STAND ANALYSIS OF AN INVADING FIRETREE (*MYRICA FAYA* AITON) POPULATION, HAWAI'I

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INTRODUCTION

Firetree (*Myrica faya*), an aggressive, noncommercial, exotic species that is native to the Azores, Madeira, and Canary Islands, has been spreading rapidly in Hawai'i for approximately 80 years. This tree was introduced in Hawai'i for reforestation in the late 1800's, but by 1944 it had become so aggressive in colonizing agricultural and forested land that the Board of Agriculture and Forestry was pursuing a control program to eradicate it (Neal 1965).

Distribution and Controls

Firetree concentration is dense on the islands of Maui and Hawai'i. However, the major efforts of control have been on the island of Hawai'i. In 1961 Kawasaki (unpublished) reported that the major concentrations on the island of Hawai'i were along the Hamakua Coast from Laupahoehoe to Honoka'a, then mauka (toward the mountain) to the Parker and Kukaiau Ranches. A smaller population covering 300-400 acres in the 'Ola'a Forest near Hawaii Volcanoes National Park (HVNP) was also reported in the 1961 survey.

In a 1966 survey Kawasaki (unpublished) estimated that the 'Ola'a Forest infestation had increased to 4500 acres, including 1500 acres on Forest Reserve Land and 25 acres in HVNP. Two additional infestations were observed in the National Park: (1) a 50-acre site on the northeast rim of Kilauea Crater; and (2) a 150-acre site at the intersection of the Chain of Craters Road and the 'Ainahou Escape Road.

Invasion of firetree on the island of Hawai'i has increased exponentially. A 1970 survey revealed that more than 40,000 acres of the island were infested with firetree (Walters & Null 1970). The 225 acres infestion in HVNP in 1966 had increased to approximately 9000 acres in 1977. Infested acreage varied from light (1 tree/acre) to heavy (1000 trees/acre) concentrations, with the major distribution being in the seasonal dry forest section of the Park. 62,776 firetrees were removed from the Park from 1967 to 1974, and from 1975 to 1978 an additional 30,884 were destroyed, making a total of approximately 100,000 trees removed over a 10-year period (Donald Reeser, Resources Management Biologist, pers. comm.), and yet the plant continues to spread (Smathers 1976). The National Park Service considers the firetree invasion an unnatural phenomenon that threatens and impairs the natural and historic quality of the Park's vegetation.

The United States Forest Service and the Hawaii State Board of Forestry consider firetree to be an aggressive exotic with no commercial value, occupying land which should be utilized for agriculture and commercial forestry purposes. The State of Hawaii has conducted a control program for nearly 20 years, but funding and manpower have caused considerable fluctuations in this effort. Herbicides are the primary means of control. Of the various herbicides, Tordon 22k has proved the most successful in giving complete canopy kill and 99% control of sprouting (Walters & Null 1970; Walters 1973).

Controls by the National Park consist of uprooting small trees and using Kuron herbicide (2,4,5-TP) on medium and large trees. In addition to chemicals, several species of insects have been tested for control of firetree, but none have been successful (Krauss 1964).

Ecological Evaluation

As yet no comprehensive ecological evaluation has been made of the long-term impact of firetree upon the native vegetation. It seems reasonable that such a study should be conducted, considering the long period firetree has been colonizing the island ecosystems, and since its complete eradication is not likely. The latter is especially true in wildlands where agriculture and forestry are not practiced. Such a study would reveal the ecological role that firetree has with native species as well as with other exotic species now naturalized to Hawai'i. Information of this type would provide resource managers a better knowledge of how to evaluate the firetree's presence in light of their agency's mission and policy.

There is now an excellent opportunity to study firetree as it invades a series of ecosystems in Hawai'i. Since 1971, firetree has been invading the Devastation Area of the 1959 Kilauea Iki Crater eruption site in HVNP (Fig. 1) where a similar comprehensive ecological study has been underway for nearly 20 years. A main objective of the Devastation Area study is to determine the competitive relationship between native and exotic plants as they colonize recent volcanic substrates. Results of this study have shown that exotic and native plants have both a competitive and complementary relationship. In all habitats, native woody plants were eventually capable of replacing or holding their own with exotics. The Park manager has now set aside a part of the

Devastation Area for a concentrated study of the invading firetree population.

