subtotal	60.0	3.2	83.0	4.3	sig
Total Native Species	21.0	3.6	2.3	0.5	sig
Total Exotic Species	60.3	3.3	86.8	1.2	sig

Table 11. Woody plant densities (individuals/30 m. sq.) in the Kipuka Nene Burn (low intensity site), Hawai'i Volcanoes National Park.

Species and Height Class	Control n=9		Burn n=9		
	Mean	S.E.	Mean	S.E.	P<0.05
Native Shrubs					
Dodonaea viscosa					
<10 cm	1.6	0.4	3.0	0.9	ns
10-50 cm	7.4	1.7	10.3	2.0	ns
50-100 cm	4.2	0.8	1.1	0.4	sig
>100 cm	1.0	0.4	0.3	0.2	ns
subtotal	14.2	2.3	14.8	2.5	ns
Styphelia tameiameiae					
<10 cm	0.1	0.1	0.0	0.0	ns
10-50 cm	0.6	0.3	0.4	0.2	ns
50-100 cm	0.6	0.4	0.0	0.0	ns
>100 cm	0.9	0.5	0.0	0.0	sig
subtotal	2.1	0.8	0.4	0.2	sig
Total	16.3	2.3	15.2	2.5	ns
Alien Shrubs					
Myrica faya					
<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	0.1	0.1	0.6	0.3	ns
subtotal	0.1	0.1	0.6	0.3	ns
Psidium guajava					
<10 cm	0.0	0.0	0.1	0.1	ns
10-50 cm	0.0	0.0	0.1	0.1	ns
50-100 cm	0.0	0.0	0.2	0.2	ns
>100 cm	0.0	0.0	0.0	0.0	ns
subtotal	0.0	0.0	0.4	0.3	ns
Total	0.1	0.1	1.1	0.4	sig

Table 12. Percent cover of plant species (means and their standard errors) in the Kipuka Nene Burn (high intensity site), Hawai'i Volcanoes National Park.

	Control n=4		Burn n=4		
	Mean	S.E.	Mean	S.E.	P<0.05
Native Woody Plants					
Dodonaea viscosa	1.4	1.0	0.2	0.2	ns
Sophora chrysophylla	0.0	0.0	0.6	0.5	ns
Styphelia tameiameiae	12.9	4.4	0.0	0.0	sig
Subtotal	14.2	4.4	0.9	0.8	sig
Native Herbs, Ferns & Sedges					
Pteridium aquilinum	0.5	0.3	2.9	1.0	ns
Subtotal	0.5	0.3	2.9	1.0	ns
Exotic Woody Plants					
Chamacrista nictitans	0.1	0.1	0.2	0.2	ns
Lantana camara	0.0	0.0	0.5	0.4	ns
Myrica faya	0.2	0.2	0.0	0.0	ns
Psidium guajava	1.0	0.9	0.6	0.5	ns
Subtotal	0.3	0.3	3.8	3.1	ns
Exotic Herbs, Ferns & Sedges					
Bulbostylis capillaris	0.1	0.1	0.1	0.1	ns
Kyllinga brevifolia	0.1	0.1	0.0	0.0	ns
Subtotal	0.2	0.1	0.1	0.1	ns
Exotic Grasses					
Andropogon virginicus	0.2	0.1	0.5	0.4	ns
Melinis multiflora	27.6	3.8	57.1	3.4	sig
Rhynchelytrum repens	1.0	0.5	0.4	0.3	ns
Schizachyrium condensatum	40.4	6.8	32.8	3.5	ns
Subtotal	69.4	8.6	90.8	0.2	ns
Total Native Species	14.8	4.4	3.8	0.6	ns
Total Exotic Species	71.0	8.0	92.2	0.6	ns

Table 13. Woody plant densities (individuals/30 m. sq.) in the Kipuka Nene Burn (high intensity site), Hawai'i Volcanoes National Park.

Species and Height Class	Control n=12 Mean	Control n=12 S.E.	Burn n=12 Mean	Burn n=12 S.E.	P<0.05
Native Shrubs					
Dodonaea viscosa					
<10 cm	3.0	1.4	2.8	1.5	ns
10-50 cm	2.6	0.4	5.3	1.4	ns
50-100 cm	1.2	0.3	0.7	0.3	ns
>100 cm	0.1	0.1	0.2	0.1	ns
subtotal	6.8	1.7	9.0	2.7	ns
Sophora chrysophylla					
<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	0.1	0.1	0.1	0.1	ns
subtotal	0.1	0.1	0.1	0.1	ns
Styphelia tameiameiae					
<10 cm	4.4	2.0	0.1	0.1	sig
10-50 cm	3.2	1.2	0.1	0.1	sig
50-100 cm	0.5	0.2	0.1	0.1	sig
>100 cm	0.6	0.2	0.0	0.0	sig
subtotal	8.8	3.2	0.2	0.2	sig
Total	15.7	4.8	9.3	2.7	ns
Alien Shrubs					
Psidium guajava					
<10 cm	0.0	0.0	0.8	0.7	ns
10-50 cm	0.3	0.2	0.0	0.0	ns
50-100 cm	0.0	0.0	0.0	0.0	ns
>100 cm	0.2	0.1	0.1	0.1	ns
subtotal	0.5	0.2	0.9	0.7	ns

Table 14. Percent cover of plant species (means and their standard errors) in the Uila Burn (shrubland site), Hawai'i Volcanoes National Park.

	Control n=4		Burn n=4		
	Mean	S.E.	Mean	S.E.	P<0.05
Native Woody Plants					
Dodonaea viscosa	10.0	1.5	1.2	0.6	sig
Osteomeles anthyllidifolia	02	0.2	0.1	0.1	ns
Sophora chrysophylla	0.5	0.3	0.1	0.1	ns
Styphelia tameiameiae	24.0	3.2	0.2	0.2	sig
Subtotal	34.8	4.2	1.8	0.7	sig
Native Grasses					
Carex wahuensis	0.0	0.0	0.0	0.0	ns
Subtotal	0.0	0.0	0.0	0.0	ns
Exotic Woody Plants					
Myrica faya	0.1	0.1	0.0	0.0	ns
Subtotal	0.1	0.1	0.0	0.0	ns
Exotic Herbs, Ferns & Sedges					
Gnaphalium purpureum	0.0	0.0	0.1	0.1	ns
Subtotal	0.0	0.0	0.1	0.1	ns
Exotic Grasses					
Andropogon virginicus	12.8	2.1	22.0	5.1	ns
Melinis multiflora	44.8	5.5	64.6	5.9	sig
Pennisetum clandestinum	1.6	1.4	0.0	0.0	ns
Schizachyrium condensatum	0.1	0.1	3.5	1.4	sig
Setaria gracilis	0.1	0.1	0.0	0.0	ns
Subtotal	59.4	4.7	90.1	0.6	sig
Total Native Species	34.8	4.2	1.8	0.7	sig
Total Exotic Species	59.5	4.7	90.9	0.5	sig

Table 15. Woody plant densities (individuals/30 m. sq.) in the Uila Burn (shrubland site), Hawai'i Volcanoes National Park.

