

FIGURE 9. Study areas on the island of Hawaii

STUDY AREAS

We established seven study areas on Hawaii (Fig. 9): Kau, an isolated montane rainforest of ohia and koa on the southeast slopes of Mauna Loa; Hamakua, the windward montane rainforest of ohia and koa on Mauna Kea and Mauna Loa; Puna, the low elevation ohia rainforest on Kilauea; Kipukas, a high elevation dry scrub area on the windward side with scattered pockets of mesic forest; Kona, the diverse leeward montane area on Mauna Loa and Hualalai; Mauna Kea, the subalpine mamane-naio woodland on Mauna Kea; and Kohala, an isolated lower elevation ohia rainforest on the northern end of the island.

We established two study areas on Maui, and one each on Molokai, Lanai, and Kauai (Figs. 10–11). These areas are mostly in montane ohia rainforests, although other habitat types were also sampled. Place names referred to in text are shown in Figures 12–15.

KAU

The Kau study area is situated on the southeast slopes of Mauna Loa, covers 329 km², extends from 640 to 2225 m elevation, and is fairly isolated from other

forests (Figs. 9 and 16). Most rainfall is derived from a large horizontal vortex wind pattern, but rainfall distribution resembles the convection cell pattern of precipitation. The top boundary of the study area lies near the inversion layer in dry alpine scrub. Below this is well-developed wet native forest (Fig. 17). Areas devoted to sugar cane, macadamia nuts, and cattle border the study area below and laterally.

The Kau study area is relatively undisturbed by human activity, as reflected in the closed canopy cover (Fig. 18). Decreasing canopy cover at higher elevations marks the transition to subalpine scrublands. No station had more than 20% cover of introduced trees, introduced shrubs, or passiflora. Koa-ohia forest is the dominant habitat in the northeast half of the study area, and ohia forest elsewhere. Mamane and naio are absent as dominants, and matted ferns are common in only one area. A vegetation map of the study area has been published (Jacobi 1978).

HAMAKUA

The Hamakua study area is situated on the eastern slopes of Mauna Kea and northeastern slopes of Mauna

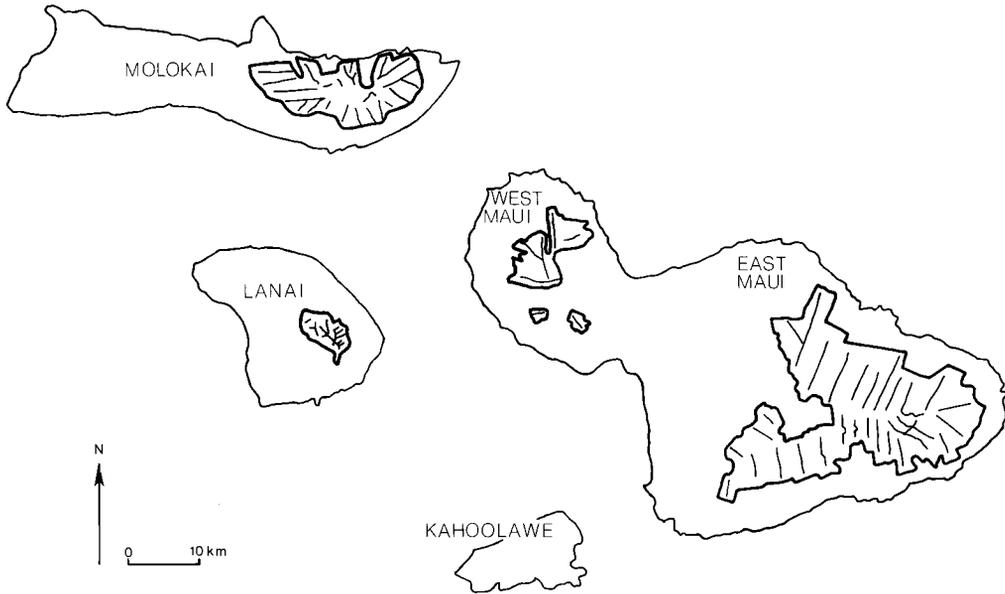


FIGURE 10. Study areas on Maui, Molokai, and Lanai.

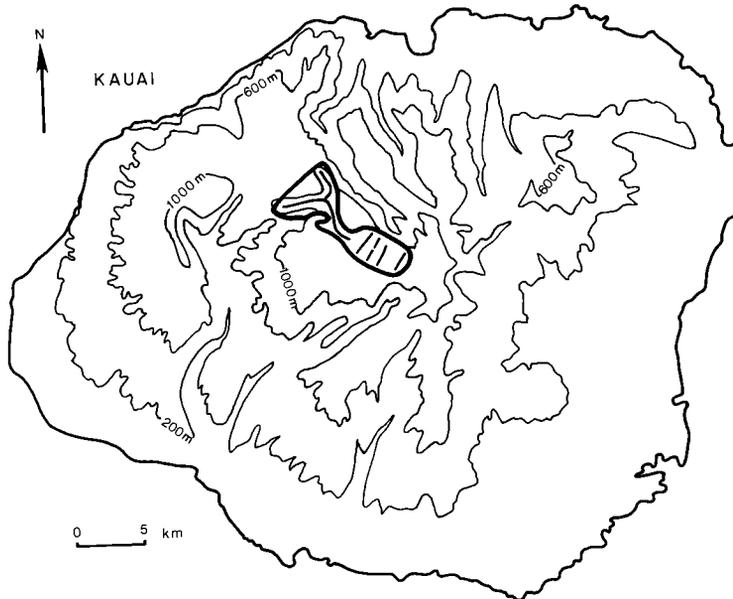


FIGURE 11. Study area on Kauai.

Loa (Figs. 9 and 19), and constitutes transects 12 to 32 of windward Hawaii. The study area covers 1112 km² and extends from approximately 300 to 2300 m elevation. The upper boundary lies near the inversion layer in dry, disturbed pastures and grasslands. Below this area are well-developed native forests, with introduced plants common at lower elevations (Fig. 20).

Trade wind precipitation predominates, with a median annual rainfall of 700 cm (highest on the island) on the lower slopes of Mauna Kea (Blumenstock and Price 1967). Below the lower forest boundary, sugar cane plantations and cattle ranches extend as high as 1200 m elevation. Several recent lava flows (1852, 1855, 1880, 1899, 1935, 1942, 1984) from Mauna Loa