STUDY AREA

In December 1959 Kilauea Iki, a pit crater on the summit of Kilauea Volcano, erupted and deposited a blanket of pumice over an area of 500 hectares. Later the entire area, which is approximately 1200 m in elevation, became known as the Devastation Area. The latter name was given to the area because of widespread destruction of both a montane rain forest and a seasonal dry forest. With its variety of climates, substrates, and contiguous populations of native and exotic plants, the area provided a unique opportunity to study the formation of new plant communities.

Immediately after the eruption, a study was begun of plant invasion and recovery within the six habitats. These habitats were recognized by kinds of substrate and remains of the former vegetation. A series of permanent photo stations, belt transects (Fig. 2), and quadrats were established to record the chronological sequence of plant succession and recovery. The results of this study have provided information heretofore unknown on the phytosociological relationships of native and exotic plants (Smathers and Mueller-Dombois 1974; Smathers 1976).

During the 15-year observation period (in 1974) a small population of firetree seedlings was recorded in the western part of Habitat 5 near Byron Ledge. It is estimated that the initial invasion started about 1971.

The habitat is characterized by the large number of surviving native 'ohi'a (Metrosideros collina subsp. polymorpha) trees with a pumice layer that varies from approximately 30 cm to 3 m in depth (Habitat 5 in Fig. 3). It is in the lee of the cinder cone that formed during the 1959 eruption and slopes gently in a southwesterly direction. This habitat is somewhat protected from the prevailing northeasterly trade winds. However, it receives greater insolation in the lower sectors because of decreased cloud cover. The approximate mean annual air temperature is 17°C and the mean annual rainfall approximates 2700 mm. Mean evaporative rate from a Livingston atmometer was 6 ml/day/week with a standard deviation of 2.7. The climate is characterized by humid mild winters and warm dry summers (Smathers & Mueller-Dombois 1974).

METHODS

A survey was made of the firetree infestation pattern in Habitat 5 to determine its boundary, homogeneity, and the direction of invasion before placement of transects for stand analysis. Two permanent belt transects at right angles to one another were established in the infested area to meet the above criteria. It was not possible to determine direction of invasion as size classes (height and diameter) were found evenly distributed throughout the populated area. One transect, C-C', which was 180 m long and consisted of contiguous 10 x 10 m plots, was originally established in 1960 for the Devastation Area study. The other transect W-W', was 70 m long and consisted of 10 x 20 m contiguous plots (Fig. 2).

Ninety-six firetrees were sampled within the transects for height, basal diameter, vigor, and phenological characteristics. A vigor rating of good to average included specimens with dark green to green foliage, mature fruits, and strong to medium terminal growth. A rating of poor included specimens with numerous pale green to chlorotic leaves, defoliated branches, fruit falling before maturity, and terminal die back. Associated plant species were recorded as to their physical position in relation to each firetree. Parameters of density, frequency, and percent cover were determined for the various height and diameter ranges. Unusual growth forms were also recorded.

RESULTS AND DISCUSSION

Stand Structure and Vigor Characteristics

The structure and vigor of the firetree population are shown in Table 1. By totaling both transects (C-C' and W-W') the highest number of trees (61) is in the 2-5 cm range; the second highest (32) is in the < 2 cm seedling range; and the next lowest number (2) is in the 6-7 cm range. The number trend in diameter sizes indicates that firetree is making a steady-progressive invasion of the area, but the small number of trees with mature fruits (Table 2) could not likely be the parent stock of the large number (32) of seedlings (< 2 cm).

Of the 96 firetrees examined, 89 were directly associated with the native 'ohi'a trees by being rooted beneath their crowns. In the < 2 cm diameter range, 27 seedlings, having a height range of 0.20-2.00 meters, grew beneath 'ohi'a trees, and 10 of these over 1 m tall were beginning to interlock with the lower 'ohi'a branches. In the 2-3 cm range, 34 shrubby firetrees were growing beneath 'ohi'a trees, and 25 of these were interlocking with 'ohi'a branches. In the 4-5 cm range and up to the 4 m height range, 25 shrubs grew beneath 'ohi'a with 20 exhibiting strong interlocking of branches with 'ohi'a. In the 6-7 cm small tree range, 100% had interlocking of most branches with both 'ohi'a and firetree seedlings become established beneath 'ohi'a trees and then grow upwards and into the 'ohi'a crown with interlocking branches. This direct aggressive behavior of firetree toward 'ohi'a would appear to end in competitive replacement of the latter. However, in all but one firetree'ohi'a interlock situation, 'ohi'a was exhibiting average to good vigor. The only interlocking 'ohi'a with low vigor was recorded in plot 8 of transect C-C'. On the other hand, firetree was not faring as well as shown in Table 1. In Transect C-C' its vigor was from average to good in the < 2 cm range. However, this condition shifted in the 2-3 cm range where 82.4% of the firetrees exhibited average vigor, but on reaching the 4-5 cm range, average vigor had decreased to 54.5%, and 27.3% of the trees exhibited poor vigor. In transect W-W' a similar relationship existed with poor vigor continuing to increase with diameter range. At range 6-7 cm, 50% of the trees showed poor vigor, and at 10-11 cm the single tree recorded in this range had poor vigor.

