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The Impact and Spread of *Rubus ellipticus* in 'Ola'a Forest Tract Hawai'i Volcanoes National Park

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ABSTRACT

Rubus ellipticus (Rosaceae), is a large thorny shrub that has demonstrated the capability of establishing itself in the canopy of tree-fern dominated rain forest areas as well as in open pastures, old sugar cane fields and drier areas of Hawai'i Volcanoes National Park. Introduced to the Volcano Agricultural Experiment Station in 1961, it has since spread to adjacent areas on the island of Hawaii as well as to areas over 120 km from the Station. This study focused on quantifying the impact on the native vegetation as well as the rate of spread within Hawaii Volcanoes National Park's 'Ola'a Large Tract. Total cover of *R. ellipticus* per transect doubled over 5 years from a transect average of 6% to 13%. Impact on vegetation cover was assessed by comparing understory vegetation beneath *R. ellipticus*, tree ferns and random forest locations in a stratified block design. Total understory cover was significantly lower under *R. ellipticus* as was species diversity. A finding that the pig-free section of the unit showed almost no increase in *R. ellipticus* cover suggests that pigs contribute to the expansion of this weed in Hawai'i's native montane rain forests.

INTRODUCTION

The Himalayan yellow raspberry (*Rubus ellipticus* var. *obcordatus* Focke: Rosaceae) is a large, thicket-forming, thorny shrub that is invading various habitats, including the native montane rain forests of the Island of Hawai'i (Fig.1). It is a particularly serious threat because its stout stem gives it the ability to grow tall (3-7 meters) and establish itself within the tree fern canopy. Thus, unlike shorter pioneer weeds which may be shaded out in the successional process, *R. ellipticus* can remain in the middle canopy where there are higher light levels. Certain weeds are considered to be more disruptive than others based on their ability to invade many habitats, to alter those habitats or replace natives in the community (Smith, 1985). *Rubus ellipticus* grows in large thickets which not only displace natives but may inhibit future regeneration by less shade-tolerant natives.

Rubus ellipticus was introduced to Volcano Agricultural Experiment Station in 1961 (Jacobi & Warshauer, 1992). The current range of *R. ellipticus* extends from Laupahoehoe Forest Reserve, in the north, to Ka'u Forest Reserve, in the south, to Pu'u La'ala'au, west. It most concentrated around the site of introduction along Wright Road, Route 11 and Stainback Highway as well as throughout Hawai'i Volcanoes (HAVO) National Park's 'Ola'a Large Tract. A distribution map illustrating the known 1992 distribution created by Gerrish *et al.* (1992) has been updated for this report (Fig. 2). *Rubus ellipticus* is currently distributed between 2000 and 5000 ft. (600 - 1500 m) elevation where precipitation levels range from 2000 to 6500 mm/year.

There are no confirmed reports of *R. ellipticus* on other islands except for a single, potted specimen on O'ahu that was identified by a Department of Agriculture agent (Markin, pers com).

The spread of invasive, non-native plants is of primary concern to many natural areas managers in Hawai'i. Because soil and ground cover disturbance may contribute to the spread of alien plants, control of disturbance agents is one of the techniques being studied and used by land managers. In wet forests, where *R. ellipticus* grows, feral pigs are the primary disturbance agents and have been the subject of several studies. Charles Stone, L. Pratt and T. Tunison of HAVO briefly describe the impact feral pigs can have on a native rain forest habitat in their paper, " Responses of Hawaiian Ecosystems to Removal of Feral Pigs and Goats" (1992). Pigs may consume or damage mature tree ferns, small ferns and other native herbs and bryophytes as well as seedlings of native woody species (Giffin 1978, Diong 1983, Stone 1985). One of the effects of this behavior is to increase the level of incoming solar radiation on the forest floor which may make conditions more suitable for invasive non-natives. Pigs also "rototill" soil in their search for earthworms, rhizomes and tubers. This activity disturbs understory plant cover and exposes seeds to the increased light conditions. Pigs are known dispersers of several non-native plants (banana poka: LaRosa 1992 and Warshauer *et al.* 1983, and strawberry guava: Diong 1983), and potential dispersers of others (Stone *et al.* 1992). The impacts of pigs is related to their density although no quantitative studies have been conducted to correlate pig densities with assessments of their impact on the vegetation. This study contributes to understanding the relationship between forest quality and the spread of invasive, non-native plants.

There are three management related objectives of this study:

1) quantify the rate of spread in terms of increases in cover and range within three different management units of HAVO'S 'Ola'a Tract;

2) determine the significance of the impact on forest biodiversity by studying the association of understory forest plants growing under *R. ellipticus*;

3) assess the invasive potential of the plant by subjecting seedlings and seeds to varying light conditions and monitoring their growth and germination rates. Plants capable of invading intact forest sites are often more shade-tolerant than those incapable of invading without disturbance (Smith 1985).

Quantifying the rate of spread of a weed provides land managers with a tool to help assess the practicality of various control methods as well as the success of previous management efforts (*e.g.* fencing and ungulate control). The association of species with *R. ellipticus* is an indicator of the effect of *R. ellipticus* on the native plant community. If a deleterious effect is found, the information can be used to justify funding to control its spread. Determining light tolerances provides information about the range of habitats or microsites which are susceptible to invasion by *R. ellipticus*.

The Species

Rubus ellipticus is native to Southern Asia from Pakistan to Southwestern China (including the Himalayas), Southern India, Sri Lanka and Southeast Asia at elevations between 600 and 2300m. It is found in the wild as well as in cultivated areas as hedges around villages (Polunin & Stainton, 1984). Rainfall estimates of the regions where *R. ellipticus* grows range from 1000-5000 mm (Shrestha 1989).

It is a large shrub with stout stems covered with long rufous bristles and recurved spines. The leaves are trifoliate, elliptic or obovate and toothed with long bristles. The flowers are white and appear in clusters from February through April in the Himalayas (Polunin & Stainton, 1984) and for longer periods (Jan.- June) in Hawai'i. The yellow multiple fruit is produced in condensed panicles. The abundant summer and fall fruit production attracts a suite of bird dispersers, including the Japanese white eye (*Zosterops japonicus*) (M. Kjargaard pers. com.). There are no documented reports of pig consumption of *R. ellipticus*, although it is likely that pig disturbance increases the rate of *R. ellipticus* invasion.

STUDY AREA

The study area is HAVO's 'Ola'a Large Tract (Fig. 3 & 4). This area was selected because a detailed non-native plant survey had been conducted in 1988 and could be used as a baseline (S. Anderson, unpubl.). The original introduction was along the western boundary of the tract in the Volcano Agricultural Experiment Station and, possibly, in the Volcano Garbage Transfer Station 2 km south of the Tract. The Tract is also the site of several ecological management sub-sections called "units" in which different management strategies were evaluated (Fig. 4).

The 1400 m elevation montane rain forest is dominated by tree ferns in the sub-canopy and is characterized by the phenomenon of displacement dieback of the scattered ohi'a trees (*Metrosideros polymorpha*) (Mueller-Dombois 1985). Displacement dieback is one of several types of dieback of ohi'a described by Mueller-Dombois. Displacement dieback usually occurs at the stand level on eutrophic volcanic ash soils, similar to those in the 'Ola'a Tract, and results in a gradual replacement of dying ohi'as by other ferns, shrubs and introduced species over a 20 year period (Mueller-Dombois, 1986). In large sections of 'Ola'a tract there is little regeneration of ohi'a and total tree canopy has been reduced to less than 25% cover (Fig. 5).

The other tree species, which form a semi-open sub-canopy, include *Ilex anomala, Cheirodendron trigynum*, *Perrottetia sandwicensis*, *Coprosma ochracea* and *C. rhynchocarpa*. The primary tree fern species is *Cibotium glaucum*, but *C. chamissoi* and *C. hawaiiense* are also present. The understory is dominated by *Diplazium sandwichianum.* The primary alien plants invading the forest other than *R. ellipticus* include *Passiflora mollissima*, *Psidium cattleianum*, *Setaria palmaefolia* and *Hedychium gardnerianum* (Tunison, in press). The average rainfall is 2880 - 3050 mm/year with the greatest amounts occurring between December and March as orographic rainfall from the NE trade winds. Summer is usually the driest season. The soil is an inceptisol formed of layers of ash and cinder up to 1.5 m deep on a 4000 year old lava base (Lockwood & Lipman 1987).

'Ola'a is divided into four management areas: Pu'u, Agriculture (Ag.) and Koa units plus the unfenced remainder (Fig. 4). Each area has its own recent management history. The Pu'u unit was fenced in 1985 because it was one of the most pristine of the areas with the highest ohi'a and tree fern canopy cover (L. Pratt, pers. comm.). Pigs were hunted out of the unit within 2 years of being fenced. The Koa unit was fenced in 1989. Pigs were eradicated by the summer of 1994 after three years of intensive control efforts by the Park's resource management staff. The Agricultural unit was fenced by its previous owners and is considered pig free. It was not included in the 1988 study; therefore comparisons are not included in this analysis. The remaining area is unfenced and fairly heavily used by pigs; up to 20 pigs/km^2 (Stone, et al 1992).

METHODS AND MATERIALS

Field Methods

Data were collected along 18 belt transects ranging in length from 1200m to 5600m, duplicating HAVO's 1988 study (1988 data collected by various field technicians and analyzed by S. Anderson). Cover was estimated in the contiguous 5 X 50m plots using the following classes: 0, < 1%, 1-10%, 11-25%, 26-50%, > 50% (Mid-points were used in the analyses). Eleven of the 18 transects were re-monitored in the Koa and Pu'u management units along maintained transects. The remaining transects (7), in the unfenced and unmanaged portion of 'Ola'a, were approximated because the 5 year-old flagging had disintegrated along those unused transects.

The potential effect of *R. ellipticus* on the understory vegetation was assessed through a stratified random block design under three canopy types: *R. ellipticus*, tree ferns, and in non-*Rubus* forest plots. All plots were randomly selected from along a transect using random numbers to set the number of meters from points along the transect perpendicular to selected *R. ellipticus* plants meeting minimum size criteria. One meter radius circular plots (not including the bole of tree ferns) were evaluated for the three treatments in 25 blocks. Tree fern-centered plots were included in an attempt to control for shade effects, though the shade level under *R. ellipticus* appeared to be much deeper than that under tree-ferns. The total cover for each understory species was estimated to the nearest 5% and summed to give total cover (Appendix I). The total cover for a given plot could exceed 100% due to layering of vegetation. Species richness, a simplified measure of biodiversity, was measured using the number of different species found per plot.

The light level requirement study for *R. ellipticus* seedling growth and seed germination was conducted with three replicates of three different light levels within the forest. Twenty-five seedlings and 100 seeds were placed in each of the 9 sample units (3 X 3 design). The seedlings were grown from seeds collected from a random selection of bushes along the transects and in the pastures. Seedlings were 6 months old (2 to 5 inches tall) and growing in 8 inch tall plastic tubes with a soil and cinder mixture. The pots were placed in holes so that the roots could grow down into the ground through the open bottoms. The seeds, also 6 months old, were sown in vermiculite (as they were for original seedlings with close to 100% germination in 1 month) and covered with netting to prevent the seeds from being splashed out by rain drops. Litter fall on flats was intermittent and cleared every 2 months. Seedling growth was measured from the base to the growth point. A subjective assessment of vigor based on leaf health and the number of branches was assigned.

The light levels were: 1) full sun in a gap greater than 10 meters wide, 2) medium shade under tree ferns and 3) in full shade under uluhe (*Dicranopteris* sp.) and/or *R. ellipticus*. There was an average of a seven-fold difference in light levels between the gap and the full shade based on hemispheric photographs taken at the sites. The photosynthetically active radiation (PAR) levels were attained by combining the results of the hemispheric photographs using the Solarcalc program with the detailed light studies conducted by Burton (1980) in ʻOlaʻa Tract (Field, 1993). Burton found that maximum daily light levels were reduced by clouds to an annual average of 146 Watts/m^2. Due to frequent cloud cover only 26% of daylight hours have solar inputs greater than 700 W/m^2. Based on Burton's assessment of forest floor light levels the three treatments in this study can be characterized as having the following Average Photon Flux Density levels and total PAR levels: Open site:125 micromoles/m^2/s (53 W/m^2); medium site: 39 micromoles/ m^2/s (17 W/m^2); and closed site: 21 micromoles/m^2/s (8 W/m^2).