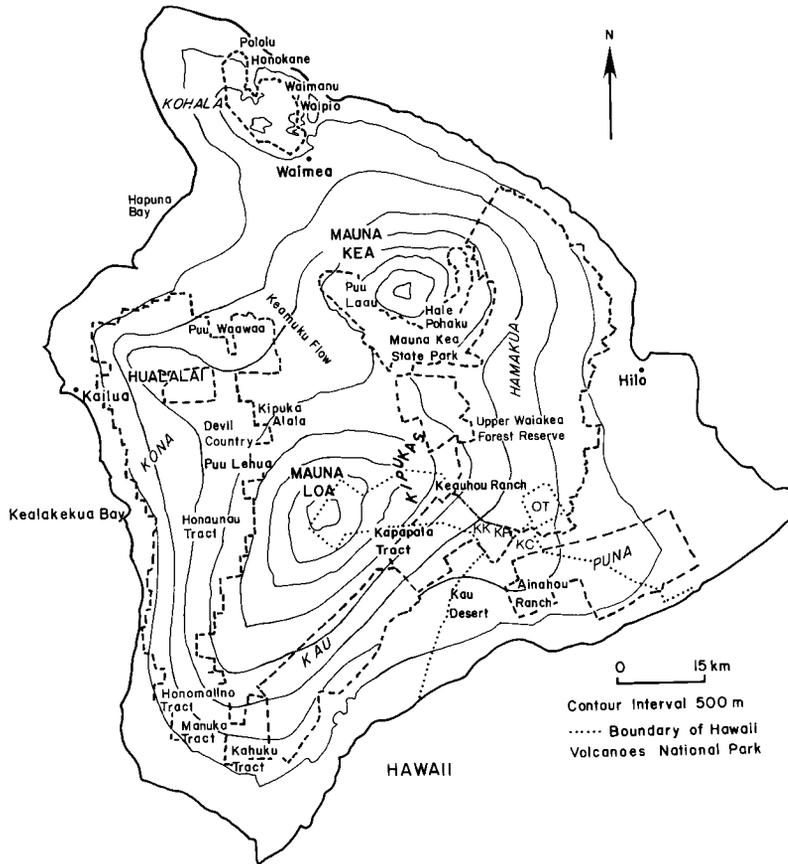


FIGURE 12. Place names on Hawaii. (KC = Kilauea Crater, KK = Kipuka Ki, KP = Kipuka Puauulu, OT = Olaa Tract).

(Stearns 1966) punctuate the mature forest and are marked by swaths of pioneer, successional vegetation that average 1 km in width.

The canopy cover varies extensively in the study area (Fig. 21). Large areas of reduced canopy cover at middle elevations reflect ohia dieback. Open canopies at upper elevations resulted from land clearing and grazing.

Koa occurs in mesic habitat, in pasture areas, and in a 5–7 km strip along the lower edge of the study area on Mauna Kea. Naio is not a dominant at any station. The small areas dominated by mamane at high elevation represent the lower degraded edges of the Mauna Kea mamane woodland. Matted ferns dominate large areas at low to mid-elevations in wet forest interiors, particularly ohia dieback areas. Tree ferns are common in most ungrazed wet forests. A large banana poka infestation occurs in undisturbed forest at 1500–2000 m elevation on the northeast slope of Mauna Kea. Introduced grasses reach their greatest cover in the park-like pasturelands below the Mauna Kea mamane woodland.

The Hamakua study area includes the last known

localities for the Greater Amakihi and the Hawaii Mamo (Berger 1981).

PUNA

The Puna study area (Figs. 9 and 19) is located south and east of Kilauea Volcano on Pleistocene and Recent lavas from the Kilauea system (Stearns 1966). The study area covers 270 km² and extends from 300 to 1300 m elevation. Dry coastal scrub borders the area at lower elevations, and rural residential subdivisions border the north sides. Southwest of the study area (Fig. 20), a strong rainshadow effect from the Kilauea shield created the Kau Desert where ohia, *Vaccinium*, and *Dodonaea* are dominant. The time elapsed since the last lava flow in an area is an important determinant of vegetation type at the south and west margins of the study area.

The canopy cover in this area varies considerably (Fig. 21). Treeless areas reflect recent volcanic activity. Koa and naio are not dominant elements at any station. Guava and Christmas-berry occur towards the lower boundary of the study area (Fig. 20), whereas the introduced fire tree, *Myrica faya*, is fairly widespread in

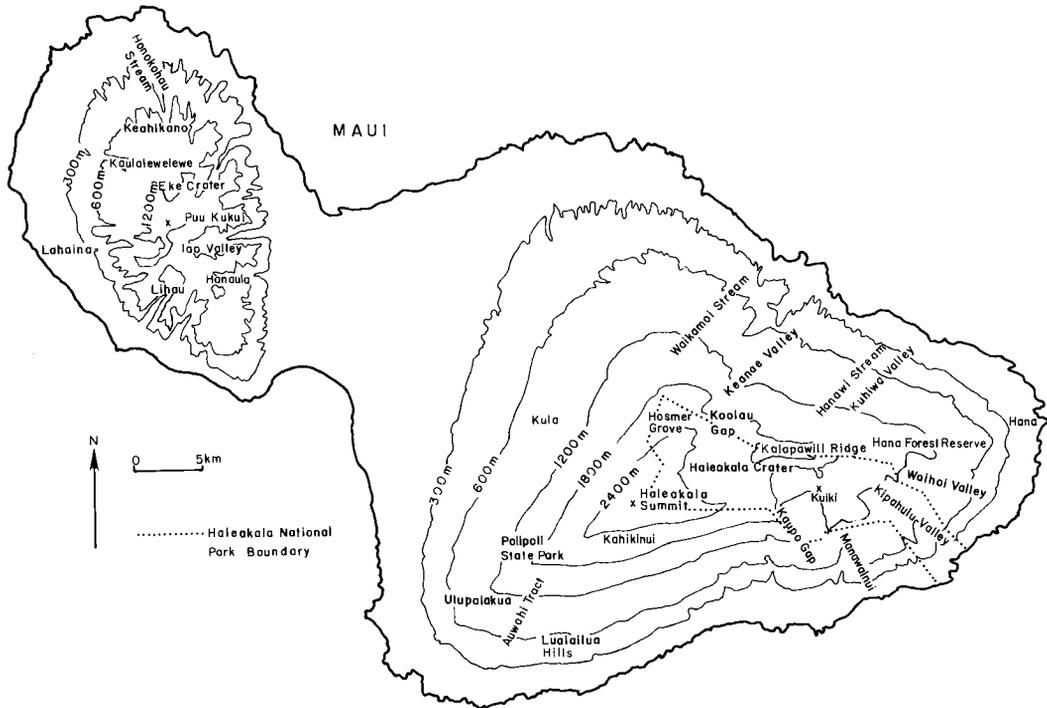


FIGURE 13. Place names on Maui.

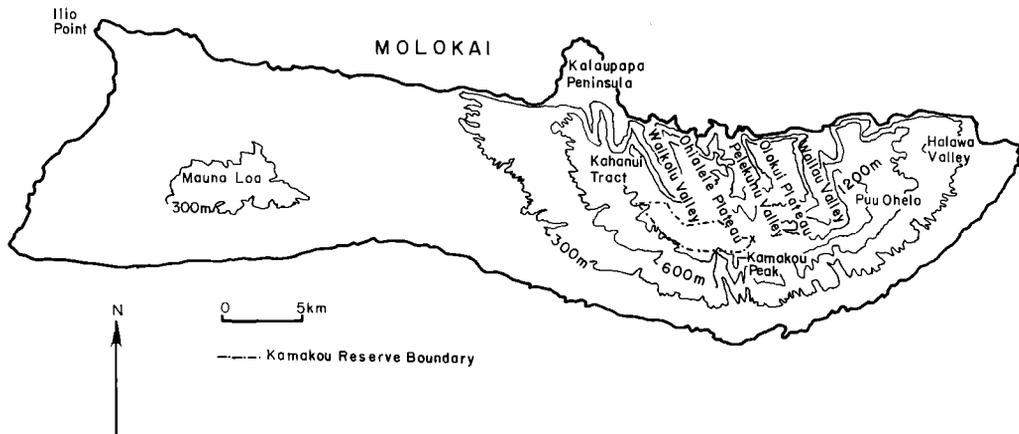


FIGURE 14. Place names on Molokai.

drier sections of the west side. Tree ferns, matted ferns, and scattered ieie occur in most wet areas. *Passiflora* is not found in the study area. Introduced graminoids have infiltrated most forested areas.