The foregoing data show that within the area considered in this study firetree tends to lose vigor as it increases in size. Cause of the vigor loss may be a lack of available soil water. The recent pumice soil is exceedingly dry regardless of the high rainfall (2700 mm) for Habitat 5. Available water for plants ranges only from 2% to 3%. Thus, there is less water available in this new volcanic material than in most sands, and plants in open areas will have water for growth only for a short period after showers (Smathers & Mueller-Dombois 1974).

The surviving 'ohi'a trees have created a mesic microhabitat beneath their canopy, in comparison to the xeric soil environment outside the canopy. Beneath each tree an accumulating litter layer has formed that is periodically moistened by through-falling rain, and protected from desiccation by the crown cover. Thus the microhabitat conditions beneath 'ohi'a favors firetree seed germination and seedling development up to a diameter range of 2-3 cm. Further growth causes a drain on the soil water, and this condition is reflected by loss of vigor. When the firetree reaches the 6-11 cm range, soil water is practically unavailable for growth, and thus vigor becomes poor. The fact that firetree has never invaded the dry, barren soil of Habitat 4 tends to support the foregoing hypothesis.

It is not known whether there is competition between the 'ohi'a and firetree root systems. Surviving 'ohi'a were rooted in the old soil layer prior to the 1959 ash fallout layer. In localities where the ash fallout was over 0.5 m, a secondary root system developed on the buried 'ohi'a trees, thus there could be competition between the two trees for water and nutrients. In any case, 'ohi'a would still have the advantage by having a rooting system in the old soil, which still receives water filtering through the new soil.

Quantitative Characteristics

The basal diameter, height, density, and frequency of firetrees are shown in Table 3. In transect C-C', the 2-3 cm range had the highest density, frequency, and second highest percentage cover, thus showing its dominance in the community structure (stratification). In transect W-W', the 2 cm class had the highest density (1.64/100 m^2) and frequency, but the 2-3 cm and 4-5 cm ranges had the same frequency and also the highest percentage cover (3.88 and 5.72, respectively). The higher total density, frequency, and percent cover of the W-W' transect than the C-C' transect is because 'ohi'a trees are spaced farther apart in the C-C' transect than in the W-W' transect. Therefore, there were more available microhabitats ('ohi'a crowns) in transect W-W' for firetree to colonize.

Phenological Characteristics

Phenological characteristics of this firetree population are shown in Table 2. The following information on flowering and fruiting was obtained in August 1977. Most noticeable was the senescence of staminate flowers and green fruits developing on several plants. Also, considerable defoliation was occurring on the branches of three plants that bore both staminate flowers and fruits. Approximately one-fourth of the fruits observed were purple, which indicated they were ripe. With the exception of defoliation, the flowering and fruiting cycle of firetree in Hawai'i probably approximates that in the plant's native habitat. In Madeira and the Canary Islands, Krauss (1964) observed firetrees in June with an abundance of male flowers and green fruits. However, he noted that the staminate flowers were drying up. From July to September he reported that most of the green fruits had turned purple, and by November there were many ripe fruits with some on the ground.

Flowering and fruiting starts with the Devastation Area firetrees in the 2-3 cm range. Of the trees in transect C-C' 17.6% had staminate flowers or fruits, while in transect W-W' 16.7% had staminate flowers or fruits. The percentage of trees with fruits increased with height and diameter size. At the 4-5 cm range, 53.8% of the trees had staminate flowers or fruits (both C-C' and W-W' combined). At the 6-7 cm range 100% of the trees had staminate flowers or fruits. There were no seedlings beneath those trees that bore fruit, even though the ground beneath some trees was covered with fruits. Overall, 24.0% of the trees had fruits: 4.2% with immature fruits, 6.3% with mature fruits, and 13.5% with both mature and immature fruits.

