FIFTEEN YEARS OF VEGETATION INVASION AND RECOVERY AFTER A VOLCANIC ERUPTION IN HAWAII

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A major volcanic eruption on the Island of Hawaii in November 1959 devastated an existing montane-rain-and-seasonal forest covering an area of about 500 ha. After the eruption, six new habitats were recognized by kinds of substrate and remains of former vegetation:

Habitat 1. A lava lake consisting of massive pāhoehoe lava with many joint cracks in the Kī-lau-ea Iki crater.

Habitat 2. The summit and sides of the conder cone, Pu'u-pua'i.

Habitat 3. A spatter area with dead tree snags.

Habitat 4. A pumice area with dead tree snags.

Habitat 5. A pumice area with surviving trees.

Habitat 6. A thin fallout area that covered a former partially cemented ash-crust habitat surface (Ka'ū Desert).

A continuing study was made of plant invasion and recovery in permanent quadrats and transects from the time of the disturbance. The first report on the study was made 9 years (1968) after the eruption (Smathers and Mueller-Dombois 1974). The present report covers from the 9th year forward to year 15 (1974) after the eruption.

In year 9 it was found that patterns of plant invasion and recovery observed depended on a number of specific factors or a combination of factors. In year 15 many of these same factors were still present, and individually or in combinations they were affecting the developing vegetation patterns. The recorded patterns of plant invasion and recovery are summarized as follows:

1. A continued directional progression of invasion on the floor of Kī-lau-ea Iki (habitat 1) that correlated with cooling of the surface area.

2. Microhabitat development in major habitats affected community development of synusia and aggregation.

3. Regression in earlier successional patterns were caused by feral pig activity.

4. Observations were made on relationships of exotic and native plants in the recovery and invasion process.

1. Factors related to directional invasion and recovery

By year 9 an analysis of the directional invasion patterns revealed that: 1) the concentric inward advance of plant life on the Kī-lau-ea crater floor was closely related to the substrate heat gradient that showed initial cooling at the crater floor margin; 2) the nearness of the seed source from the undisturbed forest was a major factor in the early invasion of habitat 3; 3) snag density accounted for accelerated invasion of habitats 3 and 4. The snags created favorable microhabitats by intercepting moisture which provided a moist soil at their bases for plant establishment; 4) ash-depth gradient correlated with both the survival and invasion of plants. The fast recovery in habitats 5 and 6 was attributed to the shallow ash deposit. In contrast plant life was still sparse on the deep open ash deposits of habitats 2 and 4 in year 15. Also the only additional directional invasion observed was on the ash deposits of habitat 4. Here the exotic weedy shrub *Buddleja asiatica* had completed its invasion from both the east and west side of the habitat. However, *Buddleja* could only get established at the snag bases, and in most instances the plants were dying or exhibiting low vigor. This species is being gradually replaced by the native low shrub *Dubautia scabra*.

Concentric invasion of the Kī-lau-ea Iki crater floor was continuing in year 15. Temperature measurements made by USGS through a drill hole in the lake surface in 1974 revealed that the interior of the lake was still molten rock at approximately 1075°. However, as the cooling process continued the crater floor had thickened from 30 m in year 9 to 40 m in year 15 (personal correspondence R. I. Tilling). This thickening trend with a corresponding drop in surface temperature accounted for the advancement of plants into the center of the crater. Continued cooling of the lake interior will affect the invasion pattern of plant life for some time on the crater floor. As the interior cools, shifts in the crater can occur causing surface temperatures to rise in some localities. These shifts in temperature could explain the loss of some plants from several quadrats in the 1974 survey (year 15). Shifts of temperature in cooling volcanic materials is a common occurrence. It seems likely that it will be at least another decade before vascular plants will have arrived at the center of habitat 1.

2. Microhabitat development in major habitats

Renewed analysis of the permanent transects and quadrats in year 15 revealed that community developments were taking place in some habitats through the development of plant aggregates. In habitat 2 an aggregate community of *Vaccinium reticulatum* was developing in a low depression on the lee side of the Pu'u-pua'i cinder cone.