KIPUKAS

The Kipukas study area is situated west and south-west of the Hamakua study area (Figs. 9 and 19). This area covers 295 km², extends from 1100 to 2400 m elevation, is relatively high and arid, and lies mostly

above the thermal inversion or in the Kilauea and Mauna Loa rainshadows. Kipukas, "island-like areas of older land ranging in size from a few square [meters] to several square [kilometers] surrounded by later lava flows" (Stearns 1966:58), are numerous and have more mature soils supporting a more mesic, more developed vegetation than the surrounding dry scrub habitat. Forests dominated by koa and other trees are best developed in these mesic areas. We recorded no introduced trees, *passiflora*, or *ieie*; matted ferns were found only

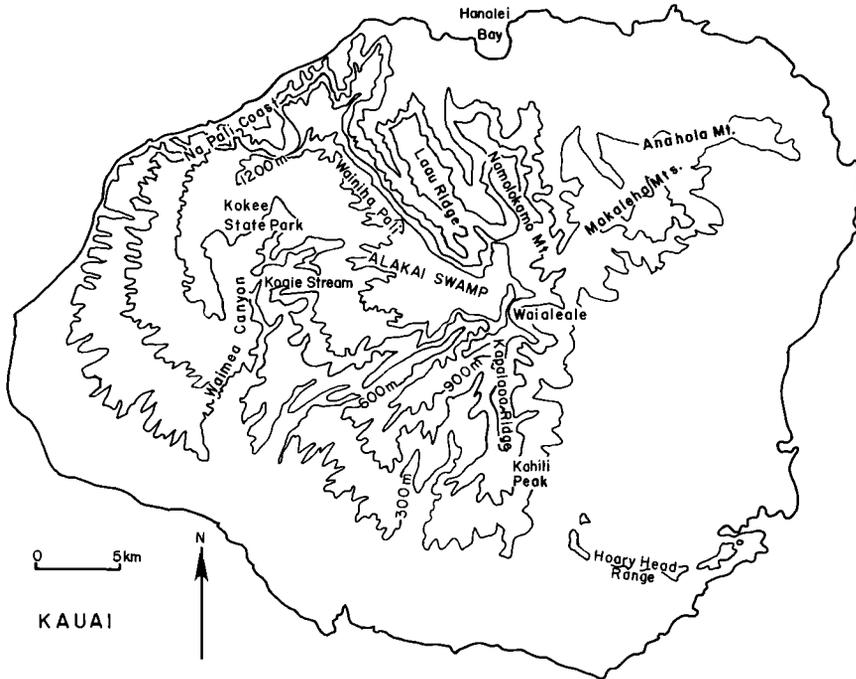


FIGURE 15. Place names on Kauai.

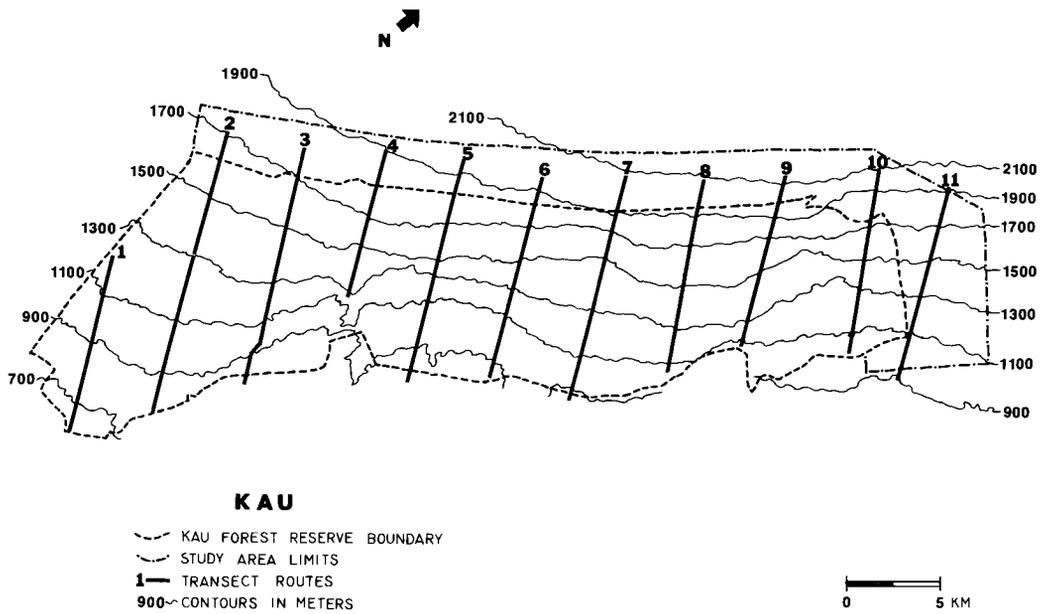


FIGURE 16. Transect locations in the Kau study area.

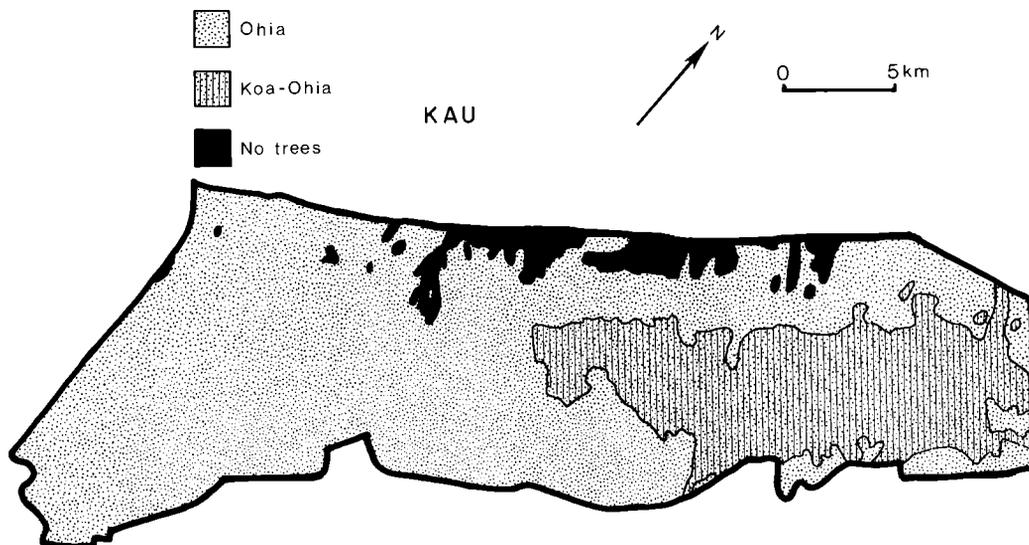


FIGURE 17. Habitat types in the Kau study area.