The light levels within the three treatments were also assessed using the Licor 2000 Leaf Area Index (LAI). The LAI instrument uses five angled circular lenses to characterized the layers of leaf cover over a site. It is a measure that can be used to quantify the productivity of a stand of vegetation as well the relative level of incoming solar radiation. Direct assessments of absolute photon flux density or photosynthetically active radiation can not be made, but it can be useful for comparisons. A comparison of LAI measurements of the Puʻu unit with LAI measurements taken in the growth and germination study was conducted to relate the study to field conditions.

A small laboratory study of seed treatments was conducted to compare germination rates for seeds from the soil seed bank, fresh seeds, and seeds that had passed through the digestive tract of one of the more common non-native forest birds, the Japanese white-eye. Seeds from the soil were taken from under a random selection of *R. ellipticus* plants at a depth of at least 3 inches. One hundred seeds from each treatment were grown in a climate-controlled chamber in vermiculite for six months. This study was carried out after all seeds had been stored in dry, cool conditions for 6 months; a factor which may have reduced the effects of scarification in the bird's digestive tract.

Analytical Methods

The transects were analyzed using non-parametric methods because the cover classes are not normally distributed (Wilcox Sign Rank) (Ryan *et al.* 1992).

The difference in the frequency of *Rubus*-free plots from 1988 to 1993 along each transect was used as a measure of the spread into previously uncolonized plots. This type of spread may be used as a measure of active dispersal of *R. ellipticus* to new areas.

The understory effects study was a stratified random block design. A 2-way Analysis of Variance (ANOVA) was used to compare total cover and total number of species between the three different types of plots (canopies). Tukey's paired tests were conducted to compare the three sets of pairs. The Wilcox Sign Rank test was used to compare cover values for groups of species by life form and native/non-native status in the forested (*Rubus* - free) plots versus *R. ellipticus* plots. A Bonferoni adjustment of the p-values was used to control the type I error rate.

The light level study data were analyzed using 1- and 2-way ANOVA analyses of seedling growth and vigor, seed germination rates.

RESULTS

Spread of *Rubus ellipticus*

The different management units showed differential rates of increase of *R. ellipticus* which suggests the importance of management efforts. All units were not equal in initial *R. ellipticus* cover thus one can not completely isolate the effects of management. The Pu'u unit received the highest priority for protection because of its pristine state. The Pu'u unit, with its denser cover (Fig. 4) and pig free status over the 5 year period had no significant increase in *R. ellipticus* cover. In 1988 the average per transect *R. ellipticus* cover within the unit was zero (Table 1). Over the five year period only four of 120 plots increased in cover, and then by less than 1% each (Table 1). *R. ellipticus* has been found along the fence line of the unit where there is more disturbance suggesting that management actions to reduce disturbance within the unit have had a positive effect.

In the Koa unit, seven of eight transects showed significant increase ($p. < .05$ Sign Rank paired test). The average increase per plot in the Koa unit was 60% based on computing a mean for all plots in the unit. The overall mean plot cover for the Koa unit was 5.1% in 1988 and 8.1% in 1993 $[(8.1-5.1)/5.1 * 100 = 60\%]$. This translates to an annualized increase of 9.3% and a doubling time of 7.5 years. Describing a unit cover in terms of an overall average cover serves to characterize a particular unit but it disguises the range in values as well as the distribution of *R. ellipticus* cover across the unit. The plot by plot cover values shown graphically in the distribution maps (Figs. 6 - 8) indicate that individual plots show increases in cover between 1% and 75%.

The distance between newly colonized plots identified in 1993 and the nearest known previously colonized plot was assessed in order to gain insight into the potential dispersal distance of the propagules. In the Koa unit the mean linear distance to new colonizations was 1.5 plots or 75 meters (n =101). The distribution of the distances to new colonizations in the Koa unit indicate that greater than 70% occurred in an adjacent plot and that the longest distance traveled was 300 meters (Fig. 9). The proportion of all plots which showed an increase in *R. ellipticus* cover (n = 284) can be divided between that occurring in new plots (36%) and that occurring in previously colonized plots (64%) (Fig. 10).

The initial cover (1988) within the Koa unit was higher than that in the unfenced area to the north and east because the Koa unit abuts the agricultural research station, where *R. ellipticus* was introduced. Its spread eastward, from the Experimental Station, is documented in the stylized maps in Figures 6, 7, and 8. Each of the seven transects in the unfenced portion of 'Ola'a (outside the Koa unit) showed a significant increase ($p < .05$ Sign Rank paired test). The average *R. ellipticus* cover, per plot, increased from the lower initial value 2.4% to 5.3%, an increase of 121% overall [(5.3-2.4)/2.4 *100]. This translates to an annual rate of increase of 15.9% and a doubling time of 4.4 years. Thus, cover in the unfenced area more than doubled in five years while the newly fenced Koa unit only increased by 60% overall. In absolute terms, both areas increased by approximately 3 percentage points but the unfenced area increased from a lower initial mean cover (2.4% versus 5.1%).

The average distance from newly colonized plots to previously colonized plots in the unfenced area was 178.5 m. (3.6 plots away). The distances to new colonies (n = 167) ranged from 50 to 1700 m. and less than half of the newly colonized plots were adjacent to previously colonized plots (Fig. 9). The proportion of plots with increased *R. ellipticus* cover in the unfenced area was 60% new colonies and 40% increases in previously colonized plots; the reverse of that in the fenced Koa unit (Fig. 10).

The increases in cover can be extrapolated to square meters for the different management units. The Koa unit is nine square kilometers; the total cover of *R. ellipticus* increased 1/4 km^2, from 459,000m^2 to 729,000m^2 (60%). The unfenced portion increased from 576,000 m^2 to 1,272,000m^2 (121%); an increase of 3/4 km^2 in a 28 km^2 area. Within the entire 'Ola'a Large tract, the area covered by *R. ellipticus* nearly doubled (98%) in the five years between 1988 and 1993.

Understory Effects

Total cover of understory plants was significantly lower under *R. ellipticus*, by 60%, than under the tree fern canopy and random forest plots ($p < .001$) (Fig. 11). Species richness was also significantly lower under *R. ellipticus* than in either the random or the tree fern plots ($p < .001$)(Fig. 12). The tree fern-centered plots and random forest plots were not significantly different from each other; indicating that light levels under the tree fern canopies are characteristic of the forest in general.

Photon flux density (avg. micromoles/m^2/sec) differences under the three canopy types was investigated to provide an explanation for the differences in cover. Average photon flux density under *R. ellipticus* was nearly half that under tree ferns (39 micromoles/m^2/sec and 21 micromoles/m^2/sec, respectively).

There were significant differences in the association of understory species and groups of species, by life-form and native/non-native status, among *R. ellipticus* and forest plots (Appendix I). Cover of all native species was significantly lower under *R. ellipticus* than in the other two plot types, while total alien cover did not differ significantly (Fig. 13). The native/alien groups are divided into the following life-form sub-categories: alien herbs and vines, alien shrubs, native herbs and vines, native ferns and bryophytes, native shrubs, native tree ferns, native trees (Fig. 14). Within those groups native ferns, native trees and native shrubs were significantly lower in cover under *R. ellipticus* ($p<.05$). *Cheirodendron trigynum*, *Asplenium lobulatum*, moss and *Vandenboschia davalliodes* accounted for a large portion of the observed differences in cover. The native herbs and vines group is the only native group which has high cover values under *R. ellipticus* canopy. *Peperomia* sp., a very shade-tolerant species, is the only plant able to maintain itself under the deep shade of *R. ellipticus*.

Seedling Growth and Germination Light Requirements

Seedling growth showed statistically significant differences under the three light level treatments (Fig 15). There was 100% seedling mortality in the deep shade after 9 months, 71% mortality of all individuals under the medium light level and 34% mortality in the full sun treatment. Overall growth, in height, was more than twice as much in the gap as in the medium light level ($p< .001$).

Germination rates would have followed the same pattern except that a small gap opened over the seeds in one of the deep shade treatments and 50% of the seeds germinated between the 6 and 9 month point. Otherwise germination rates in the deep shade were 4%. At 9 months 18% of the seeds had germinated in the medium light level. In the gap treatment there was a 30% germination rate at 9 months. The unusual event in the one shade treatment demonstrates that the seeds can remain viable until suitable germination conditions develop.

A comparison of LAI measurements of the Pu'u unit with LAI measurements taken in the growth and germination study indicate that light levels on growing surfaces in the Pu'u unit fall between the medium and deep shade levels in the growth study. The Pu'u unit LAI values had a mean of 5.95 with a SE of .125 (n=20) while LAI values in the growth study were 4.25, 5.52 and 7.13 in the open, medium and closed canopy sites (n=9, respectively). The closed canopy conditions were, thus, darker than one might find in a healthy forest.

The laboratory experiment comparing germination rates for seeds from the soil seed bank versus fresh seeds and seeds that had passed through a Japanese white-eye gut indicated that seeds from the soil had the highest germination rates (25% versus 2% and 3%).

Summary of Island-wide *R. ellipticus* Distribution:

The author conducted a 1994 reconnaissance of island-wide reports of *R. ellipticus* (Fig. 2) (Gerrish, *et al* 1992 and Markin, pers comm). Gerrish *et al* (1992) reported that *R. ellipticus* is well established along Wright Road in farm lots near the town of Volcano to the rim of Kilauea and down slope to 1800 ft. (550 m) elevation. It is established eastward through ‘Ola‘a Large Tract to Stainback Highway where clumps are scattered from 1800 to 5100 ft. (550 - 1550 m) elevation. Along Route 11 large populations are established from the Volcano Garbage Transfer Station, through the Glenwood subdivision and into Mountain View. Control efforts along the Pu‘u Maka‘ala Natural Area Reserve boundary with ‘Ola‘a Large Tract are continuous although there are few reports of it spreading far into the interior of that Natural Area Reserve (J. Leialoha, DOFAW pers. comm).

Gerrish reports, and author searches confirm, that it has also become established in areas as far away as Laupahoehoe Forest Reserve on the Hamakua coast (60 miles/150 km away). The furthest sighting is from Pu‘u La‘ala‘au, on the Kona side, where 12 seedlings were pulled up (R. Warshauer, pers. com.). Another population is well established north east of Hilo at 3800 ft. (1150 m) near a *Eucalyptus* grove along the Pukihale stream on land managed by C. Brewer, Inc. Two sightings were made in the region between the Saddle road and Stainback Highway: one along the Flume Road west of the golf course and a second at 4900 ft. (1500 m) in a kipuka on the ocean side of Tree Planting Road. R. Warshauer reported a population at 4900 ft. (1500 m) in Kapapala Ranch on the N.E. side of Ka‘u Forest Reserve.

DISCUSSION

Spread of *Rubus ellipticus*

This study strongly suggests that management practices can play an important role in protecting native natural resources. It is difficult to draw specific conclusions about management practices based on this observational study because fencing and pig control efforts were conducted in an opportunistic fashion as funds became available to protect the forest rather than being done in a random or experimental design. For example, the most pristine area (Pu‘u unit) within the ‘Ola‘a Large Tract was made pig free and fenced by 1985, much earlier than the other areas. Thus, we can not conclude that the management practices alone limited the spread of weeds within the unit. Clearly other factors also contributed to the Pu‘u unit's more pristine state. Nevertheless, the area remained almost free of *R. ellipticus* over the 5 year period from 1988 to 1993 while it spread aggressively in the unfenced, pig-infested areas (Fig. 8). The Koa unit was fenced in the middle of the time period and pig control efforts were completed by August 1994. The initial cover within the Koa unit was much higher than in the unfenced area because the Koa unit is adjacent to the origin of *R. ellipticus* as well as to a large propagule source from numerous plants growing in nearby pastures (Fig. 16a). The difference in the annual rates of increase of *R. ellipticus* inside and outside the Koa unit (9.3% versus 15.9%) suggests that the fencing and pig control efforts had an effect.