Species and Height Class	Control n=12		Burn n=12		
	Mean	S.E.	Mean	S.E.	P<0.05
Native Shrubs					
Dodonaea viscosa					
<10 cm	6.0	1.8	3.8	1.1	ns
10-50 cm	10.6	1.7	8.7	2.3	ns
50-100 cm	4.4	0.6	1.8	0.6	sig
>100 cm	0.5	0.2	0.2	0.1	ns
subtotal	21.5	2.3	14.5	3.1	sig
Osteomeles anthyllidifolia					
<10 cm	0.2	0.2	0.0	0.0	ns
10-50 cm	0.5	0.2	0.0	0.0	sig
50-100 cm	0.2	0.1	0.1	0.1	ns
>100 cm	0.1	0.1	0.0	0.0	ns
subtotal	1.0	0.4	0.1	0.1	sig
Styphelia tameiameiae					
<10 cm	10.6	4.7	0.6	0.3	sig
10-50 cm	1.4	0.3	2.5	1.5	ns
50-100 cm	1.3	0.4	0.6	0.3	
>100 cm	0.9	0.3	0.2	0.2	sig
subtotal	14.2	5.0	3.8	1.8	sig
Total	37.2	6.1	18.5	3.7	sig
Alien Shrubs					
Myrica faya					
<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	0.1	0.1	0.1	0.1	ns
subtotal	0.1	0.1	0.1	0.1	ns
Psidium guajava					
<10 cm	0.0	0.0	0.0	0.0	ns
10-50 cm	0.2	0.2	0.3	0.2	ns
50-100 cm	0.5	0.2	0.3	0.2	ns
>100 cm	0.0	0.0	0.2	0.2	ns
subtotal	0.8	0.3	0.9	0.3	ns
Total	0.8	0.3	1.0	0.3	ns

Table 16. Percent cover of plant species (means and their standard errors) in the Uila Burn (woodland site), Hawai'i Volcanoes National Park.

	Control n=3		Burned n=3		
	Mean	S.E.	Mean	S.E.	P<0.05
Native Woody Plants					
Dodonaea viscosa	4.3	1.2	0.3	0.1	sig
Osteomeles anthyllidifolia	0.8	0.4	1.0	0.5	ns
Styphelia tameiameiae	22.8	5.0	2.2	0.1	sig
Subtotal	28.0	5.4	2.2	0.1	sig
Native Grasses					
Carex wahuensis	0.5	0.4	0.0	0.0	ns
Subtotal	0.5	0.4	0.0	0.0	ns
Exotic Woody Plants					
Myrica faya	0.0	0.0	1.0	0.8	ns
Subtotal	0.0	0.0	1.0	0.8	ns
Exotic Grasses					
Andropogon virginicus	7.0	1.3	12.3	1.6	sig
Melinis multiflora	21.5	1.2	47.2	2.2	sig
Schizachyrium condensatum	39.7	8.1	37.0	3.2	ns
Subtotal	68.2	5.7	96.5	0.8	sig
Total Native Species	28.5	5.2	2.3	0.1	sig
Total Exotic Species	68.2	5.7	97.5	0.2	sig

Table 17. Woody plant densities (individuals/30 m. sq.) in the Uila Burn (woodland site), Hawai'i Volcanoes National Park.

Species and Height Class	Control n=9 Mean	S.E.	Burn n=9 Mean	S.E.	P<0.05
Native Shrubs					
Dodonaea viscosa					
<10 cm	0.2	0.1	0.2	0.2	ns
10-50 cm	6.0	1.6	2.2	0.6	sig
50-100 cm	7.1	1.4	1.1	0.5	sig
>100 cm	0.6	0.2	0.0	0.0	sig
subtotal	13.9	2.2	3.6	0.6	sig
Metrosideros polymorpha					
<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	0.2	0.1	ns
subtotal	0.3	0.2	0.2	0.1	ns
Osteomeles anthyllidifolia					
<10 cm	0.0	0.0	0.1	0.1	ns
10-50 cm	1.9	0.6	1.2	0.5	ns
50-100 cm	1.7	0.6	4.6	1.2	sig
>100 cm	0.6	0.3	1.0	0.7	ns
subtotal	4.1	1.1	6.9	1.9	ns
Styphelia tameiameiae					
<10 cm	0.4	0.4	0.0	0.0	ns
10-50 cm	3.3	0.9	1.6	0.8	ns
50-100 cm	6.3	1.2	1.6	0.4	sig
>100 cm	4.3	1.1	0.4	0.2	sig
subtotal	14.4	2.1	3.6	0.8	sig
Total	32.8	3.6	14.2	2.0	sig
Alien Shrubs					
Myrica faya					
<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	0.4	0.2	0.1	0.1	ns
subtotal	0.4	0.2	0.1	0.1	ns
Total	0.4	0.2	0.2	0.1	ns

Table 18. Percent cover of plant species (means and their standard errors) in the Napau Burn (shrubland site), Hawai'i Volcanoes National Park.

	1972 Burn n=5		1992 Burn n=5		
	Mean	S.E.	Mean	S.E.	P<0.05
Native Woody Plants					
Dodonaea viscosa	50.2	3.3	31.0	1.0	sig
Osteomeles anthyllidifolia	0.3	0.3	0.0	0.0	ns
Styphelia tameiameiae	0.0	0.0	0.2	0.1	ns
Waltheria indica	0.0	0.0	9.8	2.7	sig
Subtotal	46.8	9.6	27.6	2.1	sig
Native Herbs, Ferns & Sedges					
Carex wahuensis	0.3	0.3	0.0	0.0	ns
Cassytha filiformis	31.0	9.0	2.0	0.6	ns
Pycreus polystachos	0.0	0.0	0.4	0.2	ns
Subtotal	31.3	9.0	2.4	0.6	ns
Exotic Woody Plants					
Chamaecrista nictitans	2.4	0.9	4.8	1.6	ns
Lantana camara	0.3	0.3	0.3	0.3	ns
Psidium cattleianum	0.2	0.1	0.0	0.0	ns
Subtotal	2.9	0.8	5.1	1.5	ns
Exotic Herbs, Ferns & Sedges					
Bulbostylis capillaris	0.0	0.0	0.0	0.0	ns
Crassocephalum crepoides	0.0	0.0	0.4	0.4	ns
Desmodium sandwicense	0.0	0.0	1.7	1.0	ns
Nephrolepis multiflora	14.2	0.3	14.0	2.1	ns
Phymatosorus scolopendria	0.1	0.1	0.0	0.0	ns
Spathoglottis plicata	0.1	0.1	0.1	0.0	ns
Stachytarpheta jamaicensis	0.0	0.0	0.3	0.3	ns
Subtotal	14.5	0.4	16.9	3.5	ns
Exotic Grasses					
Andropogon virginicus	24.4	1.4	8.9	1.3	sig
Paspalum scrobiculatum	2.3	0.8	0.9	0.3	ns
Rhynchelytrum repens	0.3	0.2	0.0	0.0	ns
Schizachyrium condensatum	0.8	0.5	1.7	0.6	ns
Subtotal	28.8	1.8	11.4	2.0	sig
Total Native Species	81.8	6.4	43.4	3.6	sig
Total Exotic Species	46.1	2.1	33.4	3.2	sig

Table 19. Woody plant densities (individuals/20 m. sq.) in the Napau Burn (shrubland site), Hawai`i Volcanoes National Park.