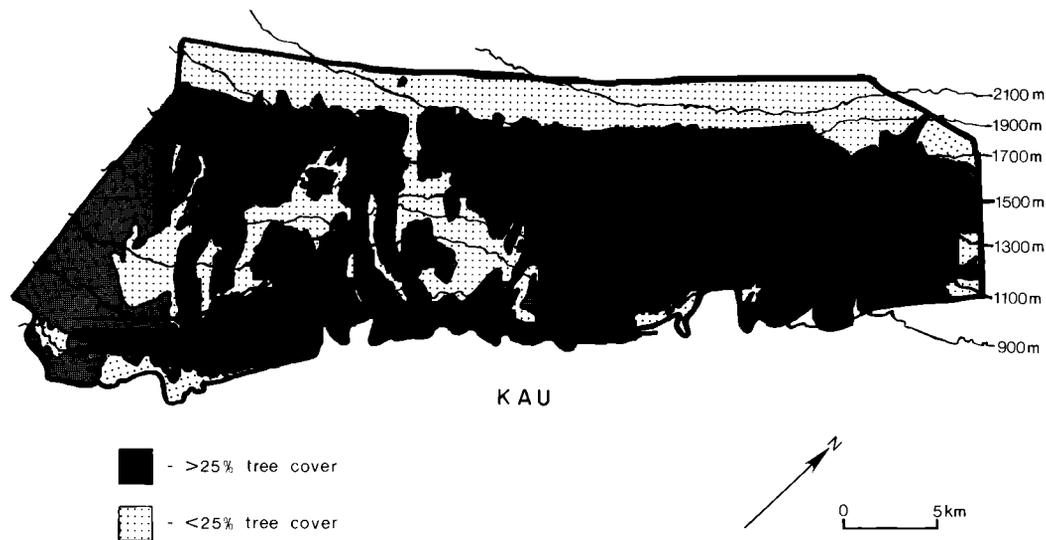
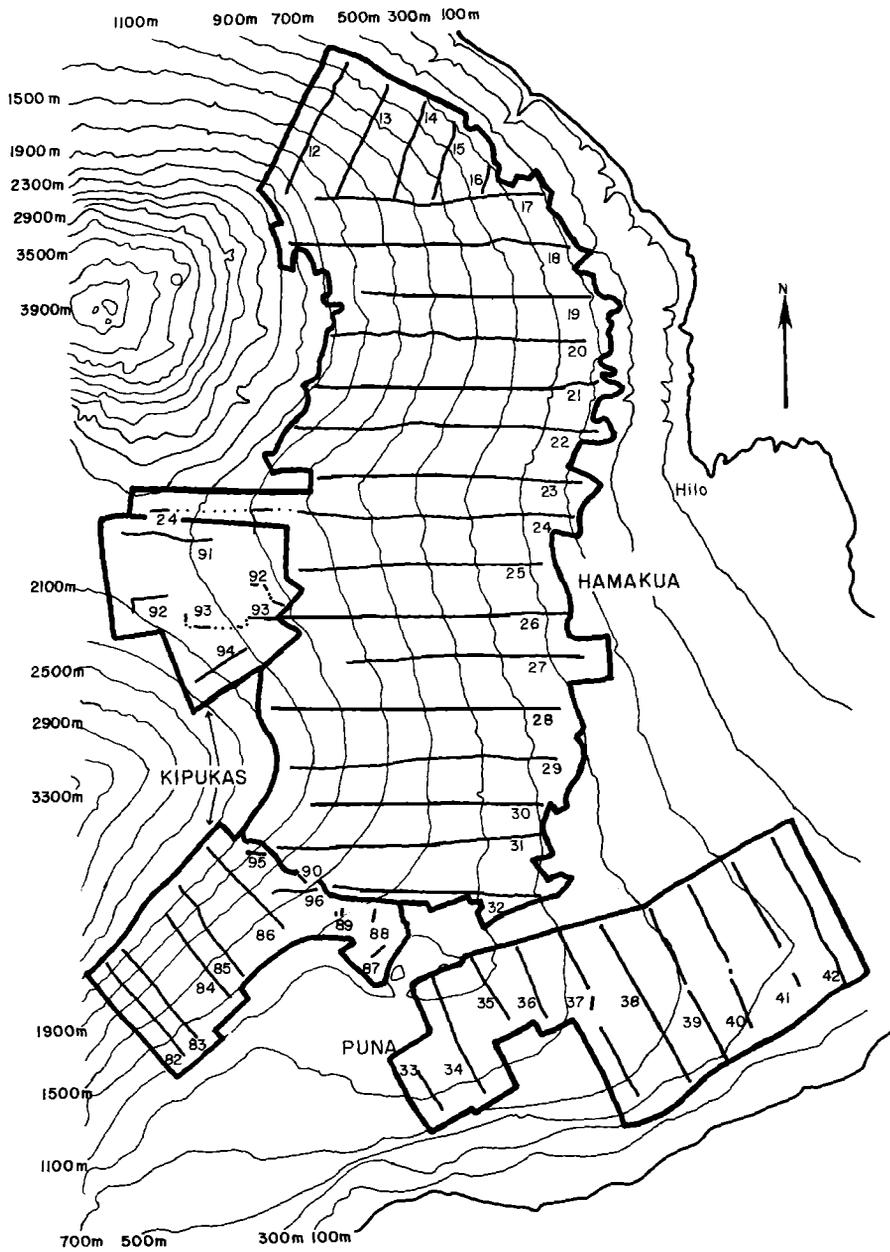


FIGURE 18. Canopy cover in the Kau study area.

at two localities, and tree ferns only at Kipuka Ki and Kipuka Puauu (Fig. 20). The Kipukas study area includes the upper half of the Mauna Loa transect of the International Biological Program study in Hawaii (Mueller-Dombois et al. 1981). Canopy cover is scattered throughout much of this area (Fig. 21). An exceptionally intact mature mesic forest remnant (Table 2; Mueller-Dombois and Lamoureux 1967) at Kipuka Puauu once supported the Greater Koa-Finch, Hawaiian Akiialoa, Akiapolaau, Hawaii Creeper, and Akepa (Perkins 1903, Baldwin 1953, Banko and Banko 1980).

KONA

Kona, the largest area studied, is situated on Hualalai and Mauna Loa on western Hawaii (Figs. 9 and 22). The study area covers 1265 km² and extends from 200 to 2500 m elevation. Forests reach their best development in convection cells on the south and west slope of Hualalai and on the slopes of Mauna Loa in south Kona. Elsewhere the habitat is generally dry. Mostly treeless areas on the high eastern slopes of Hualalai and parts of the Hualalai-Mauna Loa saddle were omitted from the study area.



WINDWARD HAWAII

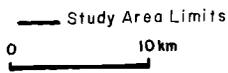


FIGURE 19. Transect locations in the windward Hawaii study areas (Hamakua, Puna, and Kipukas).