One of the more significant findings of this study is that the majority of the increase in the unfenced area was into previously uncolonized plots (60%), while inside the fenced Koa unit the increase was largely in plots that had already been colonized (64%)(Figs. 10 &17). Another way of presenting this is to compare the increase in colonization of all plots by *R. ellipticus* . The proportion of plots colonized by *R. ellipticus* within the Koa unit increased by 17% over the 5 years from 77% to 90%, while the frequency in the unfenced area increased by 50% (from 48% to 72%). This is a three-fold increase in spread to new areas in the unfenced area. The spread to new plots in the unfenced area suggests that there was a more active dispersal of propagules there as well as a higher abundance of germination sites. The vegetation and canopy cover map (Fig. 5) indicates that both areas are characterized by about equal proportions of the two primary canopy types and densities: *Cibotium* dominated (5-25% tree cover) and relatively closed ohi'a dominated cover (60-25%). The proportion of empty plots was much higher in the unfenced area (52%) than in the fenced Koa unit (23%) so the potential for spread into new plots was reduced in the Koa unit. Nevertheless, the combination of the increased distance to newly colonized plots in the unfenced areas (178 m versus 75 m) supports the idea that there was more active dispersal where pig numbers were higher.

Furthermore, increases in plot by plot cover outside the Koa unit included higher increases (into categories of >26% cover, Fig. 18). Total cover distribution by cover class in 1993 (Fig. 16b) falls in higher categories within the Koa unit, but the majority of the plots outside the unit now have greater than 1% cover which will make future increases into higher cover categories even more rapid. Hunters in a survey conducted in January 1995 (unpublished data) claim that pigs control understory vegetation and help limit the establishment of weedy plants such as Banana Poka (*Passiflora mollissima*). The fact that increases in cover of *R. ellipticus* were higher in the region with higher pig numbers indicates that *R. ellipticus* growth and establishment are not limited by pig activity as the hunters suggest. It is difficult to know if this is a result of pig aversion to the plant's thorniness, a reflection of the strength of the stout main stem or some other cause. The absolute number of pigs in the unfenced area may have been so low that established *R. ellipticus* plants were not affected by pig rooting or trampling.

The fenced, pig-free Pu'u unit had no significant increase in cover with only 4 plots of 120 colonized in the 5 year period. Vegetation studies by National Biological Service (NBS) research staff have found higher cover of understory ferns and tree ferns within the Pu'u unit (L. Pratt, pers. comm.). The increased shade under the continuous cover and a lack of soil disturbance and ungulate dispersers may have been great enough to prevent the wide-scale invasion of *R. ellipticus* found elsewhere. The vegetation maps of 'Ola'a (Fig. 5) show that the Pu'u Unit is characterized by "open canopy *Cibotium/Metrosideros* dominated native forest" with 25% to 60% cover while the majority of the area outside of the Pu'u Unit is characterized as having "scattered trees" (5-25% cover) and snags (dieback) (Jacobi 1989).

The high proportion of newly colonized plots in and out of the Koa unit since 1988 (Figs. 10 &17) strongly suggest that *R. ellipticus* is spread through active dispersal as well as vegetative or dropped-seed spread. Birds, pigs and humans are the likely dispersers. One known disperser of *R. ellipticus* is the introduced Japanese White-eye (*Zosterops japonicus*) which is common in 'Ola'a (LaRosa, *et al.* 1985, M. Kjargaard, unpublished Ph.D. Thesis, UH-Manoa 1994). The Kalij Pheasant may also contribute to its dispersal (Lani Stemmermann, M. Kjargaard, pers comm). I also observed rats on *R. ellipticus* and believe that they may contribute to its dispersal. Finally, HAVO resource management personnel consider pigs to be major dispersers. Efforts to control *R. ellipticus* in pig-free areas ('Ola'a Small Tract) were successfully conducted in one or two intensive weed-control sessions over 2 years, while control efforts in pig-infested areas were rarely successful and required repeated weed control sessions to limit the spread (J. Leialoha, pers comm 1994).

Understory Effects: Discussion

The impact study results support the hypothesis that *R. ellipticus* is adversely affecting native understory species. Some alien plant species are considered particularly problematic because they may alter the environment in ways that promote invasion by other aliens (Mueller-Dombois and Whiteaker 1990). They may accomplish this through alteration of soil nutrient conditions, altering the light regime, or by providing food and roosts for alien avifauna which may deposit seeds of other alien plant species. This study showed no significant difference in alien understory plant cover in the three treatments although there was a significant reduction in native cover under *R. ellipticus* thickets. These results indicate that most natives are less able to thrive in environment created under a *R. ellipticus* canopy than are a few particularly shade tolerant native herbs and the weeds invading 'Ola'a tract (Fig. 14). I propose that the deep shade under *R. ellipticus* creates an unsuitable habitat (dark and wet) for regeneration or re-establishment of most native species. Allelopathy, nutrient use differences and alteration of soil characteristics may also be involved.

Light Requirement Study: Discussion

The results suggest that *R. ellipticus* growth in forest shade is reduced significantly (the mid-level light treatment) and that it is most successful in gaps. The near total mortality under the deep shade of large *R. ellipticus* and *Dicranopteris* thickets is to be expected because of the low light levels and increased soil moisture creating potentially anaerobic conditions. The comparison of LAI measurements of the Pu'u unit with LAI measurements taken in the growth and germination study indicated that light levels on growing surfaces in the Pu'u unit fall between the medium and deep shade levels in the growth study. Results from the medium sites may be most reflective of germination and mortality rates in the forest although there may be a fine line in that range that depends on sun flecks and other chance light occurrences. Thus the lack of survivorship and growth in the closed canopy site only suggests that *R. ellipticus* may have a difficult time regenerating in its own shade, but not that it would be limited to that degree under healthy forest light conditions.

The germination studies conducted in the field and lab demonstrate that seeds from the soil seed bank and dry storage seeds may remain viable for long periods of time. The success of the germinants in the accidental light gap created in the closed treatment provides a warning of the potential regenerating power of this species even after adults have senesced, particularly if the adults limit the re-growth of other species as well. Clearly long term efforts to control *R. ellipticus* will be required where ever it has become established.

Statewide Spread and Management Recommendations

The distribution in the montane rain forest and along streams and gullies suggests that water facilitates a rapid, healthy establishment of *R. ellipticus.* A total reconnaissance of the island was not conducted so there are probably other new colonizations. Another bird/weed survey would certainly help identify such satellite populations.

This study has demonstrated that *R. ellipticus* is capable of significantly reducing native regeneration and of spreading rapidly into wet, forested areas disturbed by pigs. Areas with dense native vegetation and no pig disturbance seem to be more resistant to invasion (Pu'u unit), and hence easier to keep free of *R. ellipticus.* Management recommendations are to fence and control pigs in all wet, montane forests that have been identified for their ecological value in order to enhance native cover before *R. ellipticus* and other invasive weeds can become established. Otherwise, opportunities for cost-effective management will be lost. Satellite populations further away from the source may merit more extensive manual and herbicide containment efforts in order to limit 'leapfrogging' spread to otherwise pristine areas. Populations along streams may be particularly important to control since the stream may be a conduit for dispersal. Eradicating such 'satellite' populations is key to cost-effective control because populations grow in an exponential way once established (Mack & Moody, 1992).

Biocontrol efforts have been negligible due to a lack of funding. Approximately $5,000 has been used to date for biocontrol studies in conjunction with blackberry (*Rubus argutus*) research (G. Markin, pers com). This project is particularly challenging and controversial because there are native *Rubus* species in Hawai'i which may be vulnerable to the biocontrol agents introduced to control the other *Rubus* species.

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Table 1. ***Rubus ellipticus*** **cover in Ola'a, Hawaii Volcanoes National Park: 1988 and 1993. Based on continuous belt transects of 5m x 50m plots.**

Mgmt Unit	Transect number	p-value	sig* at p. < .05	Number of plots	Total length (m)	'88 mean % cover	'93 mean % cover	'88 *Rubus ellipt*-free	'93 *Rubus ellipt*-free
Puu	1b	--	insig.	24	1200	0.0	0.0	23	20
Puu	2b	--	insig.	24	1200	0.0	0.0	24	24
Puu	3b	--	insig.	24	1200	0.0	0.0	24	24
Puu	4b	--	insig.	24	1200	0.0	0.0	24	23
Puu	5b	--	insig.	24	1200	0.0	0.0	24	24
Puu out	1c	--	insig.	5	200	1.1	2.1	3	2
Puu out	2c	--	insig.	5	200	0.0	0.0	5	5
Puu out	3c	--	insig.	5	200	0.0	0.0	5	5
Puu out	4c	--	insig.	5	200	0.0	0.0	5	5
Puu out	5c	--	insig.	5	200	0.0	0.3	5	3
Koa	12	0.001	sig **	64	3200	3.0	5.3	18	10
Koa	13	0.001	sig **	64	3200	.8	4.2	33	5
Koa	14	0.00	sig **	73	3650	1.3	6.3	16	8
Koa	15	.001	sig **	64	3200	4.5	8.4	17	4
Koa	16	0.97	insig.	67	3350	14.4	9.9	11	9
Koa	17	0.000	sig **	56	2800	6.5	12.9	7	6
Koa	18	0.000	sig **	70	3500	6.4	10.7	8	9
Koa	19	0.000	sig **	73	3650	4.3	7.7	10	2
Ola'a	1	0.000	sig **	82	4100	0.5	2.2	67	38
Ola'a	1a	0.000	sig **	105	5250	0.4	3.6	75	44

Table 1. (*Continued*)

Mgmt Unit	Transect number	p-value	sig* at p. <.05	Number of plots	Total length (m)	'88 mean % cover	'93 mean % cover	'88 *Rubus ellipt*-free	'93 *Rubus ellipt*-free
Ola'a	3	0.000	sig **	97	4850	0.5	7.6	50	3
Ola'a	4	0.027	sig *	104	5200	6.8	8.2	25	8
Ola'a	5	0.01	sig *	37	1850	1.1	2.8	15	12
Ola'a	5a	0.01	sig *	55	2750	2.1	2.4	25	29
Ola'a	6	0.001	sig **	24	1200	7.4	10.5	6	6

Figure 1.

Drawing of *Rubus ellipticus* by Nanci Sidaras (Stone, et al, 1992)

Figure 2.
Distribution map of *R. ellipticus* on the island of Hawai'i. An update of map by Gerrish *et al.* 1992.