In year 9 plant community development had been observed to some degree in all habitats. On the crater floor (habitat 1), several fern plants became established in the joint cracks. When one individual fern became established, it soon was joined by several other members. Also, the microhabitat conditions that favored this aggregation were not always present in other joint cracks since ferns did not get established there. Since other plants such as individual woody *Metrosideros* seedlings became established more in these cracks, and not associated with the ferns, it was reasoned that the controlling factor in individual and aggregate plant establishments was favorable moisture relations of the crack microhabitats. Thus, it seems reasonable to assume that the moisture conditions in the cinder cone depression were favorable for the establishment of the *Vaccinium reticulatum* aggregate community. Further support is given by examining the upper profile of the Pu'u-pua'i cinder cone. The B layer, which is of a near impermeable flow sheet, acts as a hard pan that supports perched water for an indefinite period of time. It is thought that this B horizon extended widely over the cinder cone summit and sides; thus it could help bring better moisture relations to depressions such as the *Vaccinium* aggregate community.

3. Regression in year 9 successional patterns

On local sites where feral pigs have scarified the developing soil, native plants have been destroyed and exoitcs have replaced them. The pig is not native to Hawaii. One form was introduced by the Hawaiians approximately 2,000 years ago. This animal has been "improved" by crossing it with the European domesticated pig. Since there are no native Hawaiian ungulates, the native plants do not have built-in mechanisms to cope with ungulate stress brought about by pigs, goats, and livestock. As a result large tracts of the native vegetation have been destroyed or seriously altered (Mueller-Dombois and Spatz, 1975).

Park managers have tried unsuccessfully to eradicate pigs from the park since its inception (1916). As yet no definitive study has been completed on pig ecology. Such a study would provide park managers with better information for the control or eradication of this pest. The present study has shown that pigs engender the spread of exotic plants by their ground scarifying activities, but the most significant aspect of the study has been to prove that native plants can indeed competitively replace exotics (primarily *Rubus penetrans, R. rosaefolius*), when substrate disturbing factors such as pig stress are removed. Mueller-Dombois and Spatz (1975) have also shown that

when goat stress was removed, a new endemic legume vine (*Canavalia kauensis*) became established in two years. This was the first recording of this species in Hawai'i. Their study, like the present Devastation Area Study, revealed the high recovery potential of the native vegetation, once ungulate stress is removed.

4. Relationships of exotic and native plants in the recovery and invasion process

The park manager of Hawaii Volcanoes National Park is charged to keep the park ecosystems in as near a pristine condition as possible. The invasion of exotics is looked upon as an unnatural phenomenon and a threat to the native flora. Regardless of over a 50-year effort to eradicate exotic plants from the park, the majority of vascular species present are exotic (Smathers, 1968). Most of them are found on man-disturbed sites (road and trail sites, etc.). As was earlier noted, several exotic plant species such as *Buddleja asiatica, Rubus rosaefolius* and *Rubus penetrans* were identified as early invaders in the recovery process in some habitats after the natural disturbance by ash fall. In the last several years an exotic low stature tree species, *Myrica faya*, has been observed to invade habitat 5, the pumice area with surviving trees. This plant, a native of the Azores and Canary Islands, was introduced in Hawai'i for reforestation. By 1944 it had succeeded so well that the Board of Agriculture and Forestry were pursuing a program to eradicate it (Neal, 1965). Although the state controls are still in effect, *Myrica faya* continues to spread. By mid-1960 the plant was already established in the montane rain forest of the park and beginning to invade the seasonal dry forest. Over the past decade the park has extended and intensified its control of *Myrica faya*. Control is carried out by direct eradication (uprooting) and use of a herbicide (silvex). From 1967 to 1974, 62,776 *Myrica faya* trees were removed from the park (personal communication with former Park Superintendent Bryan Harry)--yet it continues to invade. A definitive study is needed to determine the ecological role of *Myrica faya* in the Hawaiian islands. Such a study would provide the basis for the control of this species. General observations tend to conclude that it rapidly invades most vegetation types in the park in great hordes as do many other exotic plants. It readily fills the open areas, especially in the montane rain and seasonal forests. On superficial view it appears to have replaced the native trees and shrubs, but on close inspection many native woody plants are still present. The means of occupying an open niche and the degree of permanency of *Myrica faya* must be evaluated. Study of the present populations of *Myrica* in habitat 5 and its possible invasion of the remaining habitat, if carefully monitored, can answer some important questions on the invasion potential and ecological adaptation of this species in this ecosystem. This information could be undoubtedly useful to understand the behavior of this exotic and its interaction with the native species and other similar habitats.

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