Thus, firetrees begin to produce seed at an early age, and the seed crop continues to increase as the stand gets older. Therefore, numerous seeds are available for stand regeneration and dispersal. This type of accelerated productivity, associated with horde invasion, tends to characterize some pioneering species, more so than a long-term colonizer. It is not known why defoliation of terminal branches of three trees occurred after producing flowers and fruits. These trees were relatively large ranging from 3.95-5.67 cm in diameter and 3.1-3.9 m in height. Two exhibited poor vigor and one average vigor. Their condition may have resulted from stress brought on by lack of available soil water. It could also indicate a response of conserving energy for fruit development.

The means of dispersing firetree throughout Habitat 5 is still unknown. As previously pointed out, it is not likely that the large number of seedlings were offspring from the small number of trees capable of producing mature fruit. Also, there was no invasion pattern characterized by a sequential trend of diameter ranges along a directional gradient. The random distribution of diameter sizes suggests a dispersal agent that would be following a similar pattern. In addition, the fact that 93% of the firetrees were established underneath 'ohi'a crowns, suggests a strong correlation with the distributional pattern other than just microhabitat conditions for seed germination.

There is good reason to believe that birds are involved in the dispersal of firetree seed. While collecting field data, the investigators observed numerous Japanese White-eye (Zosterops japonica) foraging in the 'ohi'a trees. The White-eye is an exotic bird in Hawai'i. It is native to Japan, and it has been observed to feed on insects, nectar, and fruits in Hawai'i (Guest 1973). In Australia, Gannon (1936) reported that White-eye spread blackberry, lantana, and several other species of plants. It seems logical that as Japanese White-eye forage among the 'ohi'a flowers for nectar or insects, they could be depositing firetree seeds obtained from trees outside the Devastation Area. The presence of numerous firetree seedling beneath 'ohi'a crowns and oftentimes close to the trunk, tends to support the assumption that seeds are being deposited by birds. Another exotic bird that is common to the area, and may also be capable of spreading firetree is the Red-billed Leiothrix (Leiothrix lutea).

Growth Form Characteristics

The growth form characteristics are shown in Table 1. Firetrees in the 2-3 cm and 4-5 cm ranges exhibited a high degree of basitonic branching (multiple branching near base of main stem). It was not determined what produces this type of adventitious budding. It seems likely that the basitonic branching is in response to a stressful condition. For example, one specimen found in the 1974 survey of the Devastation Area (Smathers 1976) is believed to have survived the 1959 ash fallout. This tree had a stem 10 cm in diameter that appeared to have been burned off by the hot falling ash. It was approximately 10 cm below the 1959 ash level, underneath and close to the trunk of a surviving 'ohi'a tree, and with numerous branches sprouted from the burned stump. These branches had been unable to penetrate the dense-basal branches of the surviving 'ohi'a, and thus they had grown outward, prostrate on the ground, beyond the periphery of the crown and then upward. This growth response could indicate firetree's low shade tolerance under high crown densities. A similar condition was also observed in transect C-C' and W-W' where a majority of firetrees grew into 'ohi'a with open crowns; however, where the basal canopy was dense, they grew outward, prostrate on the ground.

CONCLUSIONS

The Devastation Study Area provides a unique opportunity to study firetree ecology. Here, a self-contained population can be eventually studied under six different habitat conditions that range from rain to seasonal dry forests types.

The initial phase of the present study has provided heretofore unknown ecological information on firetree in Hawai'i. Although several factors have been evaluated, the results are preliminary. Additional investigation is needed before definitive conclusions can be made. Notwithstanding, the present results show that the firetree population is not competitively replacing 'ohi'a trees nor any other native vascular plant. On the contrary, firetree shows a decided loss in vigor as it develops into tree size, apparently a function of low availability of soil water for an increasing biomass. However, the close interlocking of 'ohi'a and firetree crowns has a threatening characteristic which must be further evaluated.

To evaluate the apparent close, physical, competitive relationship between 'ohi'a and firetree will require long-term observations on a permanent site. Data derived over an extended period of time will reveal whether firetree can competitively replace 'ohi'a, and in addition whether firetree can regenerate itself on the same site.