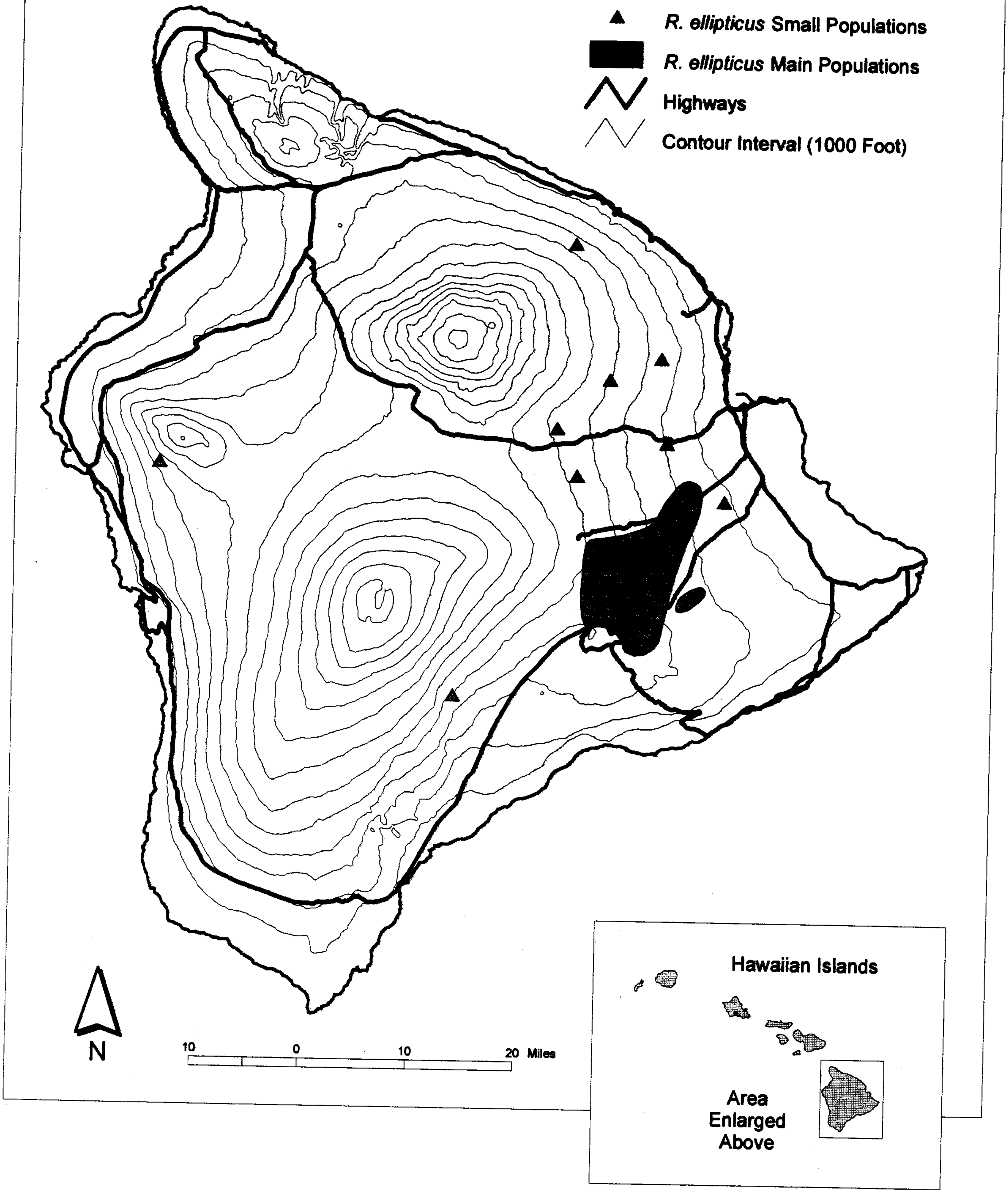


Figure 3.
Map Showing the location of Hawai'i Volcanoes National Park and the Ola'a Forest Tract (with permission, Tunison, in press)

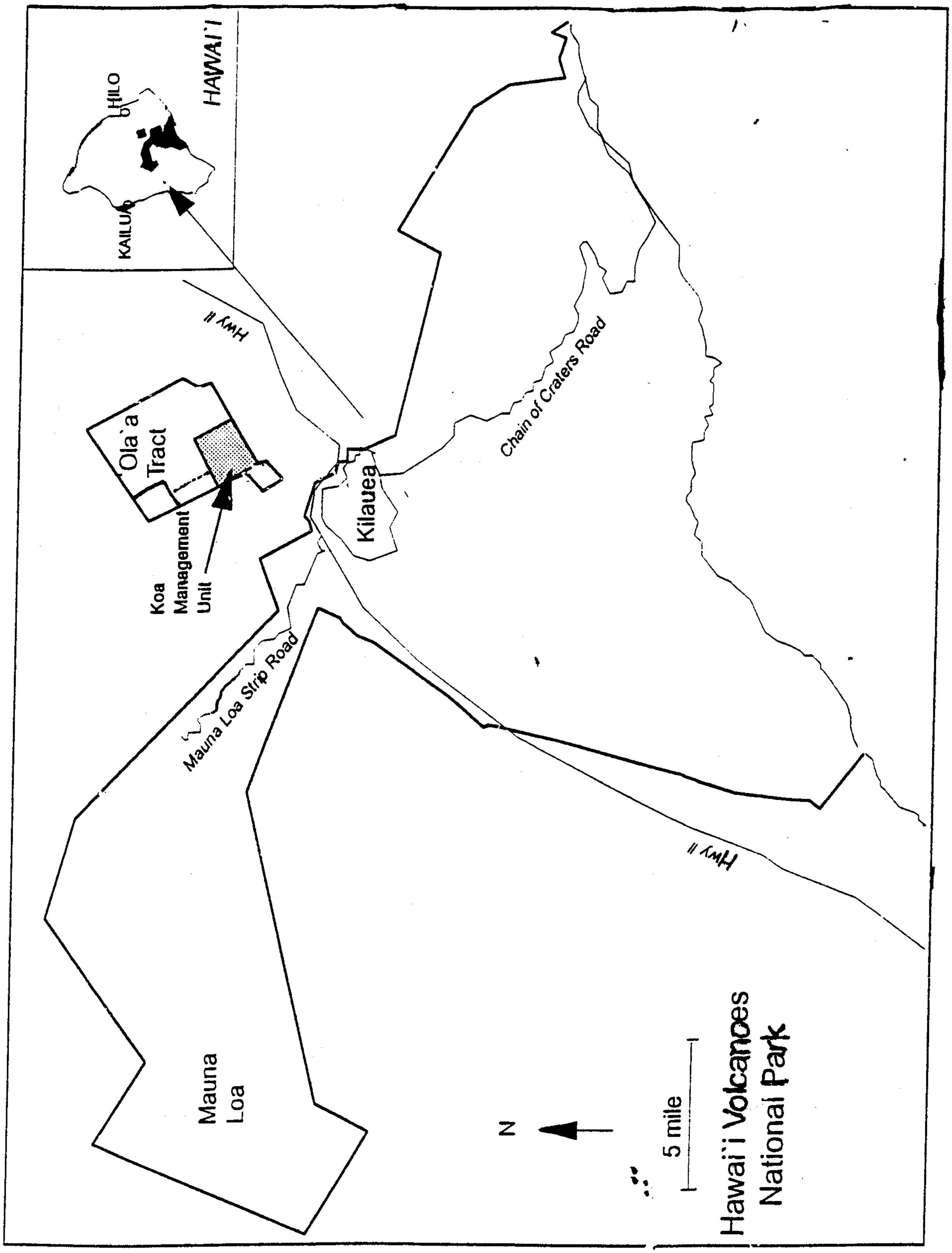


Figure 4.

Diagramatic representation of transects and management units in Ola'a Large Tract, Hawai'i Volcanoes National Park.

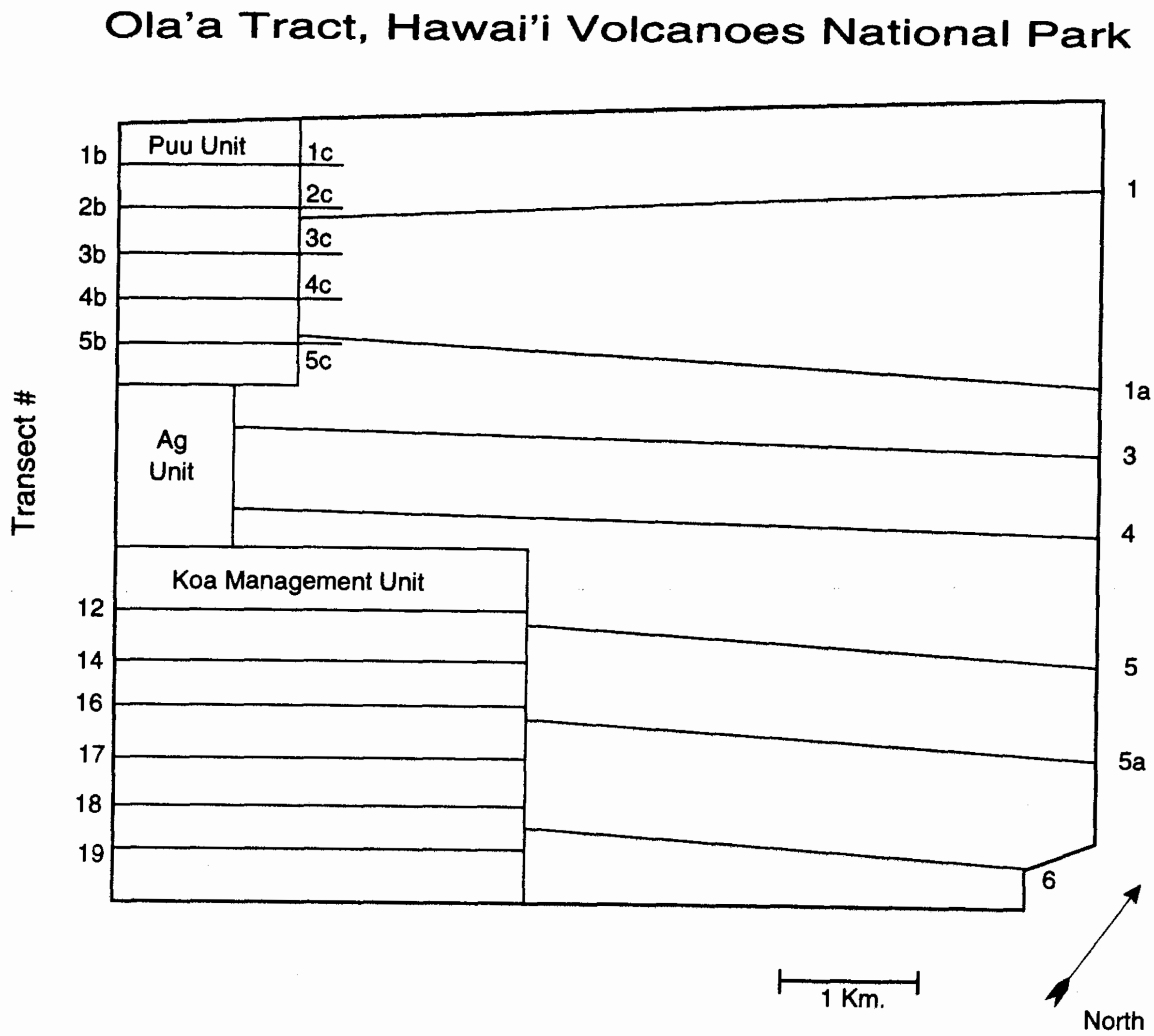
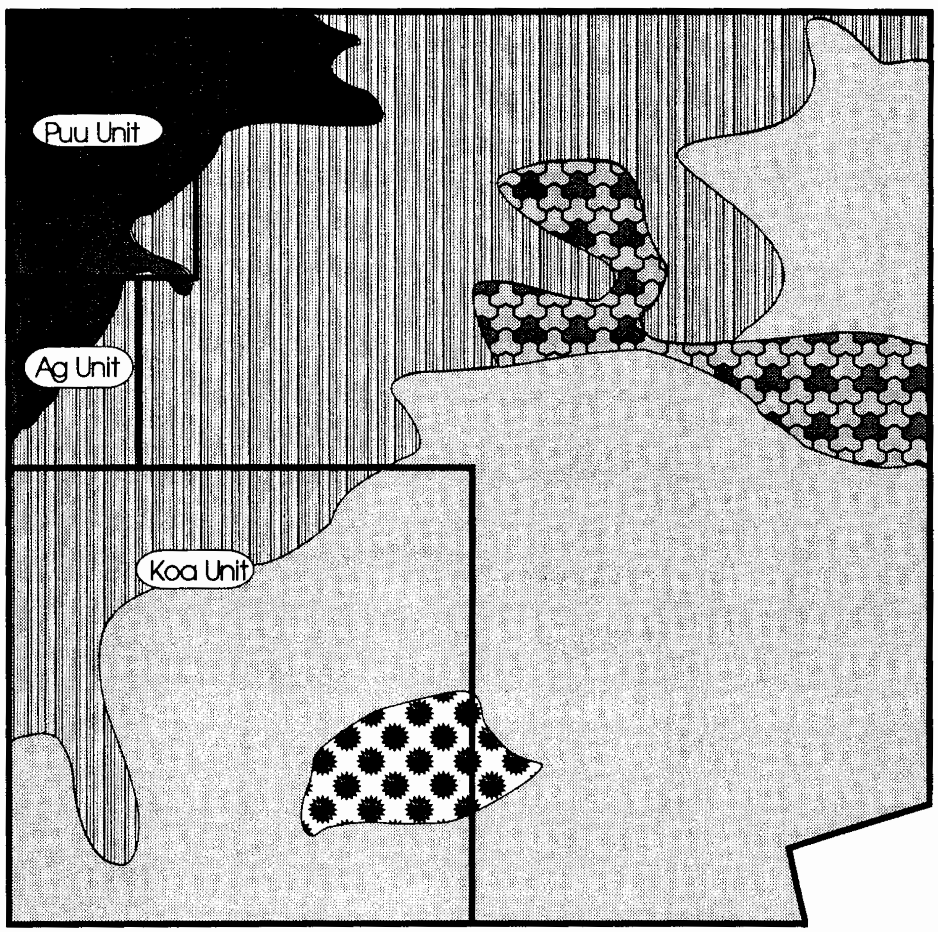


Figure 5.