Species and Height Class	1972 Burn n=40 Mean	S.E.	1992 Burn n=40 Mean	S.E.	P<0.05
Native Shrubs					
Dodonaea viscosa					
<10 cm	0.2	0.1	7.4	1.2	sig
10-50 cm	7.3	0.7	18.6	1.8	sig
50-100 cm	2.8	0.4	3.2	0.6	ns
>100 cm	0.2	0.1	0.1	0.1	ns
subtotal	10.6	0.9	29.4	2.8	sig
Osteomeles anthyllidifolia					
<10 cm	0.0	0.0	0.0	0.0	ns
10-50 cm	0.1	0.1	0.0	0.0	ns
50-100 cm	0.0	0.0	0.0	0.0	ns
>100 cm	0.0	0.0	0.0	0.0	ns
subtotal	0.1	0.1	0.0	0.0	ns
Total	10.6	0.9	29.4	2.8	sig
Alien Shrubs					
Psidium guajava					
<10 cm	0.0	0.0	0.0	0.0	ns
10-50 cm	0.1	0.1	0.0	0.0	ns
50-100 cm	0.0	0.0	0.0	0.0	ns
>100 cm	0.0	0.0	0.0	0.0	ns
subtotal	0.1	0.1	0.0	0.0	ns

Table 20. Subshrub densities (individuals/0.5 m.sq.) in the Napau Burn (shrubland site), Hawai`i Volcanoes National Park.

Species and Height Class (cm)	1972 Burn n=40		1992 Burn n=40		
	Mean	S.E.	Mean	S.E.	P<0.05
Native Subshrubs					
Waltheria americana					
>10 cm	0.1	0.1	0.2	0.1	ns
10-50 cm	0.0	0.0	0.4	0.2	sig
10-100 cm	0.0	0.0	0.1	0.1	ns
>100 cm	0.0	0.0	0.0	0.0	ns
subtotal	0.1	0.1	0.6	0.3	sig
Alien Subshrubs					
Chamacristae nictitans					
<10 cm	0.2	0.1	1.4	0.3	sig
10-50 cm	0.6	0.2	2.0	0.6	sig
50-100 cm	0.0	0.0	0.0	0.0	ns
>100 cm	0.0	0.0	0.0	0.0	ns
subtotal	0.8	0.2	3.4	0.7	sig

Table 21. Percent cover of plant species (means and their standard errors) in the Napau (woodland site), Hawai'i Volcanoes National Park.

	1972 Burn n=5		1992 Burn n=5		
	Mean	S.E.	Mean	S.E.	P<0.05
Native Woody Plants					
Dodonaea viscosa	39.8	4.8	21.7	3.0	sig
Metrosideros polymorpha	2.2	0.6	1.7	0.5	ns
Osetomeles anthyllidifolia	4.4	4.2	1.8	1.0	ns
Sida fallax	0.0	0.0	0.7	0.4	ns
Styphelia tameiameiae	0.4	0.3	0.6	0.4	ns
Waltheria indica	0.0	0.0	1.9	0.6	sig
Wikstroemia phillyraefolia	0.0	0.0	0.0	0.0	ns
Subtotal	46.8	9.6	27.6	2.1	sig
Native Herbs, Ferns & Sedges					
Carex wahuensis	0.1	0.1	0.0	0.0	ns
Pycreus polystachos	0.1	0.1	1.8	1.0	ns
Subtotal	0.2	0.1	1.8	1.0	ns
Exotic Woody Plants					
Chamaecrista nictitans	0.0	0.0	4.6	2.9	ns
Lantana camara	0.5	0.3	0.0	0.0	ns
Psidium cattleianum	0.2	0.2	0.0	0.0	ns
Subtotal	0.7	0.3	4.6	2.9	ns
Exotic Herbs, Ferns & Sedges					
Aurundina graminifolia	0.5	0.3	0.0	0.0	ns
Crassocephalum crepoides	0.0	0.0	1.8	0.5	sig
Desmodium sandwicense	0.0	0.0	0.7	0.6	ns
Nephrolepis multiflora	65.9	3.8	27.0	2.8	sig
Passiflora foetida	0.0	0.0	0.1	0.1	ns
Phaius tankervilleae	0.0	0.0	0.1	0.1	ns
Spathoglottis plicata	0.5	0.3	0.1	0.1	ns
Stachytarpheta jamaicensis	0.0	0.0	0.8	0.3	sig
Subtotal	66.9	3.9	31.0	3.2	sig
Exotic Grasses					
Andropogon virginicus	2.8	0.9	1.6	0.6	ns
Paspalum condensatum	0.5	0.3	2.2	1.0	ns
Paspalum scrobiculatum	0.4	0.3	2.5	1.0	ns
Subtotal	3.6	0.8	8.1	1.1	sig
Total Native Species	47.0	4.2	29.4	2.2	sig
Total Exotic Species	71.2	3.8	43.6	4.2	sig

Table 22. Woody plant densities (individuals/20 m. sq.) in the Napau (woodland site), Hawai`i Volcanoes National Park.