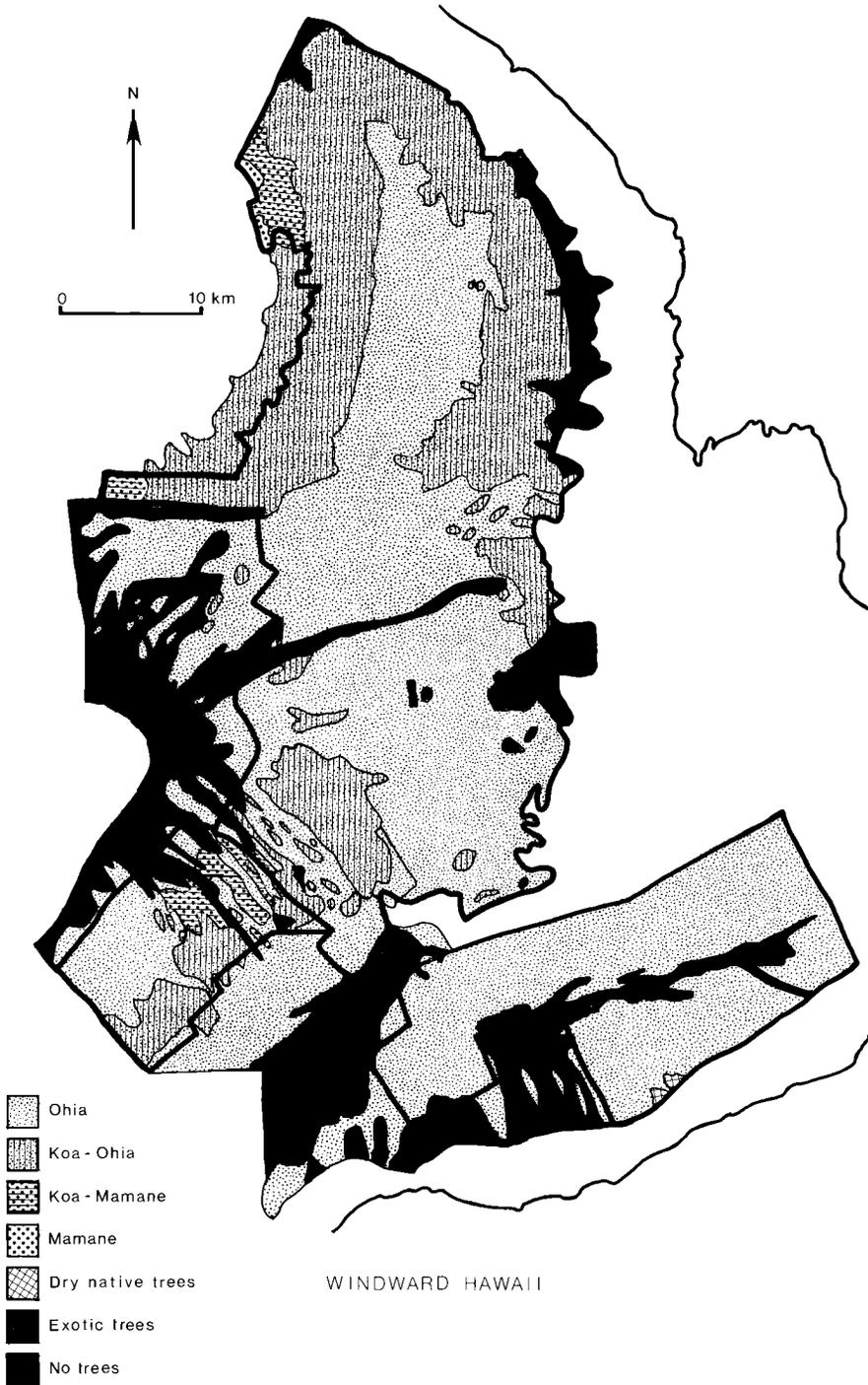


FIGURE 20. Habitat types in the windward Hawaii study areas (Hamakua, Puna, and Kipukas).



FIGURE 21. Canopy cover in the windward Hawaii study areas (Hamakua, Puna, and Kipukas).

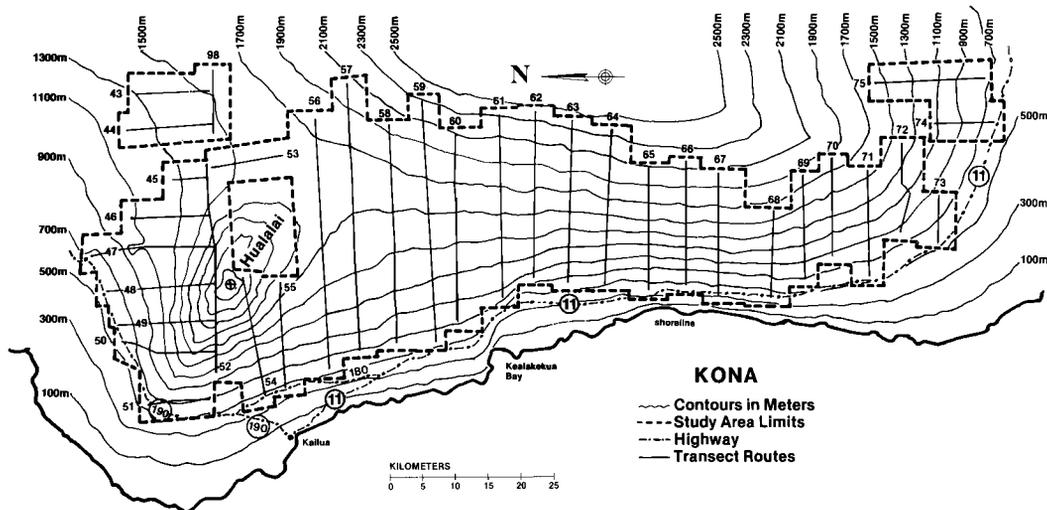


FIGURE 22. Transect locations in the Kona study area.

Koa occurs over much of the region, but is absent from dry areas at high elevations. Introduced trees, particularly guava and Christmas-berry, are common at low elevations; eucalyptus and conifer plantations are also frequent. Around the base of Hualalai, many introduced tree species occur (Fig. 23). Banana poka outbreaks occur on the mesic and wet areas of Hualalai. Ieie, matted ferns, and tree ferns are frequent in most mesic and wet areas, particularly at low elevations in south Kona. Introduced grasses are abundant in the dry areas north of Hualalai and on several large ranches in the northern half of the Mauna Loa shield. The forests have been fragmented by lumbering, grazing, and numerous historic lava flows, especially in south Kona (Fig. 24). Mature dry forest remnants occur below Puu Waawaa and on the Kapua Tract (Table 2).

Several species of extinct finch-like honeycreepers are known solely or primarily from Kona collecting stations (Berger 1981). Omao are absent from vast areas of Kona where they were formerly abundant (van Riper and Scott 1979) and Hawaiian Crows are now limited to Kona. The lower north slopes of Hualalai support many species of introduced birds (Lewin 1971).

MAUNA KEA

The Mauna Kea study area encompasses the ring of open subalpine woodlands on the east, south, and west slopes of Mauna Kea (Figs. 9 and 25). This area covers 139 km² and extends from 1900 to 3100 m elevation. The area generally lies above the inversion layer and supports dry habitat. Mamane is found throughout the area, and naio is dominant on the arid southwest slopes (Fig. 26). Native shrubs and introduced grasses are the most frequent understory cover, although native grasses predominate towards treeline. The canopy cover is far more open in this study area than in others (Fig. 27). Detailed descriptions of the area have been given by Hartt and Neal (1940) and Scott et al. (1984).

KOHALA

Kohala Mountain is the remnant of an old volcanic system forming the northern projection of the island of Hawaii (Figs. 9 and 28). The study area covers 124 km² and extends from 300 m to the highest peak, Kaunu o Kaleioohie, 1670 m elevation. Large deep valleys with steep sides (Waipio, Waimanu, Honokane, Pololu) run to the northeast dissecting the volcanic shield. The trade wind pattern of precipitation predominates. Southwest of the study area lies a rainshadow, where the native vegetation has been almost entirely replaced by introduced grasses. Over 95% of the study area is classified as wet habitat, and bogs are frequent. The central portion has the greatest precipitation, the highest values for tree biomass, tree ferns, and matted ferns, and the lowest proportion of introduced plants. Introduced trees, principally conifers, eucalyptus, and guava, are most common on the northwest and southwest edges (Fig. 29). Introduced grasses are common along forest margins. Passiflora was restricted to one locality on the southwest margin. No koa, naio, mamane, or ieie were recorded at any station. The canopy cover is primarily closed to open (Fig. 30). Kohala Mountain is the last known locality for the presumably extinct *Ula-ai-hawane*, *Ciridops anna* (Munro 1944).