Canopy vegetation and estimated cover for Ola'a Large Tract, Hawaii Volcanoes National Park.

Ola'a Tract - Vegetation Cover Types



(adapted from Mueller-Dombois & Fosberg 1974; Jacobi 1989)

- Closed *Metrosideros* dom. / *Cibotium* understory (> 60% cover, Jacobi)
- *Metrosideros* / *Acacia* forest (25-60% *cover, Jacobi)*
- *Cibotium* dom. / *Metrosideros* forest (25-60% *cover, Jacobi)*
- Open *Metrosideros* dom. / *Cibotium* understory forest (5-25% cover, Jacobi)
- *Cibotium* dom. / *Metrosideros* forest (5-25% cover, Jacobi)

Figure 6. *Rubus ellipticus* cover in HAVO's Ola'a Large Tract in 1988.

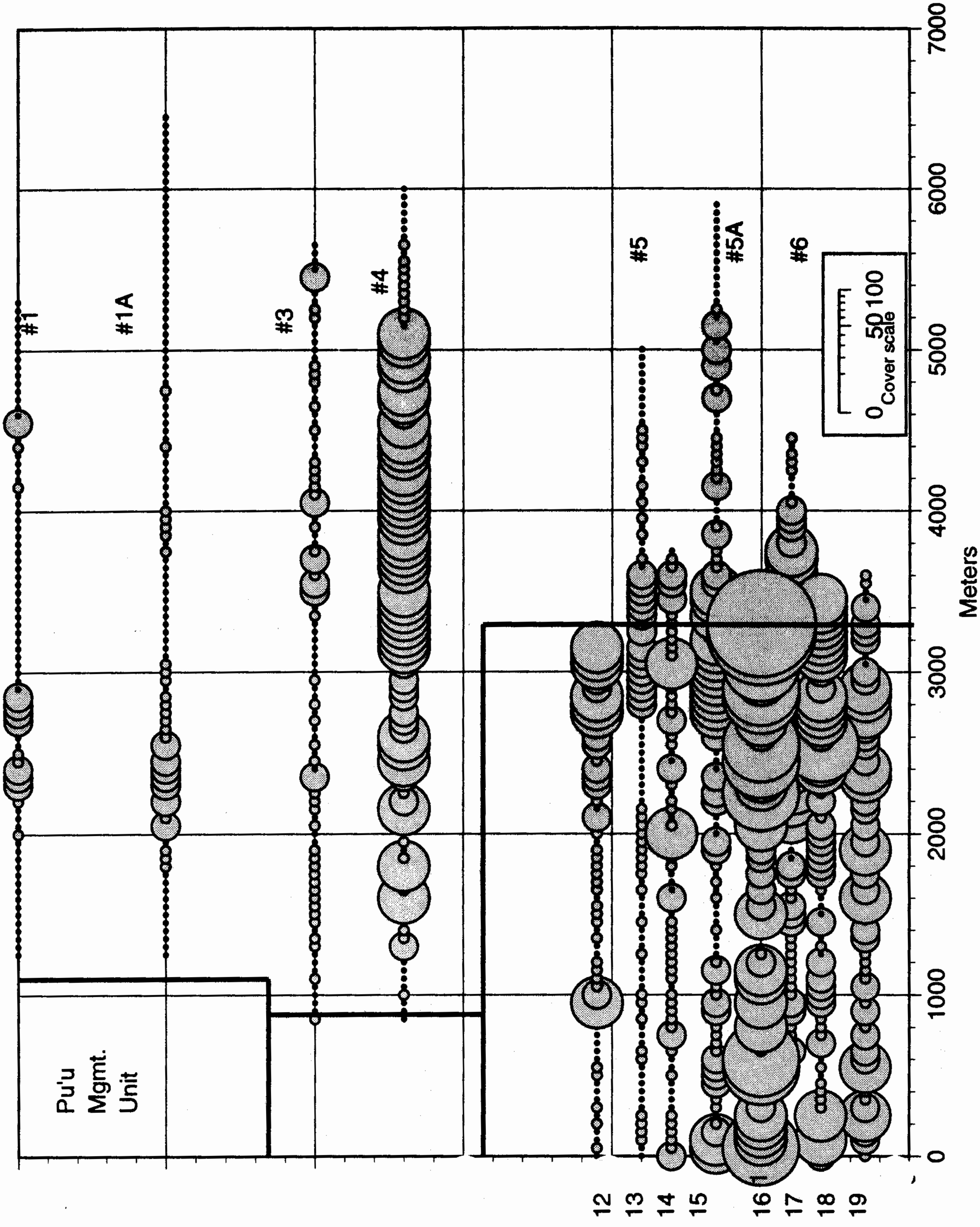


Figure 7. *Rubus ellipticus* cover in HAVO's Ola'a Large Tract in 1993.

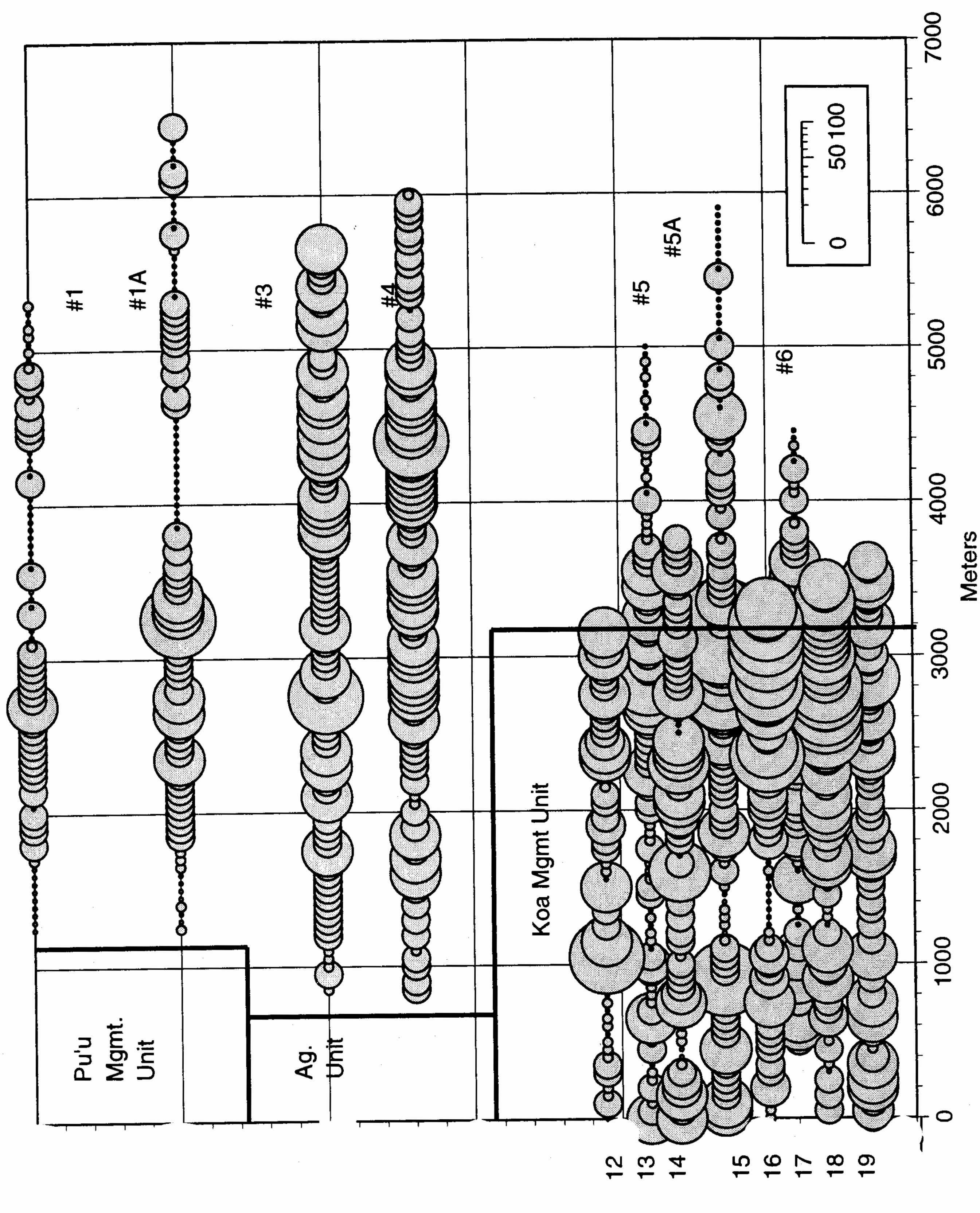
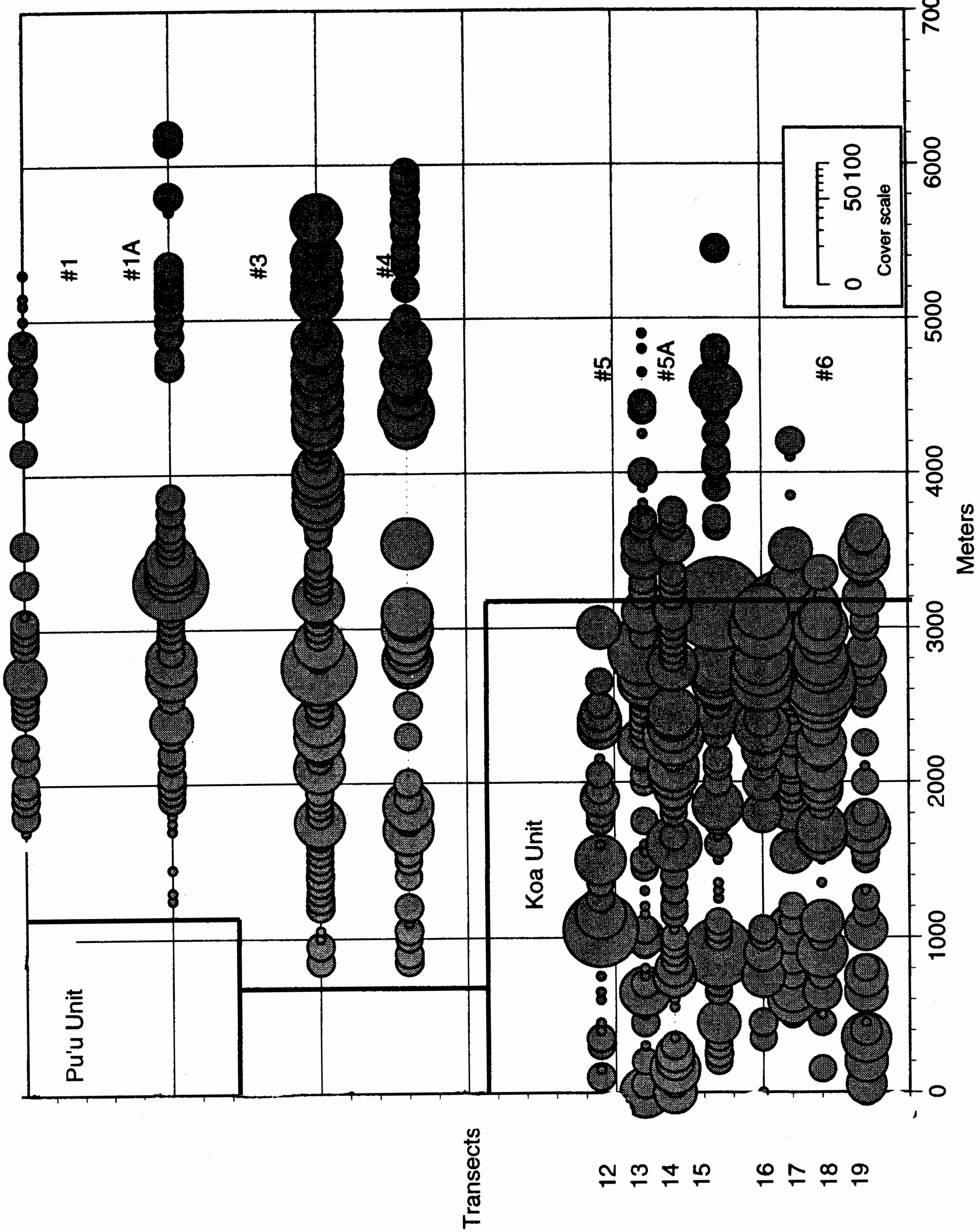