Species and Height Class	1972 Burn n=40 Mean	S.E.	1992 Burn n=40 Mean	S.E.	P<0.05
Native Shrubs					
Dodonaea viscosa					
<10 cm	19.4	2.6	5.7	1.1	sig
10-50 cm	15.2	1.8	1.4	0.3	sig
50-100 cm	6.5	0.8	2.1	0.3	sig
>100 cm	0.2	0.1	1.3	0.2	sig
subtotal	41.5	3.9	10.4	1.3	sig
Metrosideros polymorpha					
<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	0.1	0.1	0.0	0.0	ns
subtotal	0.1	0.1	0.0	0.0	ns
Osteomeles anthyllidifolia					
<10 cm	0.0	0.0	0.0	0.0	ns
10-50 cm	0.1	0.0	0.1	0.1	ns
50-100 cm	0.0	0.0	0.0	0.0	ns
>100 cm	0.0	0.0	0.0	0.0	ns
subtotal	0.2	0.1	0.4	0.1	ns
Sida fallax					
<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	0.1	0.1	0.0	0.0	ns
subtotal	0.1	0.1	0.0	0.0	ns
Styphelia tameiameiae					
<10 cm	0.1	0.1	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	0.0	0.0	0.0	0.0	ns
subtotal	0.1	0.1	0.0	0.0	ns
Wikstroemia phyllreifolia					
<10 cm	0.0	0.0	0.0	0.0	ns
10-50 cm	0.0	0.0	0.1	0.1	ns
50-100 cm	0.0	0.0	0.0	0.0	ns
>100 cm	0.0	0.0	0.0	0.0	ns
subtotal	0.0	0.0	0.1	0.1	ns
Total	41.9	4.0	11.0	1.3	sig

Table 23. Subshrub densities (individuals/20 m. sq.) in the Napau Burn (woodland site), Hawai'i Volcanoes National Park.

Species and Height Class	1972 Burn n=40		1992 Burn n=40		
	Mean	S.E.	Mean	S.E.	P<0.05
Native Subshrubs					
Waltheria indica					
<10 cm	0.0	0.0	0.0	0.0	ns
10-50 cm	0.0	0.0	0.0	0.0	ns
50-100 cm	0.0	0.0	0.0	0.0	ns
>100 cm	0.0	0.0	0.0	0.0	ns
subtotal	0.1	0.1	0.0	0.0	ns
Alien Subshrubs					
Chamaecrista nictitans					
<10 cm	1.4	0.6	0.6	0.3	ns
10-50 cm	0.7	0.5	0.1	0.1	ns
50-100 cm	0.6	0.6	0.0	0.0	ns
>100 cm	0.0	0.0	0.0	0.0	ns
subtotal	2.7	1.7	0.7	0.4	ns

Table 24. Woody plant mortality/recovery in three burns in the submontane seasonal zone.

Species	Kipuka Nene n	Kipuka Nene % Live	Pepeiau n	Pepeiau % Live	Uila n	Uila % Live	Total n	Total % Live	P<0.05
Dodonaea viscosa									
High Intensity	0	0.0	0	0.0	30	3.3	30	3.3	ns
Low Intensity	199	8.5	0	0.0	97	5.1	296	7.4	
Osteomeles anthllidifolia									
High Intensity	0	0.0	0	0.0	15	73.3	15	73.3	ns
Low Intensity	0	0.0	0	0.0	3	100.0	3	100.0	
Psidium guajava									
High Intensity	0	0.0	0	0.0	1	100.0	1	100.0	ns
Low Intensity	0	0.0	0	0.0	44	81.8	44	81.8	
Sophora chrysophylla									
High Intensity	32	59.4	0	0.0	0	0.0	32	59.4	ns
Low Intensity	0	0.0	0	0.0	4	100.0	4	100.0	
Styphelia tameiameiae									
High Intensity	8	12.5	94	31.9	92	8.7	194	20.1	sig
Low Intensity	54	46.3	100	75.0	20	5.0	174	58.0	

Table 25. Biomass of dead and live grasses in Lucky Eddie, Uila ,and Namakani Paio Burns. Hawai'i Volcanoes National Park.

	Control (g)	Burn (g)	$P \leq 0.05$
Lucky Eddie Burn	53.9 ± 6.5	90.2 ± 7.7	sig
Uila High Intensity Burn	55.2 ± 6.5	143.3 ±10.3	sig
Namakani Paio Low Intensity Burn	55.1 ± 5.7	137.8 ± 7.5	sig

Table 26. 'Ohi'a mortality/recovery in the Uila Burn, Hawai'i Volcanoes National Park.

	n=	live	dead	P<0.05
High vs Low Intensity Burn 1990				
low intensity	77	63	14	sig
high intensity	91	45	46	
Low Intensity Burn 1990				
stems = 1	36	28	8	ns
stems > 1	41	35	6	
% Char hgt <= 33	43	36	7	ns
% Char hgt > 33	34	27	7	
% Scorch <= 75	30	27	3	ns
% Scorch > 75	47	36	11	
% Scorch < 100	48	40	8	ns
% Scorch = 100	29	23	6	
dbh <= 5	8	8	0	ns
dbh > 5	69	55	14	
dbh <=5				
% Scorch <= 75	0	0	0	na
% Scorch > 75	8	8	0	
dbh <=5				
% Scorch <100	0	0	0	na
% Scorch =100	8	0	8	
dbh > 5				
% Scorch <= 75	32	29	3	sig
% Scorch > 75	37	26	11	
dbh > 5				
% Scorch < 100	48	40	8	ns
% Scorch = 100	21	15	6	
dbh <= 10	26	21	5	ns
dbh > 10	51	42	9	
dbh <=10				
% Scorch <= 75	6	5	1	ns
% Scorch > 75	20	16	4	
dbh <=10				
% Scorch <100	7	5	2	ns
% Scorch >100	19	16	3	
dbh > 10				
% Scorch <= 75	35	33	2	sig
% Scorch > 75	27	20	7	
dbh > 10				
% Scorch < 100	40	34	6	ns
% Scorch = 100	11	8	3	

Table 26. 'Ohia mortality in the Uila Burn (continued).

	n=	live	dead	P<0.05
High Intensity Burn 1990*				
stems = 1	60	25	35	sig
stems > 1	31	20	11	
dbh <= 5	11	4	7	ns
dbh > 5	80	41	39	
dbh <= 10	22	8	14	ns
dbh > 10	69	37	32	

*Percentage scorch not determined.

Table 27 \`Ohi\`a mortality/recovery in the Napau Burn, Hawai\`i Volcanoes National Park.

	n=	live	dead	P<0.05
Total number of individuals	214	114	100	
stems = 1	137	68	69	ns
stems > 1	77	46	31	
% Char hgt <= 33	114	67	47	ns
% Char hgt > 33	100	47	53	
% Scorch <= 75	34	34	0	sig
% Scorch > 75	180	80	100	
% Scorch < 100	57	47	10	sig
% Scorch = 100	157	67	90	
dbh <= 5	84	54	30	sig
dbh > 5	130	60	70	
dbh <=5				
% Scorch <= 75	6	6	0	ns
% Scorch > 75	78	48	30	
dbh <=5				
% Scorch <100	10	9	1	ns
% Scorch >100	74	45	29	
dbh > 5				
% Scorch <= 75	28	27	1	sig
% Scorch > 75	102	33	69	
dbh > 5				
% Scorch < 100	47	38	9	sig
% Scorch = 100	83	22	61	
dbh <= 10	135	74	61	ns
dbh > 10	79	40	39	
dbh <=10				
% Scorch <= 75	15	15	0	sig
% Scorch > 75	120	59	61	
dbh <=10				
% Scorch <100	24	20	4	sig
% Scorch >100	111	54	57	
dbh > 10				
% Scorch <= 75	19	18	1	sig
% Scorch > 75	60	22	38	
dbh > 10				
% Scorch < 100	33	27	6	sig
% Scorch = 100	46	13	33	