Kawasaki's (unpublished) observation that firetree forms a dense-closed canopy forest with nothing growing beneath, seems to indicate that it is a shade intolerant species. In addition, it must be determined whether firetree can recolonize where it was previously eradicated by herbicides or natural succession.

Although the present location of firetree correlates with the foraging pattern of fruit-eating birds, primarily the Japanese White-eye, it cannot be definitely stated that this is the dispersal agency. Considerable observations, seed viability, and germination study will be needed to test this hypothesis.

It is imperative that firetree be observed in its native habitats (Azores, Madeira, and Canary Islands). This would provide a better understanding of its potential ecological role in the various ecosystems of Hawai'i. Now that firetree has become naturalized in Hawai'i, as have hundreds of other exotics, it seems that the prudent course of action would be to learn as much as possible about how it fits into the new vegetation. Knowledge of this type will provide a better understanding of what controls, if any can be effective in eliminating or stabilizing firetree populations. This viewpoint is shared by some of the foremost ecologists who have studied the nature of exotic invasions (Elton 1977).

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TABLE 1. Habitat 5. Structure and vigor of firetree population.

Basal Diameter Range (cm)	Number of Trees	Number with Basitonic Branching	Vigor Class Number of Trees/ % of Diameter Range o (poor)	+ (average)	++ (good)	Number Interlocking with 'ohi'a	Number growing Underneath 'ohi'a	Number Associated with Species other than 'ohi'a	Number Growing in Open
Transect: C-C', 18 plots, 10 x 10 meters. Total cover 1800 m^2									
* 2	9	0	0/0	6/66.7	3/33.3	2	7	0	0
2-3	17	5	1/5.9	14/82.4	2/1.2	11	6	0	0
4-5	11	2	3/27.3	6/54.5	2/18.2	7	3	0	1
Subtotal	37	7	4/10.8	26/70.3	7/18.9	20	16	0	1
Transect: W-W', 7 plots, 10 x 20 meters. Total cover 1400 m^2									
* 2	23	0	1/4.3	7/30.4	15/65.2	8	10	2	3
2-3	18	4	3/16.7	10/55.6	5/27.8	14	3	1	0
4-5	15	4	11/73.3	2/13.3	2/13.3	13	2	0	0
6-7	2	0	1/50	1/50	——	2	0	–	–
8-9	—	-	——	——	——	--	—	–	-
10-11	1	0	1/100	——	——	1	0	0	0
Subtotal	59	8	17/28.8	20/33.9	22/37.3	38	15	3	3
Both Transects Combined (Subtotals) 25 plots, 3200 m^2. Total Cover									
Totals	96	15	21	46	29	58	31	3	4

TABLE 2. Habitat 5. Phenological characteristics of firetree population.

Basal Diameter Range (cm)	Number of Trees	Immature Fruits	Mature Fruits	Both Mature & Immature Fruits (8/8/77)	Trees with Fruit (%)
Transect: C-C', 18 plots, 10 x 10 meters. Total cover 1800 m^2					
* 2	9	0	0	0	0
2-3	17	1	0	2	17.6
4-5	11	3	2	2	63.6
Subtotal	37	4	2	4	27.0
Transect: W-W', 7 plots, 10 x 20 meters. Total cover 1400 m^2					
* 2	23	0	0	0	0
2-3	18	0	0	3	16.7
4-5	15	0	3	4	46.7
6-7	2	0	0	2	100.0
8-9	0	-	-	-	———
10-11	1	0	1	0	100.0
Subtotal	59	0	4	9	22.0
Both Transects Combined (Subtotals) 25 plots, 3200 m^2. Total Cover					
Totals	96	4	6	13	24.0

TABLE 3. Habitat 5. Quantitative characteristics of firetree population.

Basal Diameter Range (cm)	Number of Trees	Height Range (m)	Density	Frequency (%)	Cover (% of Total Cover)
Transect: C-C', 18 plots, 10 x 10 meters. Total cover 1800 m^2					
* 2	9	0.34-1.80	0.50/100m^2	38.9	0.48
2-3	17	1.30-3.20	0.94/100m^2	50.0	2.79
4-5	11	2.10-4.00	0.61/100m^2	33.3	3.22
Subtotal	37	———	2.05/100m^2	72.2	6.49
Transect: W-W', 7 plots, 10 x 20 meters. Total cover 1400 m^2					
* 2	23	0.20-2.00	1.64/100m^2	85.7	0.88
2-3	18	1.85-3.60	1.29/100m^2	85.7	3.88
4-5	15	2.40-4.00	1.07/100m^2	85.7	5.72
6-7	2	2.80-4.10	0.14/100m^2	28.6	0.76
8-9	0	———	———	———	———
10-11	1	4.0	0.07/100m^2	14.3	1.22
Subtotal	59	———	4.21/100m^2	100.0	12.46
Both Transects Combined (Subtotals) 25 plots, 3200 m^2. Total Cover					
Totals/Avgs.	96	———	3.13/100m^2	86.1	9.48