Figure 8. Increases in *R. ellipticus* cover, 1988-1993, in HAVO's Ola'a Large Tract



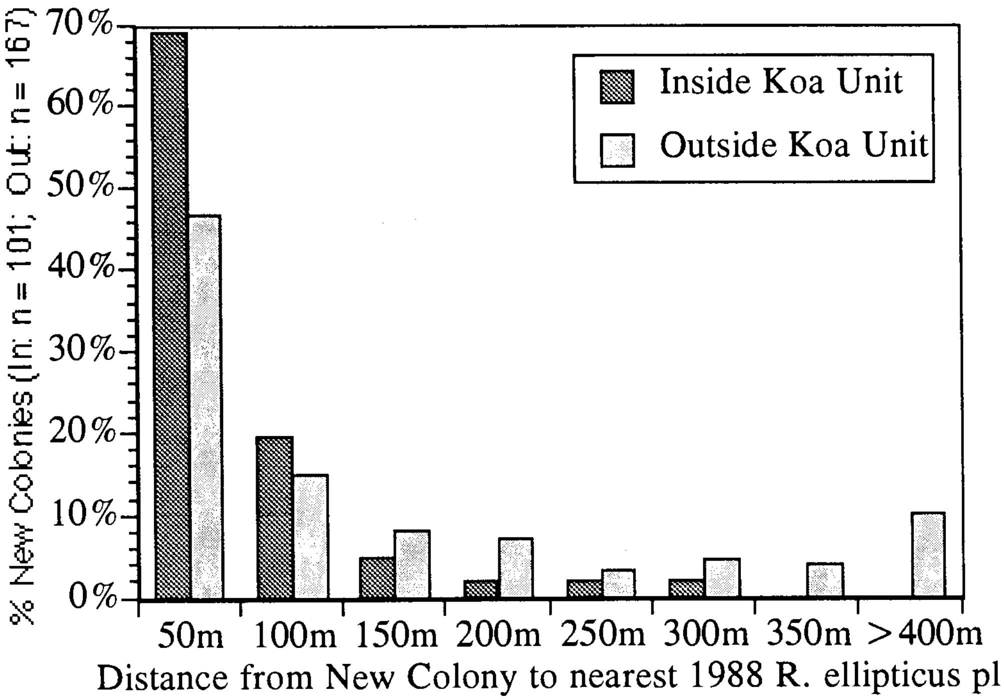


Figure 9. Distance to all newly colonized plots of R. ellipticus inside and outside the Koa Unit; n = 101 and 167 respectively.

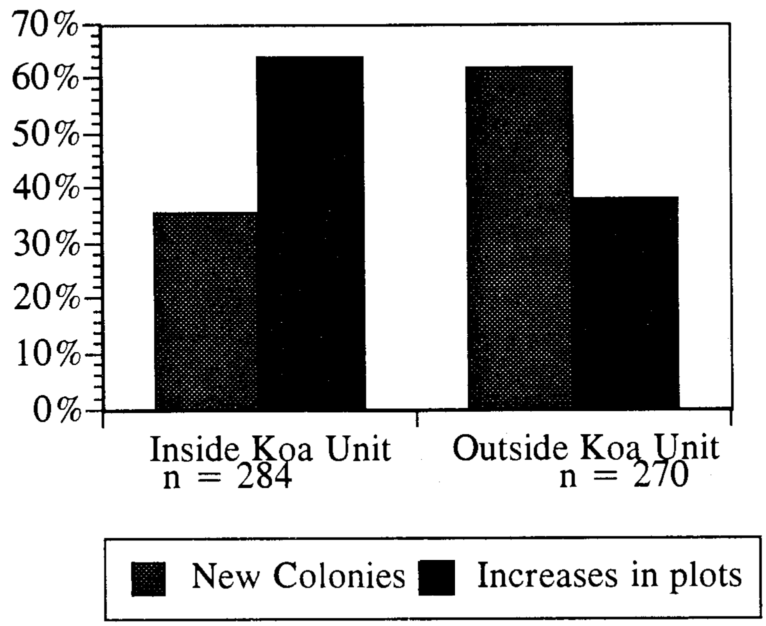


Figure 10. Relative proportions of all plot increases in *R. ellipticus* cover occuring in new and previously colonized plots within and outside of the Koa unit; n = 284 and 270 respectively.

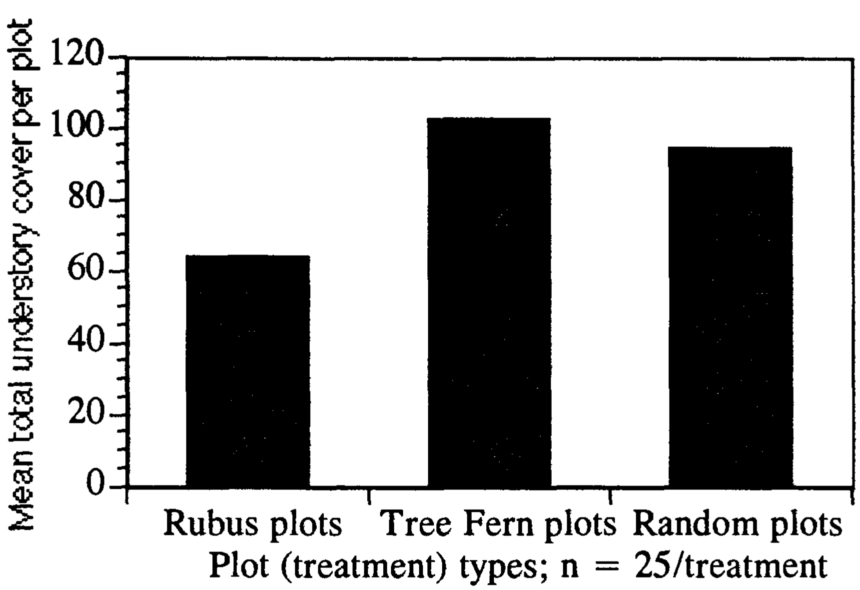


Figure 11. Mean total cover (%) of all understory species growing in the three plot types: under *R. ellipticus*, under tree ferns and at random points in the forest. *R. ellipticus* plot cover significantly lower than other treatments (p.<.001).

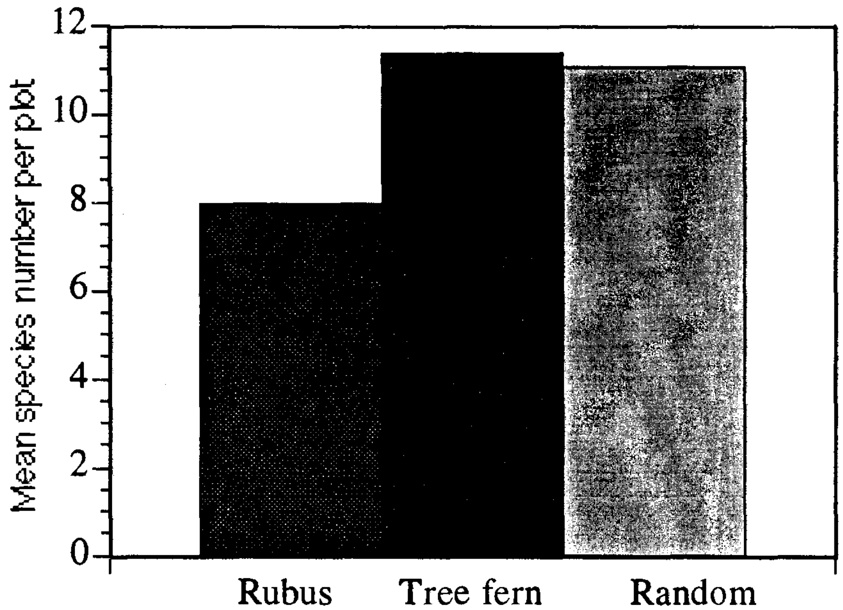


Figure 12. Mean number of understory species per plot type. *Rubus ellipticus* plots had significantly fewer species than either other plot type (p. < .001).

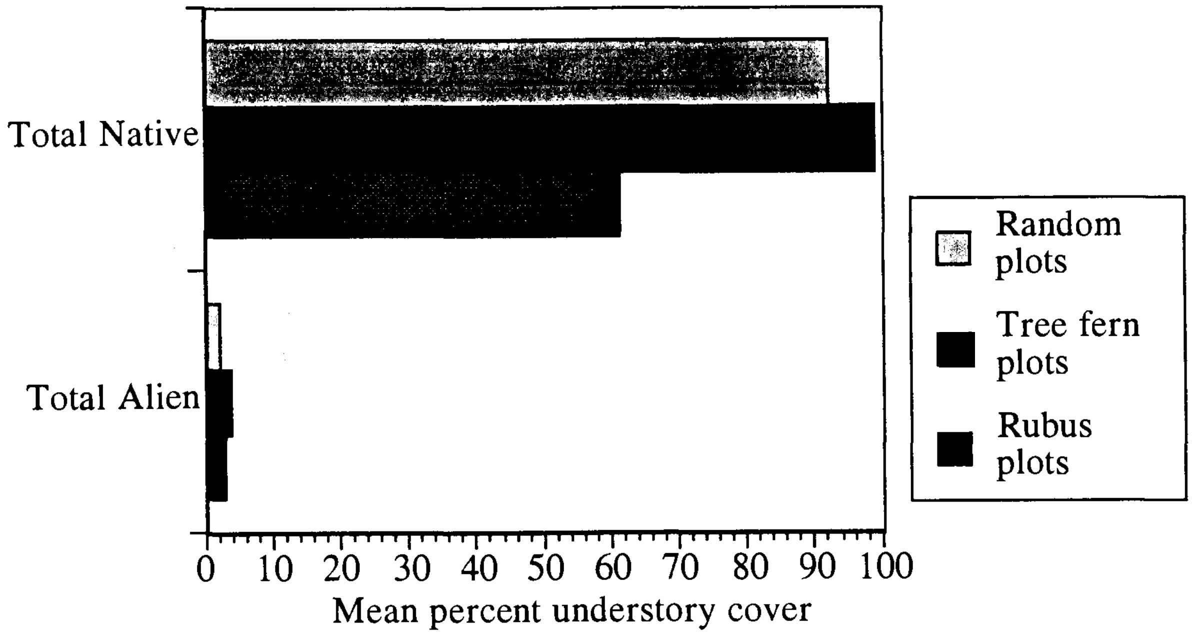


Figure 13. Comparison of the understory cover contribution of natives versus non-native species in the three plot types. Native plant cover was significantly lower under *R. ellipticus* (p. < .01). No significant differences in alien plant cover between treatments.