Table 28. `Ohi`a mortality/recovery in the Namakani Paio Burn, Hawai`i Volcanoes National Park.

	n=	live	dead	P<0.05
Low Intensity Burn	110	69	41	
dbh <= 5	52	43	19	ns
dbh > 5	48	26	22	
dbh <= 10	99	66	33	sig
dbh > 10	11	3	8	
High Intensity Burn	91	40	51	
dbh <= 5	45	20	25	ns
dbh > 5	46	20	26	
dbh <= 10	59	29	30	sig
dbh > 10	32	11	21	

Table 29. `Ohi`a mortality/recovery in Kipuka Nene, Pepeiau, and Lucky Eddie Burns, Hawai`i Volcanoes National Park.

	n=	live	dead	P<0.05
Kipuka Nene High Intensity Burn				
% Char hgt <= 33	7	0	7	na
% Char hgt > 33	21	0	21	
% Scorch < 100*	12	0	12	na
% Scorch =100	16	0	16	
Pepeiau Burn				
dbh <= 5	0	0	0	na
dbh > 5	20	11	9	
dbh <= 10	0	0	0	na
dbh > 10	20	11	9	
% Char hgt <= 33	16	10	6	ns
% Char hgt > 33	4	1	3	
% Scorch < 100*	20	11	9	na
% Scorch =100	0	0	0	
Lucky Eddie Burn				
dbh <= 5	0	0	0	na
dbh > 5	18	4	14	
dbh <= 10	7	2	5	ns
dbh > 10	11	2	9	

*Percentage of canopy scorched was not determined only as 100% or <100 %.

Table 30. `Ohi`a mortality/recovery over time in, Lucky Eddie, Uila and Napau Burns, Hawai`i Volcanoes National Park.

	n=	live	new growth	dead	% live
Lucky Eddie Burn					
12/85	18	12	7	6	67
7/86	18	8	7	10	44
1/87	18	3	3	15	17
1/88	18	4	4	14	22
Uila Low Intensity Burn					
11/87	79	59	28	20	74
4/89	77	63	63	14	82
1/90	77	63	63	14	82
Napau Forest Burn					
4/93	217	151	144	66	70
10/93	214	114	113	100	53

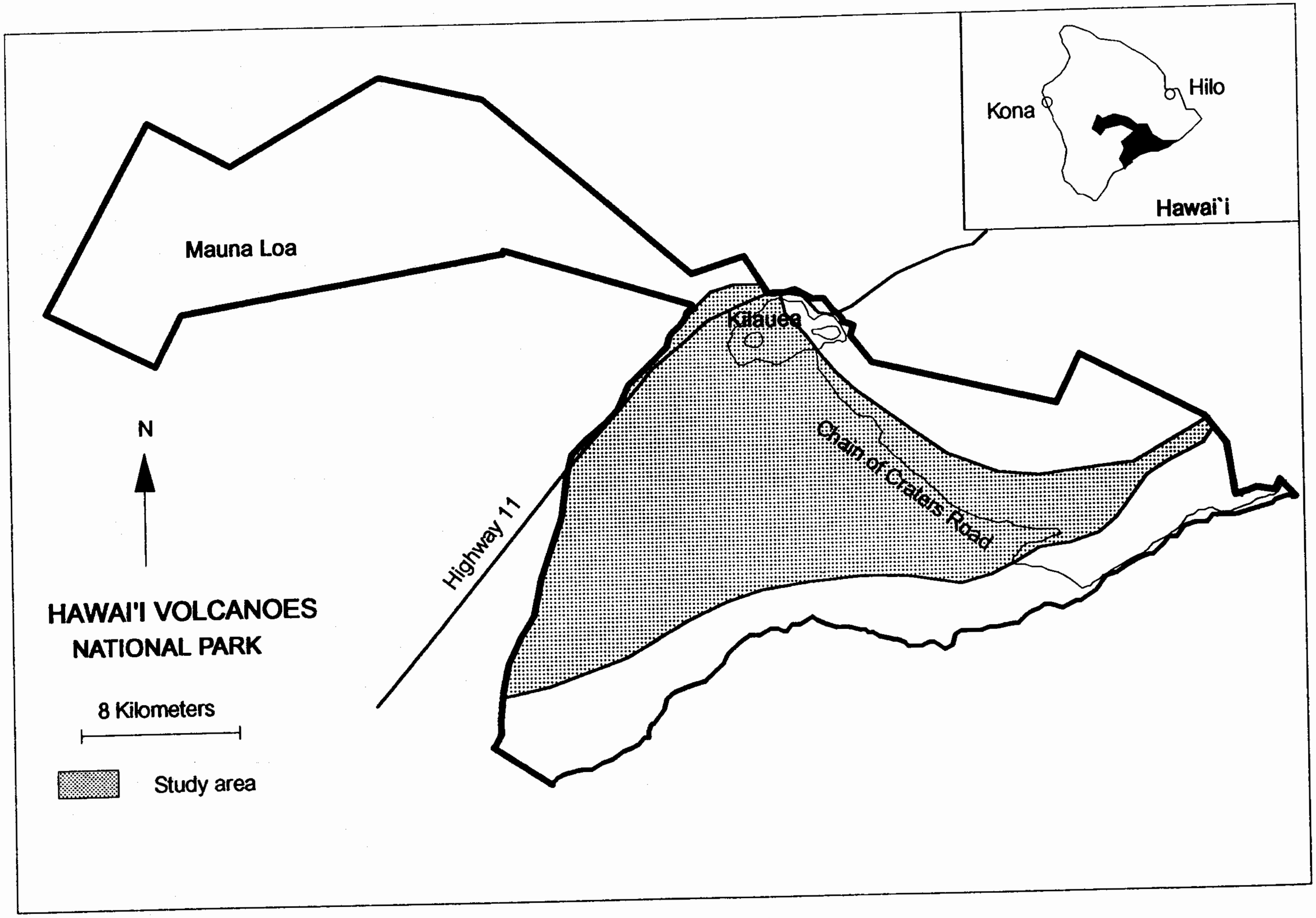

Figure 1. Submontane seasonal zone and study area in Hawai`i Volcanoes National Park