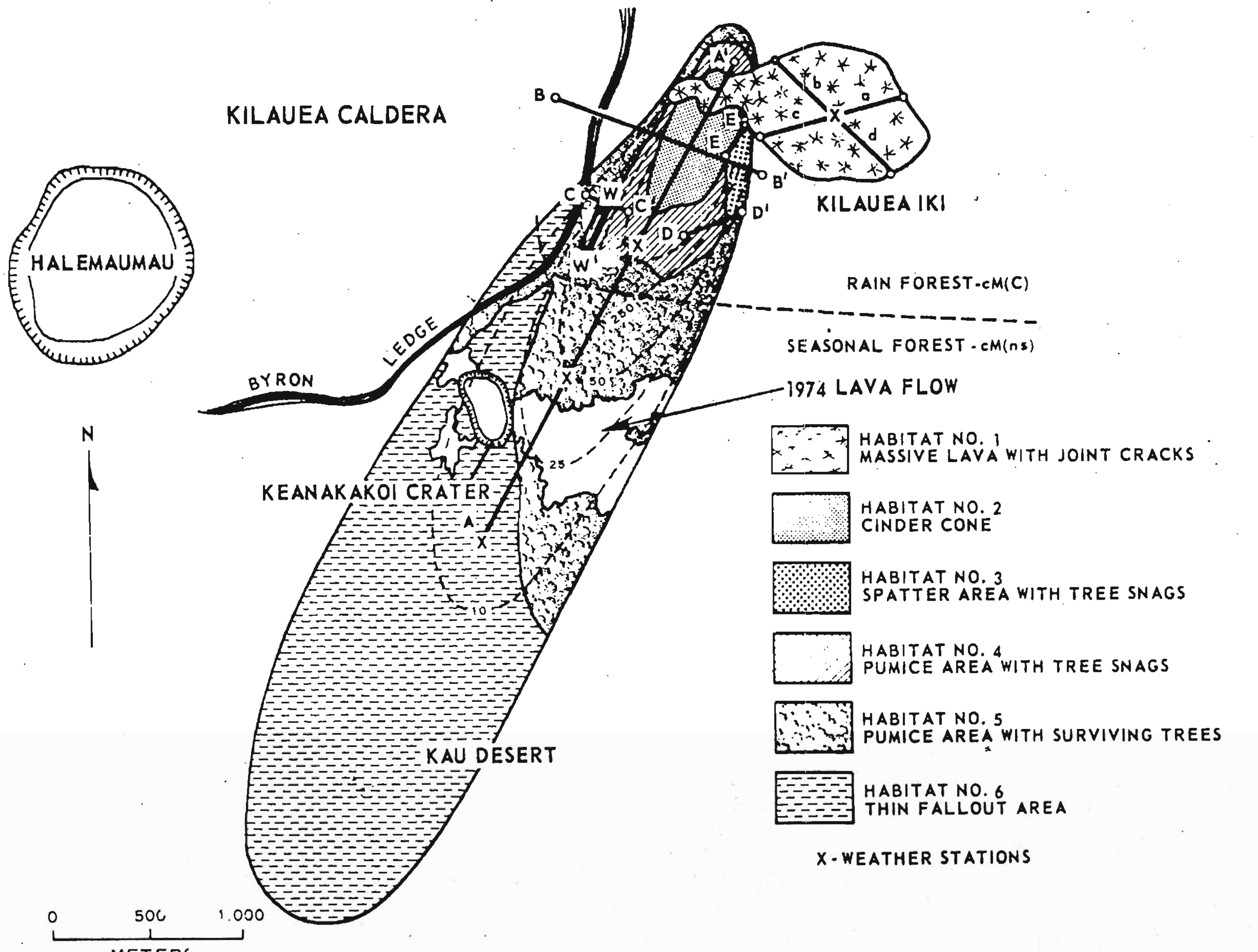

FIGURE 1. Map showing location of Kīlauea Iki crater in reference to Hawaii Volcanoes National Park.