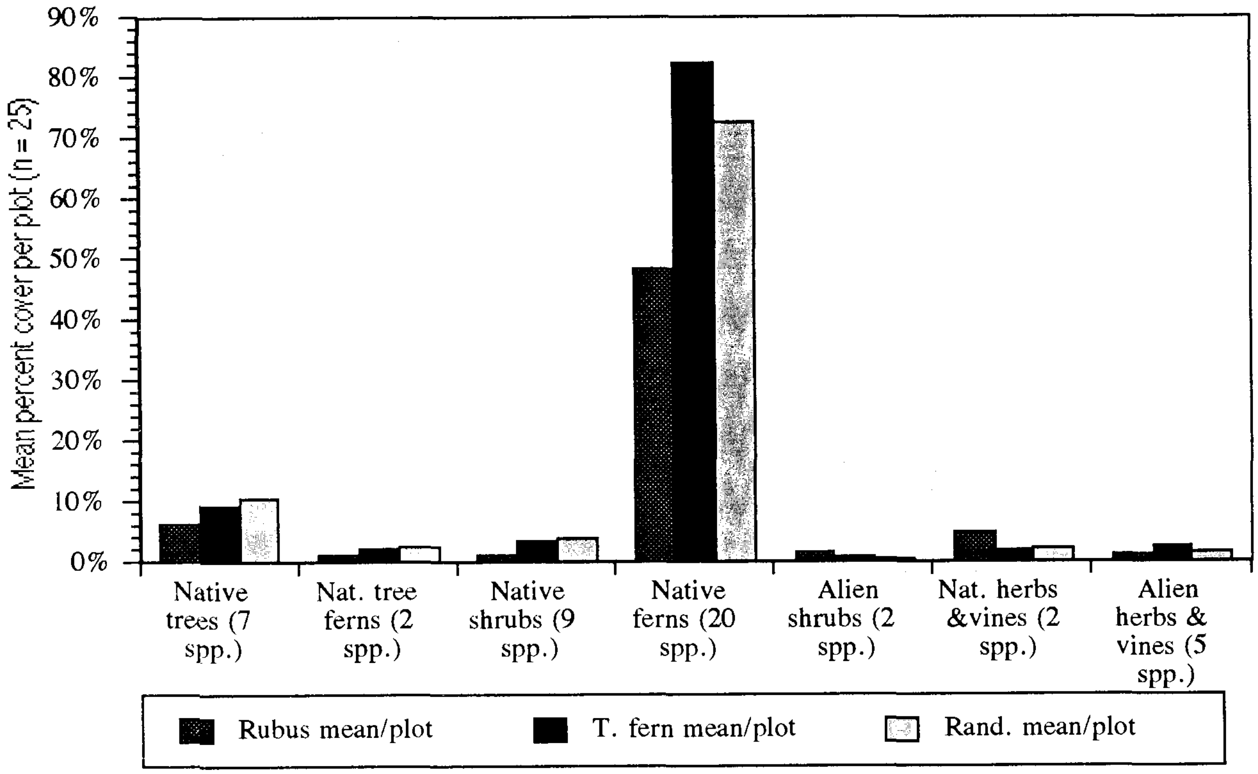


Figure 14. Total understory cover values by life-form in three Impact Study plot types.

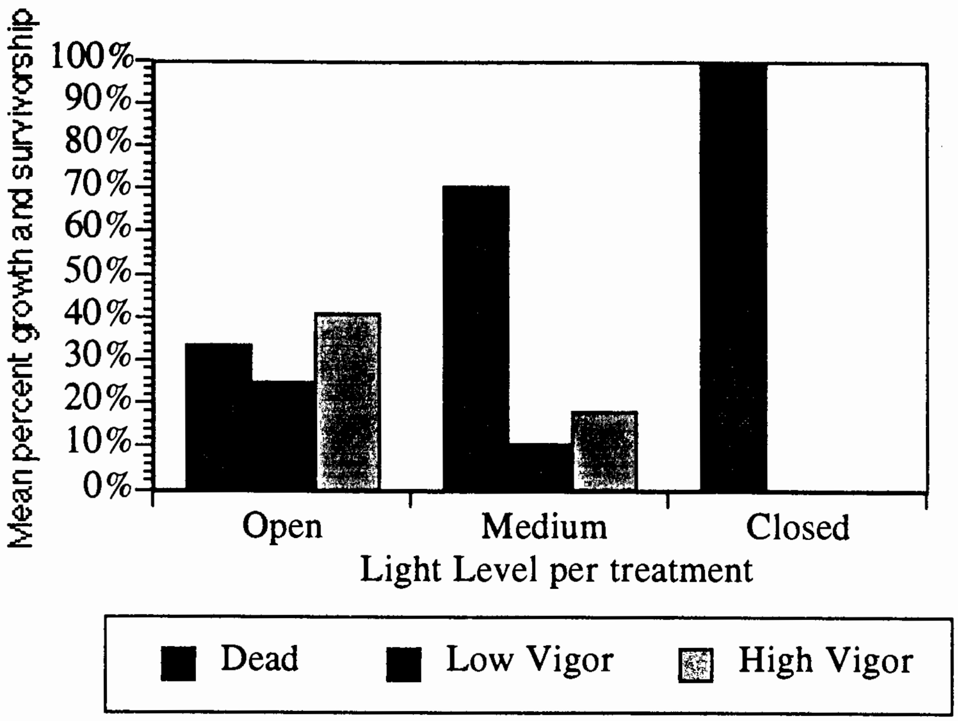


Figure 15. *R. ellipticus* seedling growth under three light regimes. Differences in survivorship and vigor significant for all treatments (p. < .01).

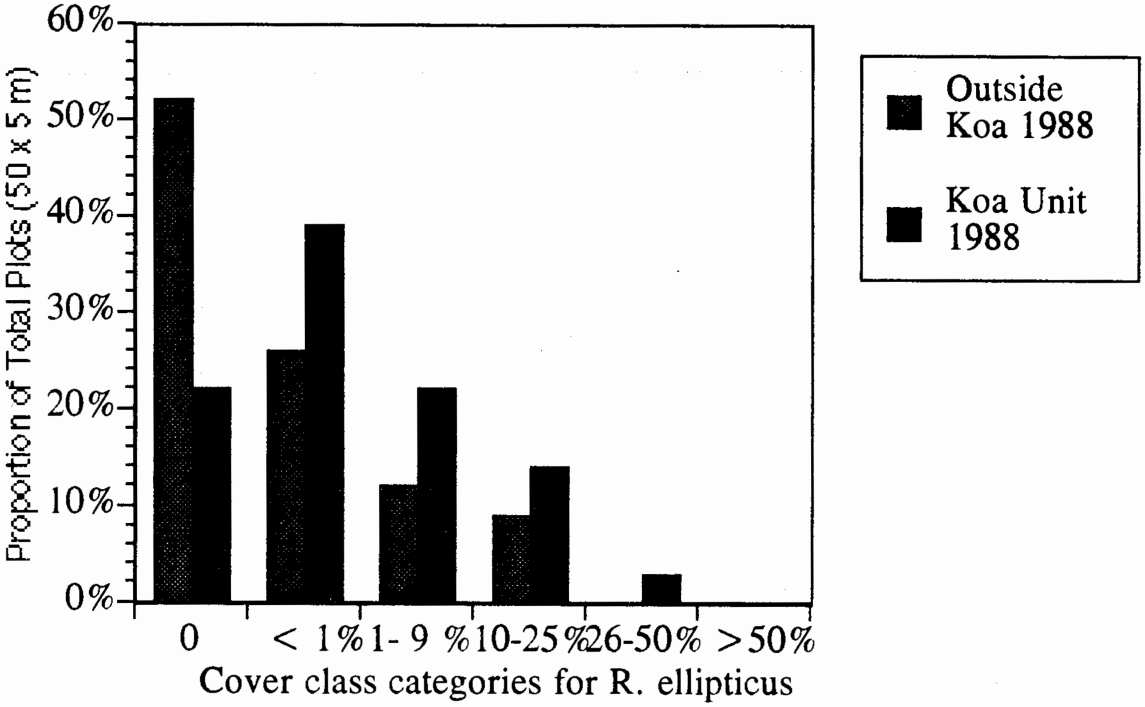


Figure 16a. Comparison of 1988 *R. ellipticus* cover inside and outside the Koa unit within HAVO's 'Ola'a tract.

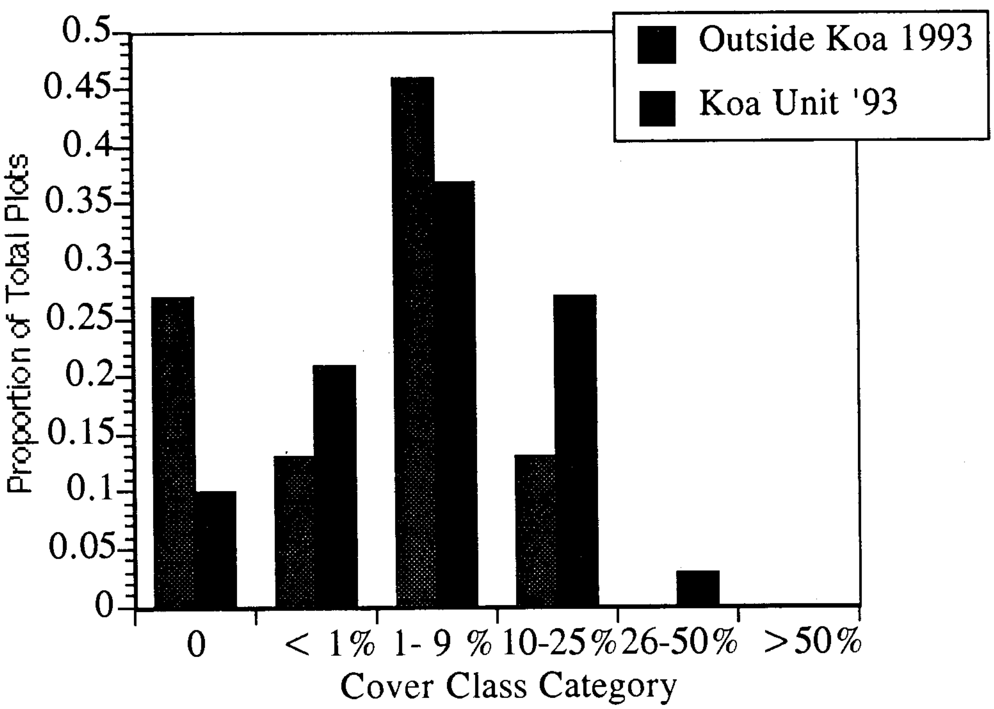
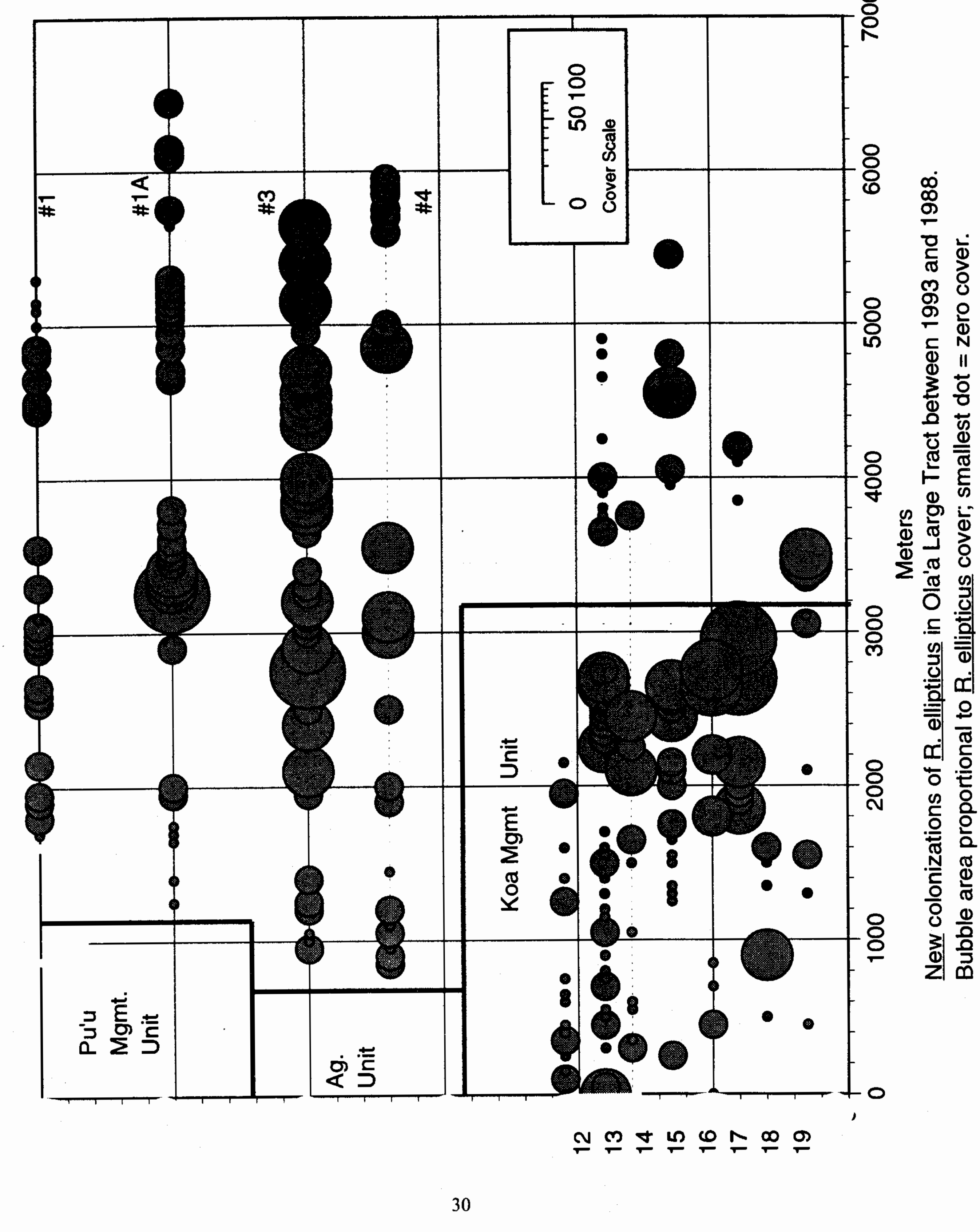


Figure 16b. Comparison of 1993 *R. ellipticus* cover classes inside and outside the Koa unit fence.