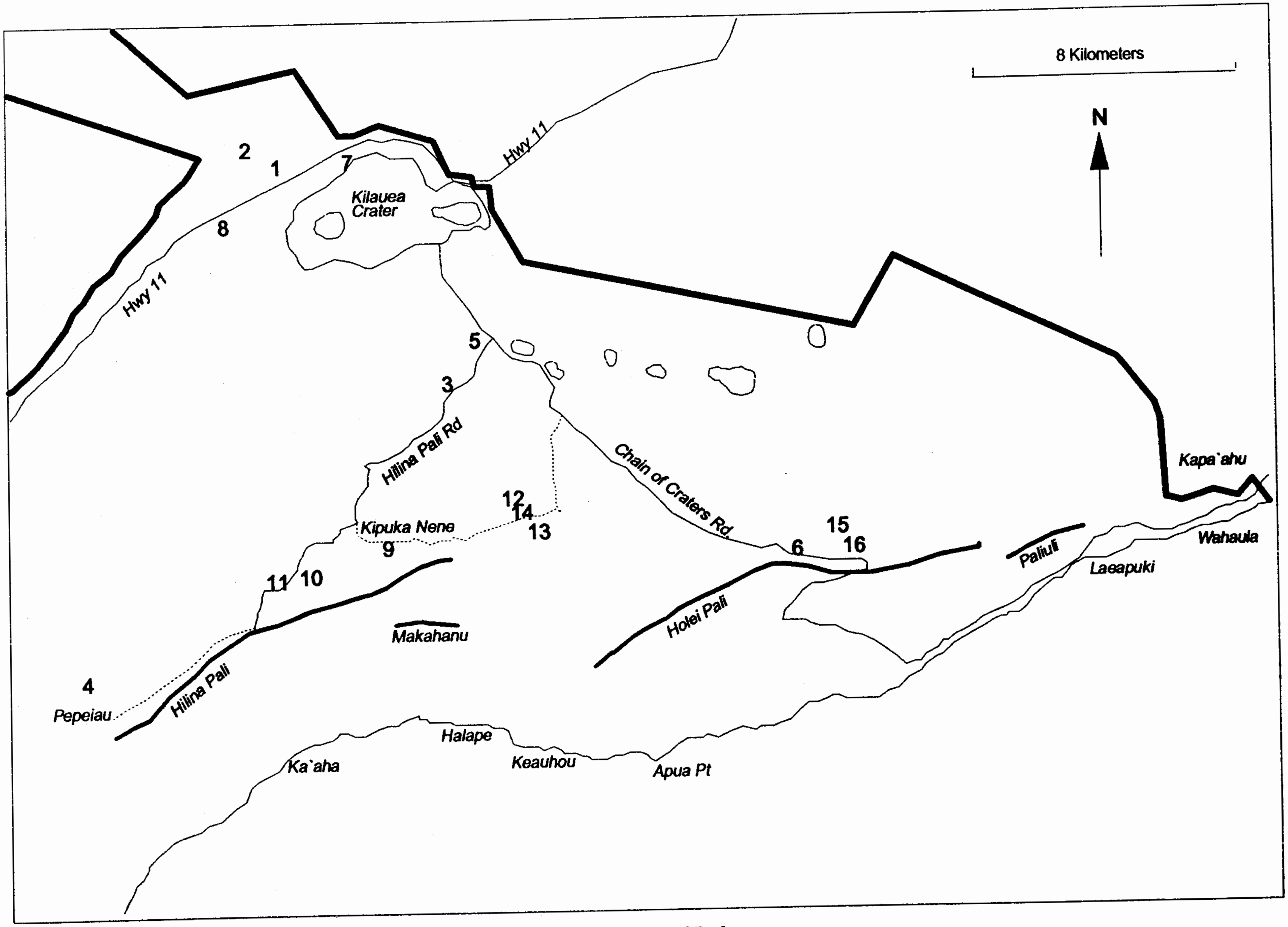

Figure 2. Location of study sites in the submontane of Hawai`i Volcanoes National Park.