EAST MAUI

The East Maui study area covers 404 km² and extends from 200 to 2800 m elevation on Haleakala, a massive shield volcano with a high elevation cinder desert in the summit "crater" (Figs. 10 and 31). The rainfall pattern on East Maui is typical for a high island: heavy trade wind precipitation on windward slopes below the inversion layer, several small convection cells, and dry leeward and high elevation areas. Ohia rainforest covers windward slopes. The zone of mesic habitat is much narrower than on Hawaii due to the smaller size and steeper slopes of East Maui. Pockets

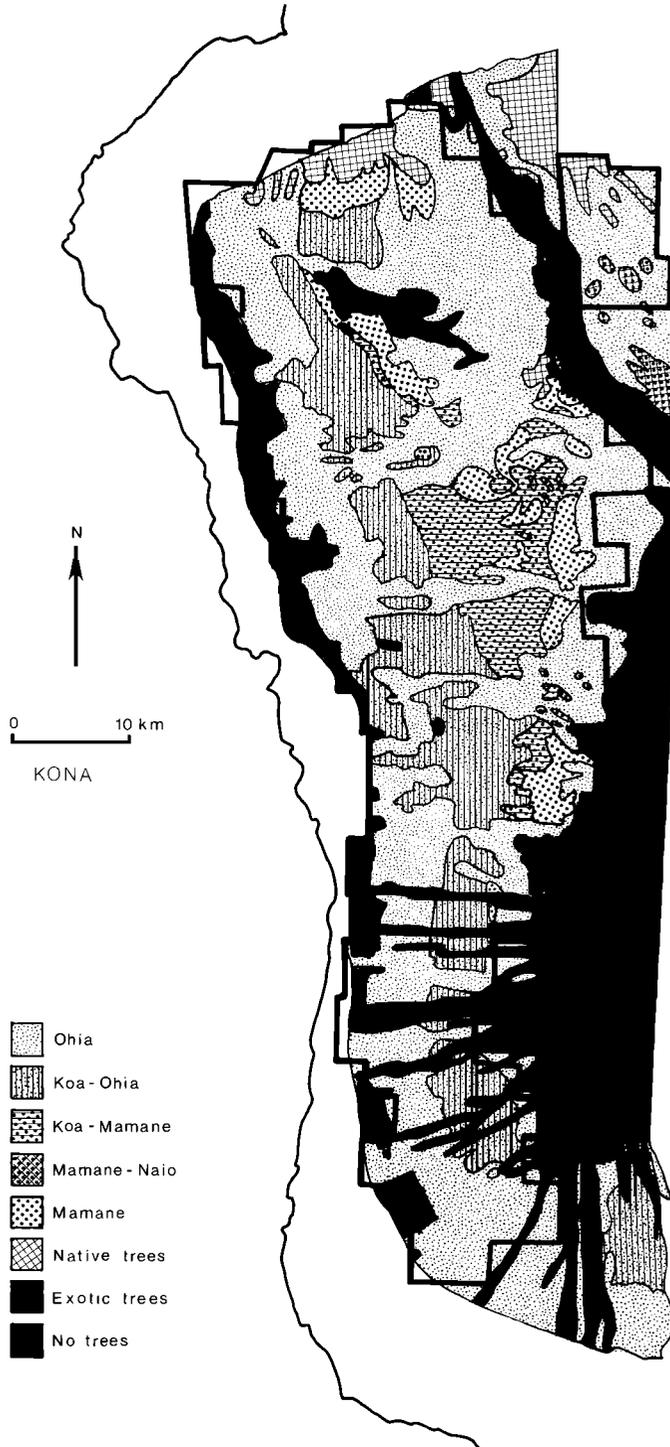


FIGURE 23. Habitat types in the Kona study area.

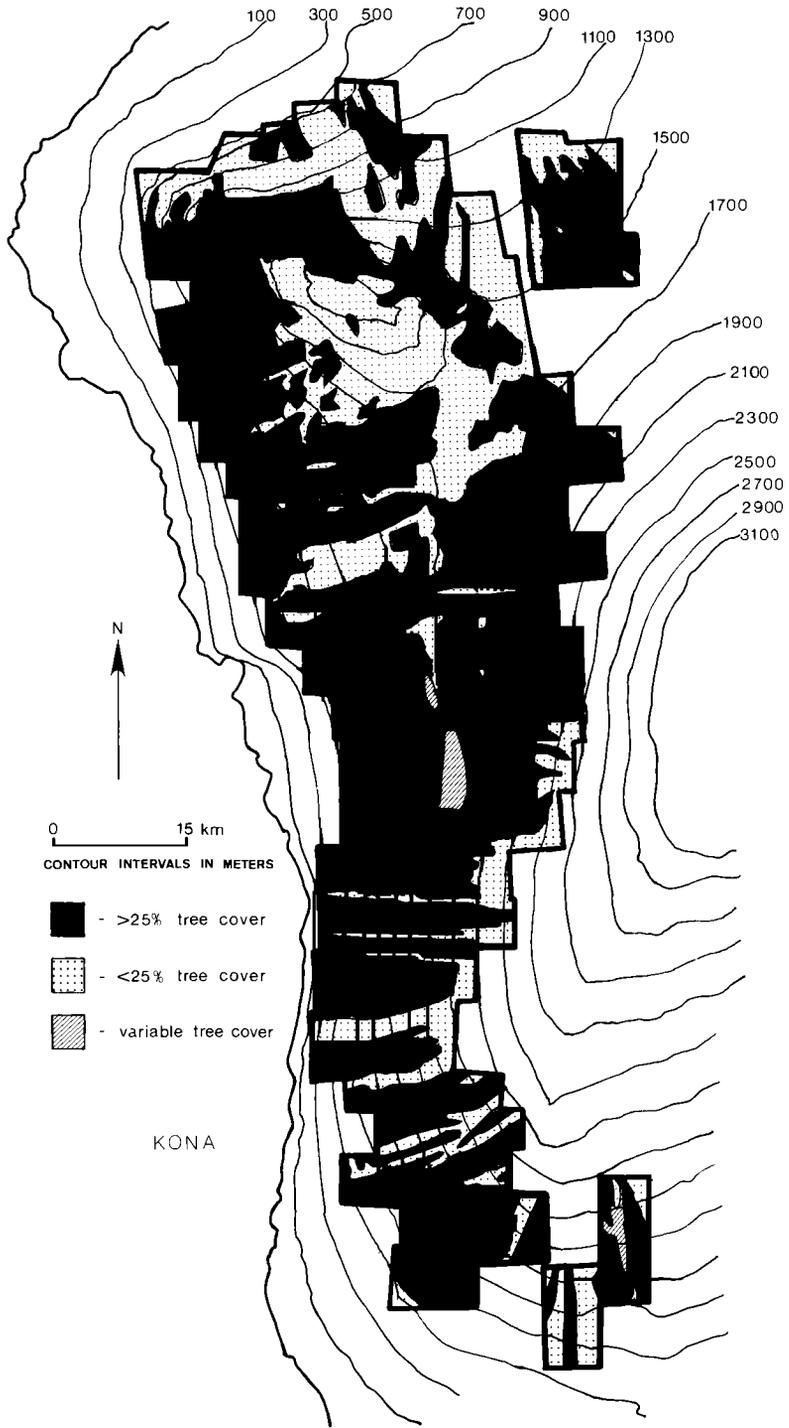


FIGURE 24. Canopy cover in the Kona study area.