Figure 17. Plots newly colonized by*R. ellipticus* in 'Ola'a large tract between 1988 and 1994.



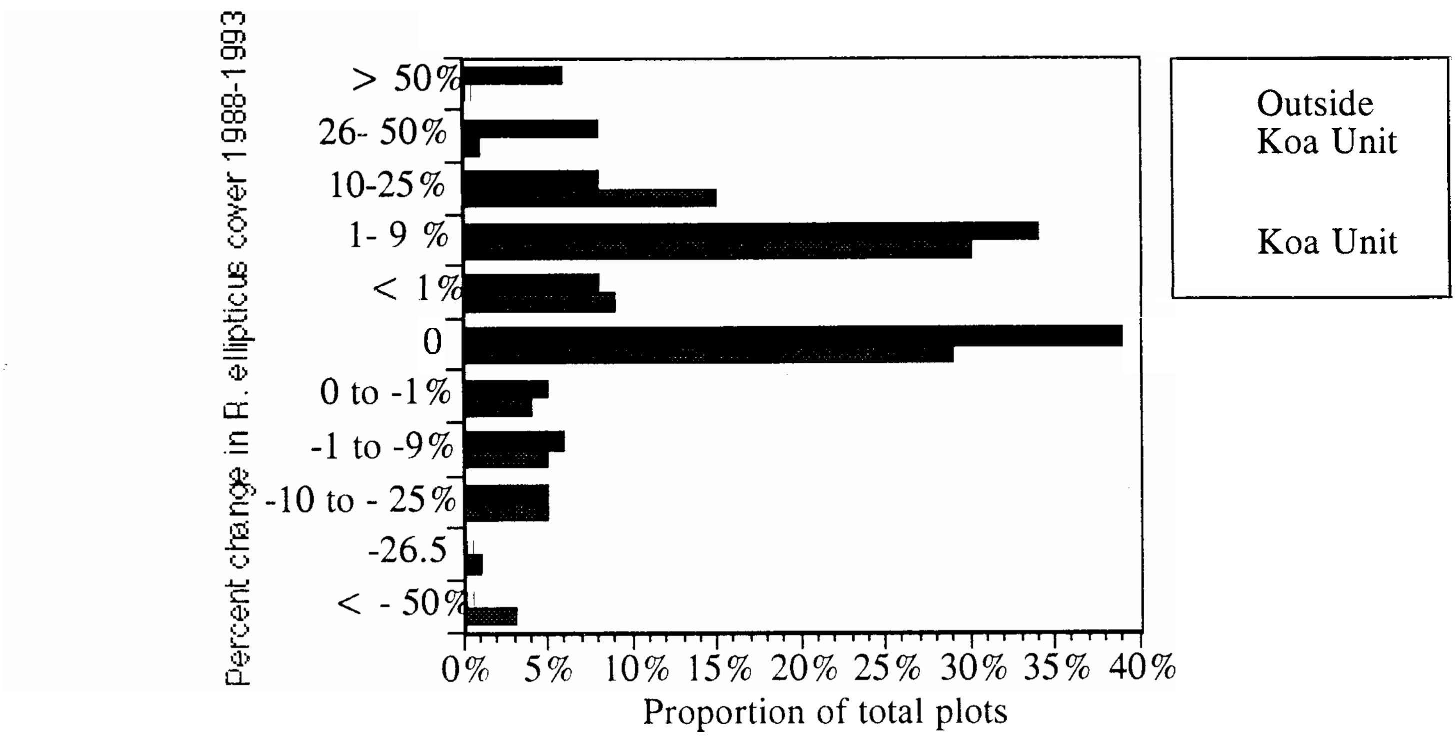


Figure 18. Plot by plot changes in *R. ellipticus* cover within and outside the fenced Koa Unit between 1988 and 1993. n=537 and 506 respectively.

Appendix I Comparison of understory cover by species. The Wilcox sign rank test *p-values* of the one-sided alternative hypothesis: Random cover > *R. ellipticus* cover are included.

Species name	*R.ellipt* Mean % Cover	*R.ellipt.* St. Error % Cover	Tree Fern Mean	Tree Fern St. Error	Random Mean % Cover	Random St. Error	Random- Rubus Wilcox p-val	Bonferoni sig *
Native Trees								
1. *Charpentiera ovata*	0.45	0.45	0.0	0.0	0.0	0.0	1.0	
2. Cheirodend. trigynum	0.25	0.18	2.5	0.84	1.4	0.40	0.03	
3. Coprosma rhynchocarpa	1.5	0.63	0.50	0.21	3.3	0.80	0.088	
4. Ilex anomala	0.15	0.15	0.90	0.34	0.50	0.29	0.361	
5. Metrosideros polymorpha	0.45	0.25	1.6	0.28	1.6	0.37	0.142	
6. Perrottetia sandwicens.	3.3	0.80	2.7	0.80	3.7	1.5	0.981	
7. Psychotria hawaiiensis	0.0	0.0	0.85	0.55	0.0	0.0	--	
Total							0.017	
Native Tree Ferns								
8. Cibotium chammissoi	1.1	1.0	0.75	0.75	0.0	0.0	0.371	
9. Cibotium glaucum (N/A)								
10. Cibotium hawaiiensis	0.20	0.20	1.5	1.2	2.4	1.2	0.108	

Appendix I (*Continued*)

Species name	*R.ellipt* Mean % Cover	*R.ellipt.* St. Error % Cover	Tree Fern Mean	Tree Fern St. Error	Random Mean % Cover	Random St. Error	Random-Rubus Wilcox p-val	Bonferoni sig *
Native Shrubs								
11. Broussaisia arguta	0.15	0.11	0.95	0.67	1.9	1.1	0.142	
12. Clermontia parviflora	0.20	0.16	0.55	0.26	0.15	0.11	1.0	
13. Cyanea sp.	0.0	0.0	0.05	0.05	0.10	0.10	1.0	
14. Cyrtandra lysio.	0.15	0.15	0.75	0.40	0.55	0.20	0.161	
15. Freycinetia arborea	0.0	0.0	0.70	0.47	0.70	0.43	0.1	
16. Melicope clusifolia	0.0	0.0	0.10	0.10	0.0	0.0	--	
17. Pipturus albidus	0.05	0.05	0.0	0.0	0.25	0.18	0.423	
18. Rubus hawaiiensis	0.40	0.40	0.05	0.05	0.15	0.15	1.0	
19. Vaccinium calycinum	0.20	0.16	0.45	0.19	0.15	0.11	1.0	
Total							0.031	
Alien Shrubs								
20. Rubus ellipticus	1.6	0.60	1.0	0.62	0.45	0.26	0.068	
21. Psidium cattleianum	0.0	0.0	0.0	0.0	0.10	0.10	1.0	
Total							0.946	

Appendix I (*Continued*)

Species name	*R.ellipt* Mean % Cover	*R.ellipt.* St. Error % Cover	Tree Fern Mean	Tree Fern St. Error	Random Mean % Cover	Random St. Error	Random-Rubus Wilcox p-val	Bonferoni sig *
Native Ferns & Bryophytes								
22. Asplenium lobulatum	0.05	0.05	1.1	0.46	1.0	0.38	0.03	
23. Asplenium polypodon	2.3	0.54	3.3	0.79	3.2	0.74	0.421	
24. Athyrium japonica	0.70	0.39	0.55	0.27	1.0	0.42	0.61	
25. Athyrium microphyllum	2.7	1.0	9.4	2.0	4.7	1.2	0.192	
26. Callistopt. spp.	0.0	0.0	1.1	0.51	0.35	0.17	0.059	
27. Coniograma sp.	0.35	0.22	0.95	0.95	0.0	0.0	0.181	
28. Diplazium sandwicensis	20.0	3.4	34.4	4.7	29.7	5.6	0.145	
29. Dryopteris wallichiana	0.20	0.16	0.25	0.20	0.05	0.05	0.593	
30. Elaphoglossum glaucum	0.15	0.11	0.05	0.05	0.05	0.05	0.593	
31. Elaphoglossum hirtum	0.10	0.10	0.0	0.0	0.0	0.0	1.0	
32. Fern sp.	1.6	1.0	0.05	0.05	0.60	0.60	0.584	
33. Grammitis hirtim	0.0	0.0	0.40	0.14	0.30	0.17	0.1	
34. Moss sp.	14.3	2.0	19.4	2.5	22.8	2.8	0.002	*
35. Mecodium recurvum	0.40	0.35	0.10	0.10	0.15	0.11	1.0	
36. Microlepia strigosa	1.60	.89	4.85	2.30	1.60	0.77	0.695	
37. Nephrolepis cordifolia	0.10	0.07	0.05	0.05	0.10	0.10	1.0	
38. Pleopeltis thunbergia.	0.00	0.00	0.00	0.00	0.05	0.05	1.0	
39. Pneumatopt. sp.	3.30	1.25	4.05	2.19	4.10	1.64	0.776	
40. Psilotum spp	0.00	0.00	0.15	0.08	0.10	0.07	0.371	
41. Vandenboschia davall.	0.25	0.14	1.95	0.43	2.80	0.73	0.002	*
Total							0.001	*

Appendix I (*Continued*)

Species name	*R. ellipt* Mean % Cover	*R. ellipt.* St. Error % Cover	Tree Fern Mean	Tree Fern St. Error	Random Mean % Cover	Random St. Error	Random-Rubus Wilcox p-val	Bonferoni sig *
Native Herbs & Vines								
42. Astelia	0.00	0.00	0.50	0.50	0.05	0.05	1.0	
43. Peperomia spp.	4.75	3.46	1.40	0.37	2.10	0.67	0.61	
Total							0.285	
Alien Herbs, Vines, Grass								
44. Erichtitis valeriani.	0.00	0.00	0.05	0.05	0.25	0.18	0.371	
45. Grass spp.	0.20	0.12	0.20	0.12	0.40	0.25	0.5	
46. Hedychium gardnerianum	0.40	0.29	0.75	0.56	0.15	0.11	0.593	
47. Passiflora mollissima	0.30	0.22	1.65	0.65	0.85	0.50	0.361	
48. Physalis peruviana	0.35	0.35	0.00	0.00	0.00	0.00	1.0	
Total							0.207	
Total Native Vegetation	61.00	0.64	98.9	0.26	91.65	0.69	0.000	*
Total Alien Vegetation	2.85	0.32	3.27	0.4	2.2	0.23	0.688	
Total Vegetation	63.85	0.59	102.2	0.28	93.85	0.62	0.000	*

* Bonferoni significance indicator adjusts for 10 sub-total tests at the p. < .05 level of significance.