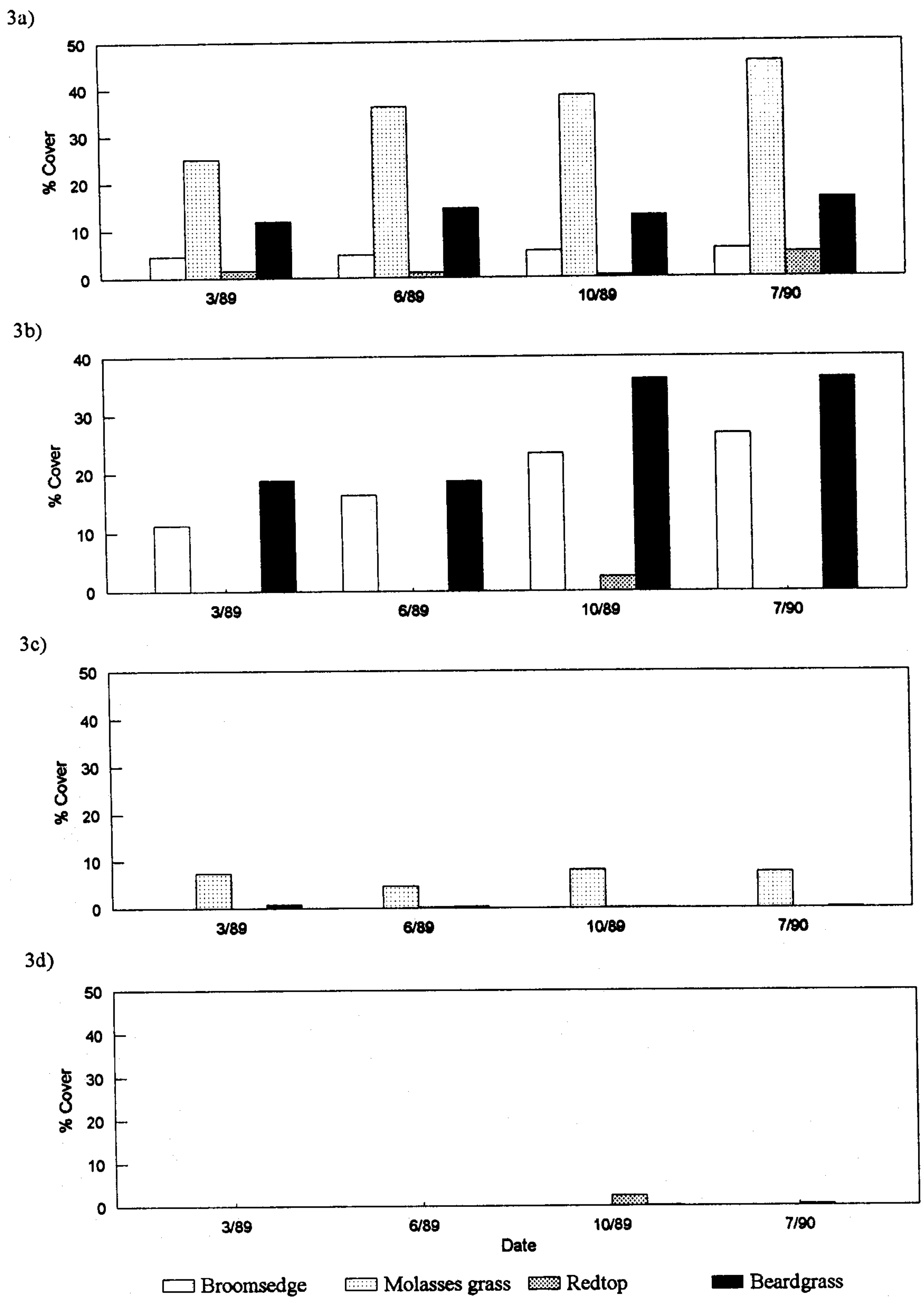

Figure 3. Percent cover of resprouting grasses and seedlings in the Pepeiau Burn. Plot A is located in a site dominated by molasses grass. Plots B, C and D, located in a beardgrass-broomsedge dominated site, equal Plot A in size. Values from Plots B, C and D were pooled. Percent cover 3a) of resprouts in Plot A; 3b) resprouts in Plots B, C and D; 3c) of seedlings in Plot A; 3d) of seedlings in Plots B, C and D.

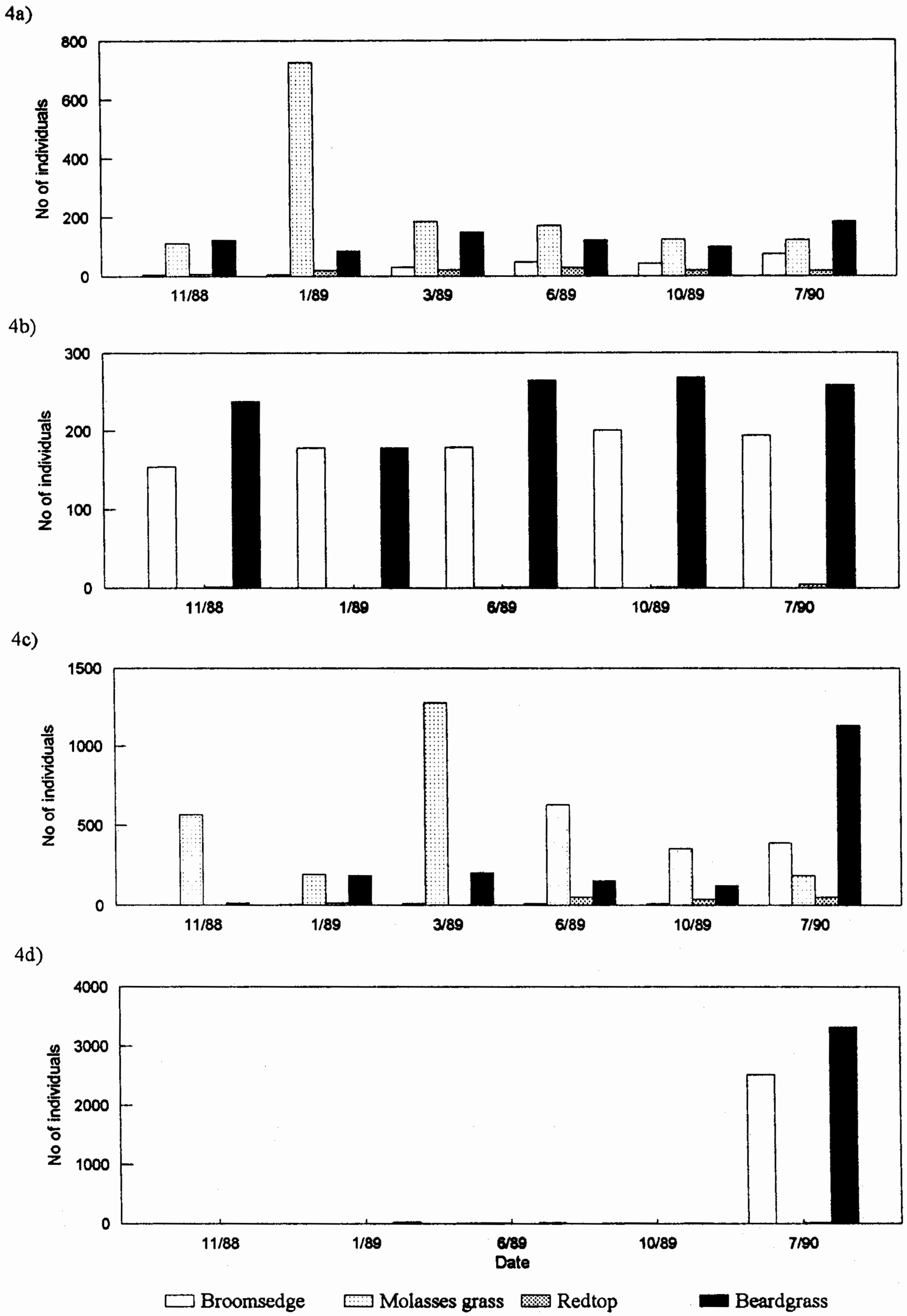

Figure 4. Density of resprouting grasses and seedlings in the Pepeiau Burn. Density is based on number of individuals/54 sq. m. Density of 4a) resprouts in Plot A; 4b) resprouts in plots B, C and D; 4c) seedlings in Plot a; 4d) seedlings in B, C and D.

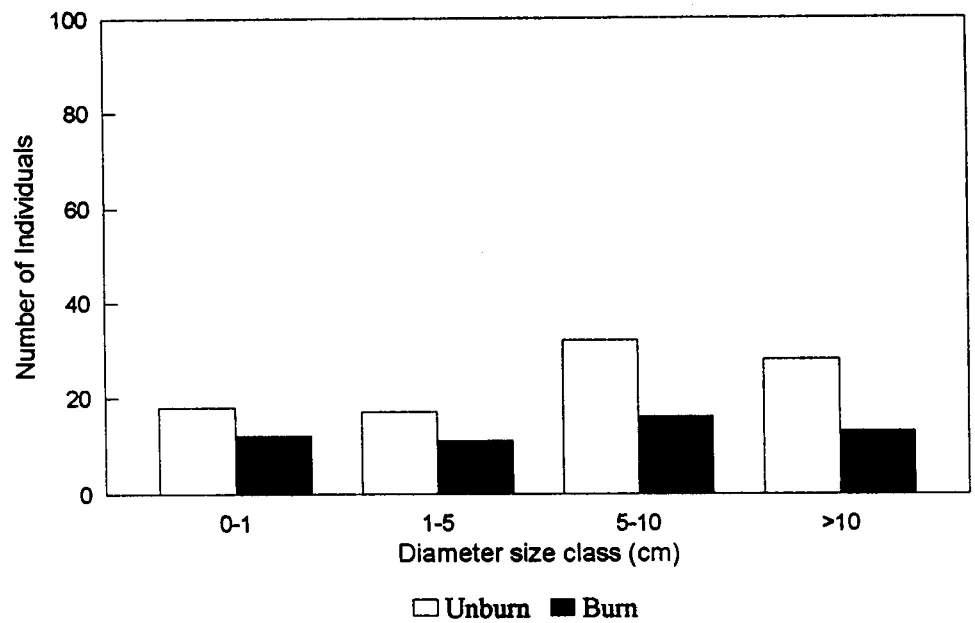

Figure 5. Number of faya tree in four diameter classes 1 year after fire in an `ohi`a woodland.