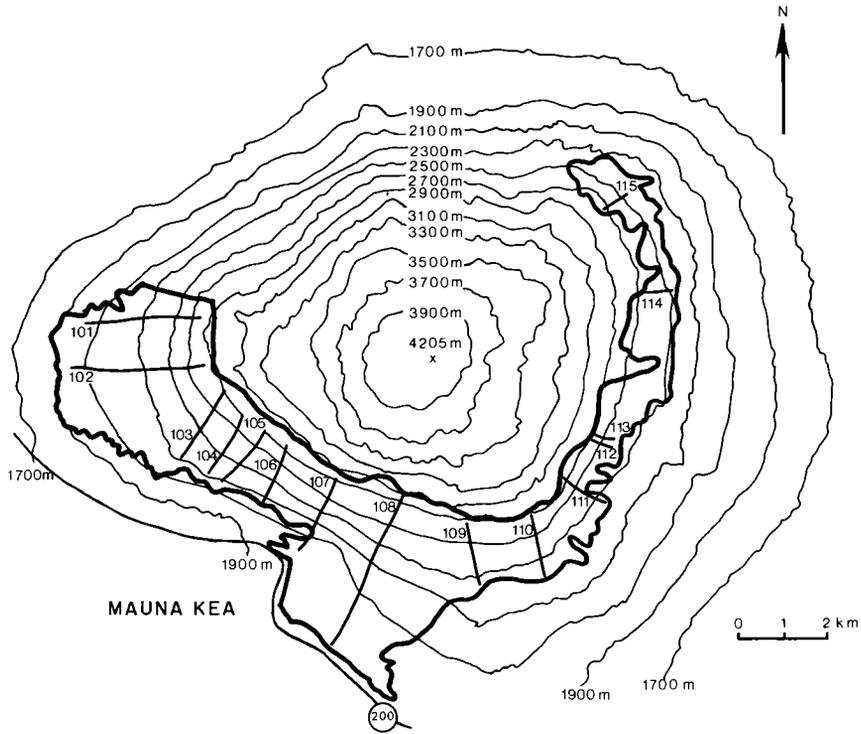


FIGURE 25. Transect locations in the Mauna Kea study area.

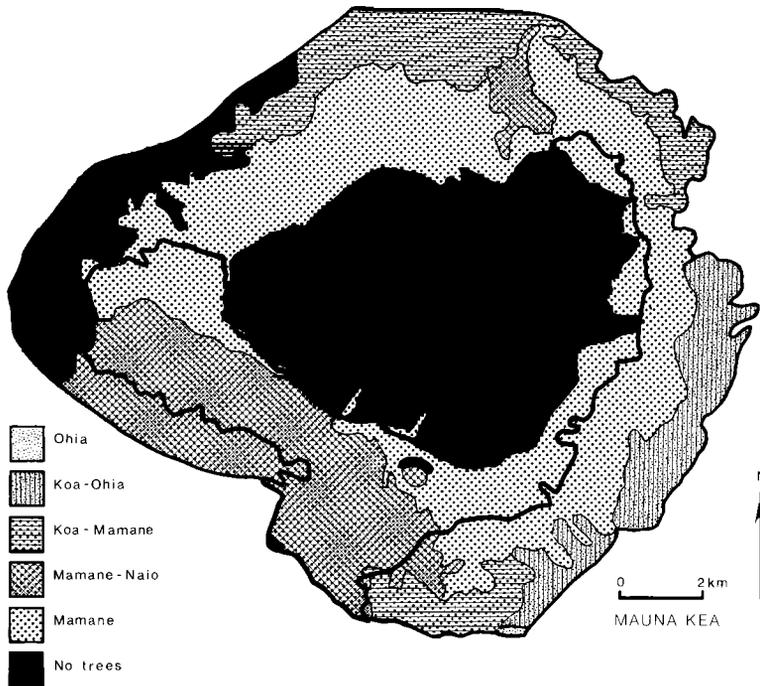


FIGURE 26. Habitat types in the Mauna Kea study area.

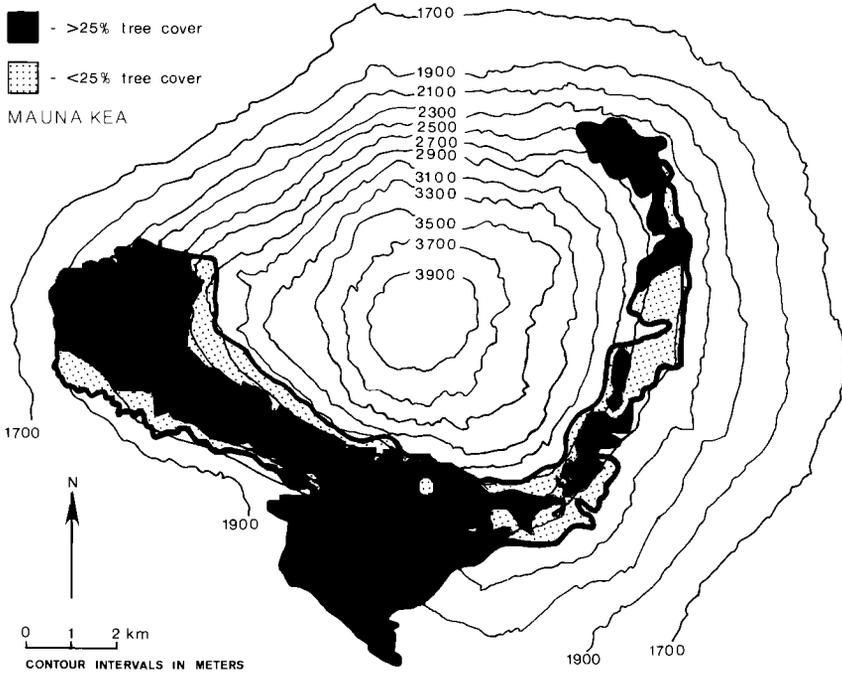


FIGURE 27. Canopy cover in the Mauna Kea study area.

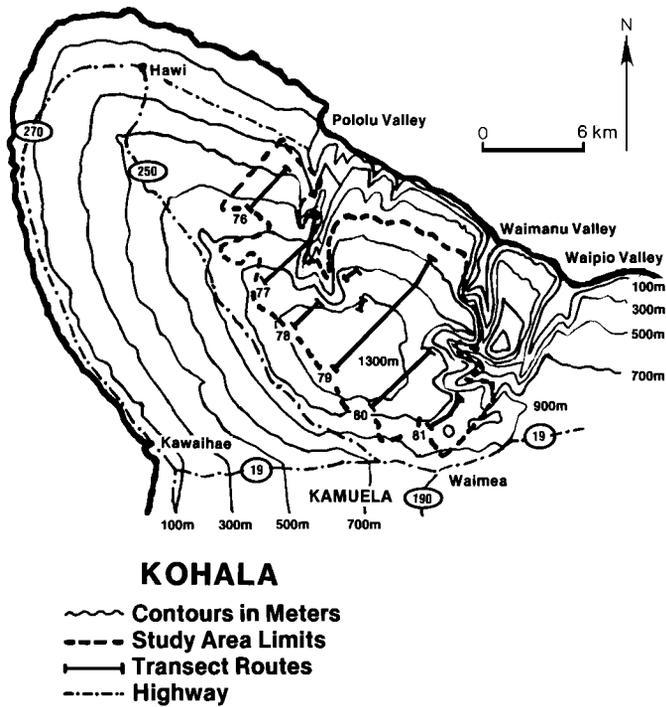


FIGURE 28. Transect locations in the Kohala study area.