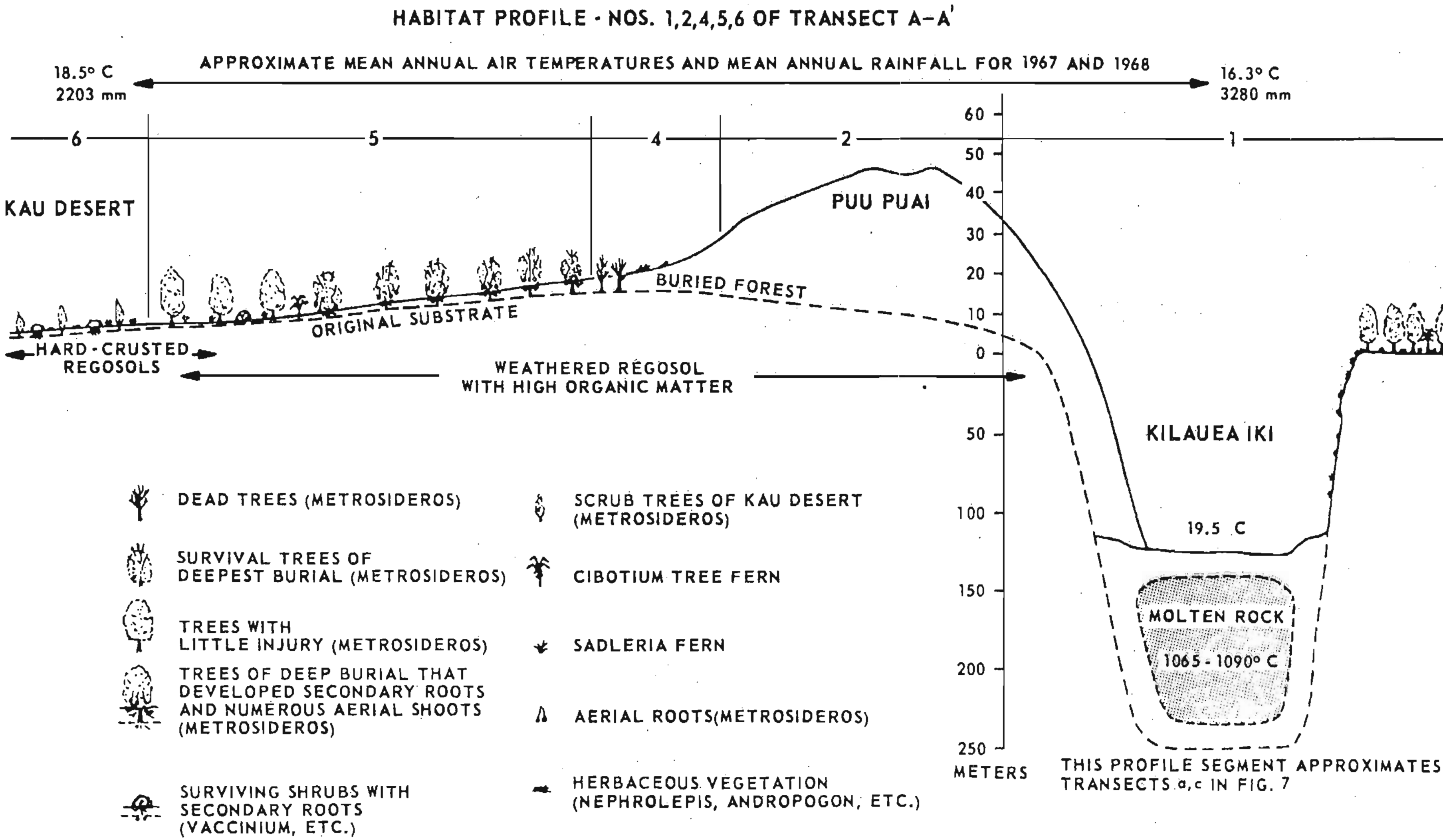

FIGURE 2. Habitat types and study transects of the 1959 Kīlauea Iki eruption site (crater floor and pyroclastic deposit).

FIGURE 3. Northeast-southwest profile of eruption site extending from Kīlauea Iki crater to upper Ka'u Desert.