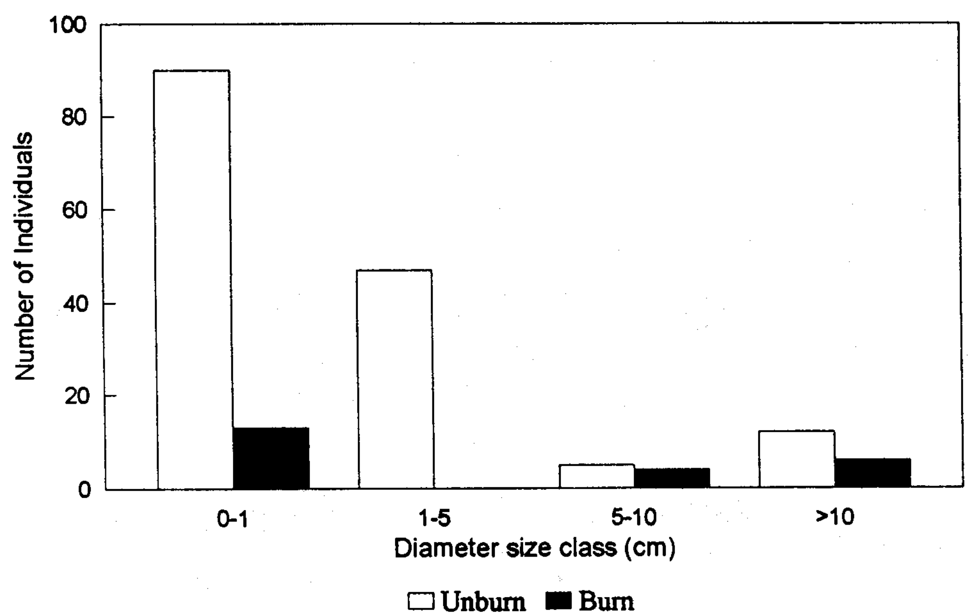

Figure 6. Number of faya tree in four diameter classes 2 years after fire in an `ohi`a shrubland.

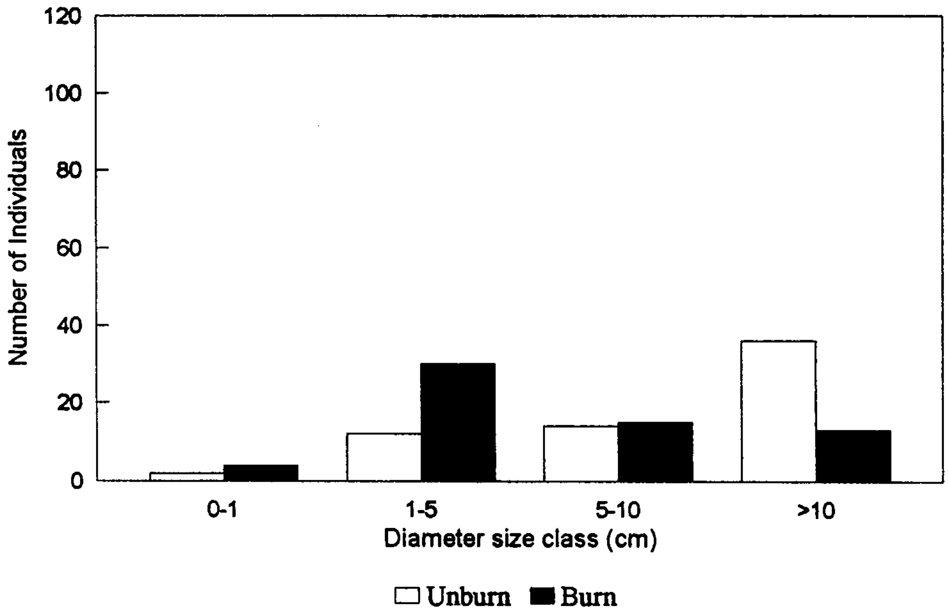

Figure 7. Number of faya tree in four diameter classes 6 years after fire in an `ohi`a woodland. Faya tree was sampled in 16, 30 x 30 m plots.

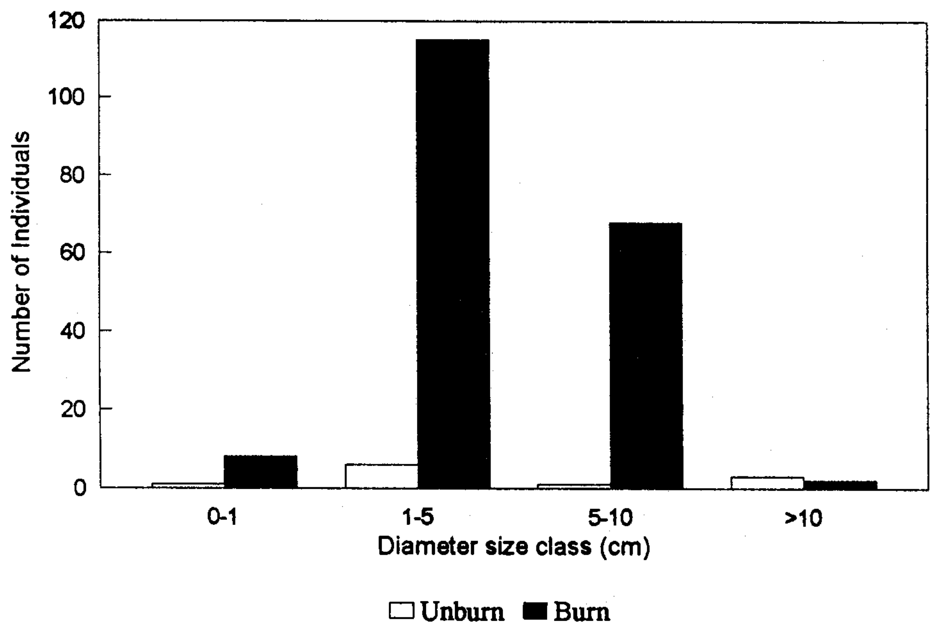

Figure 8. Number of faya tree in four diameter classes 6 years after fire in an `ohi`a shrubland Faya tree was sampled in 17, 30 x 30 m plots.