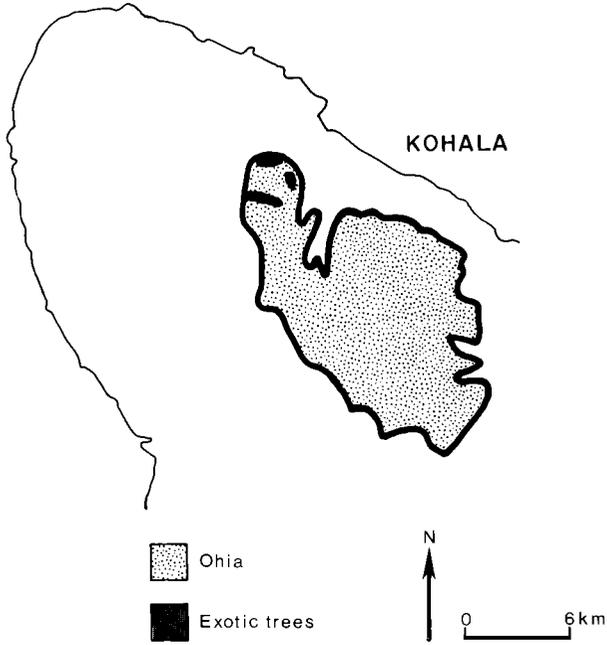


FIGURE 29. Habitat types found in the Kohala area.

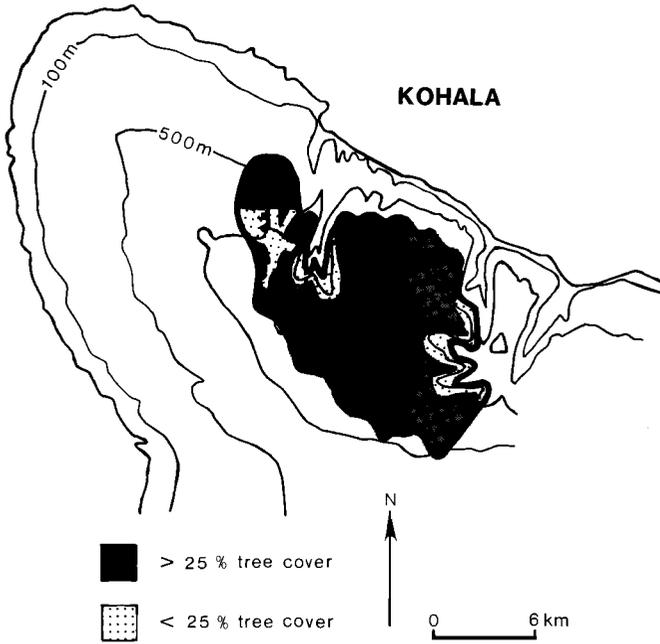


FIGURE 30. Canopy cover in the Kohala study area.

EAST MAUI

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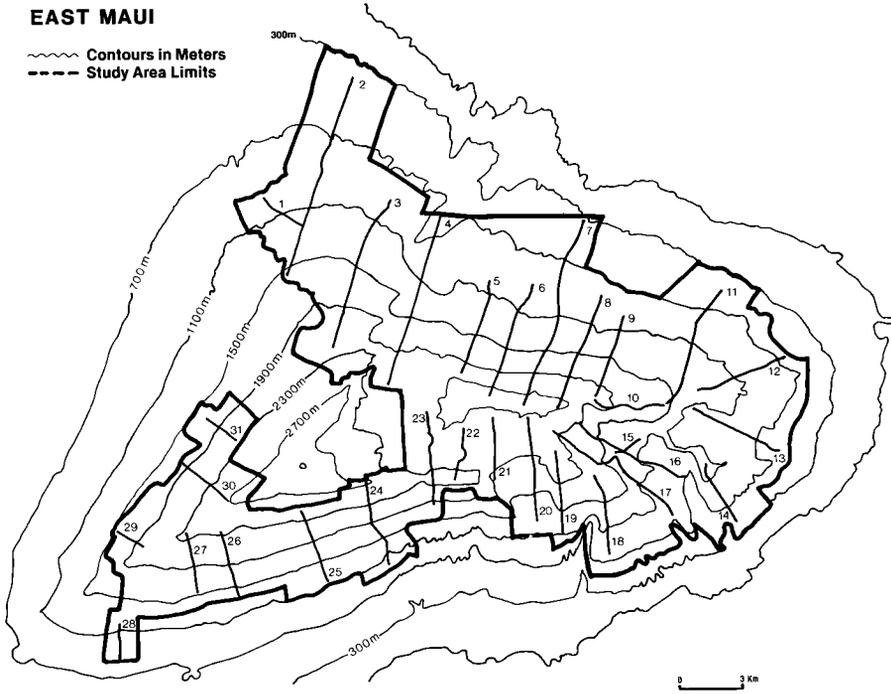


FIGURE 31. Transect locations in the East Maui study area.

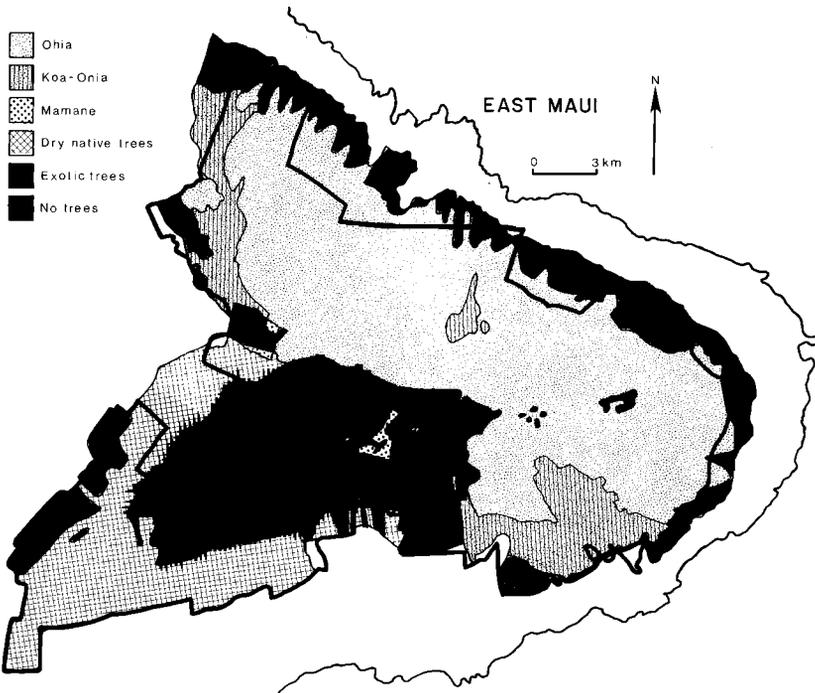


FIGURE 32. Habitat types in the East Maui study area.

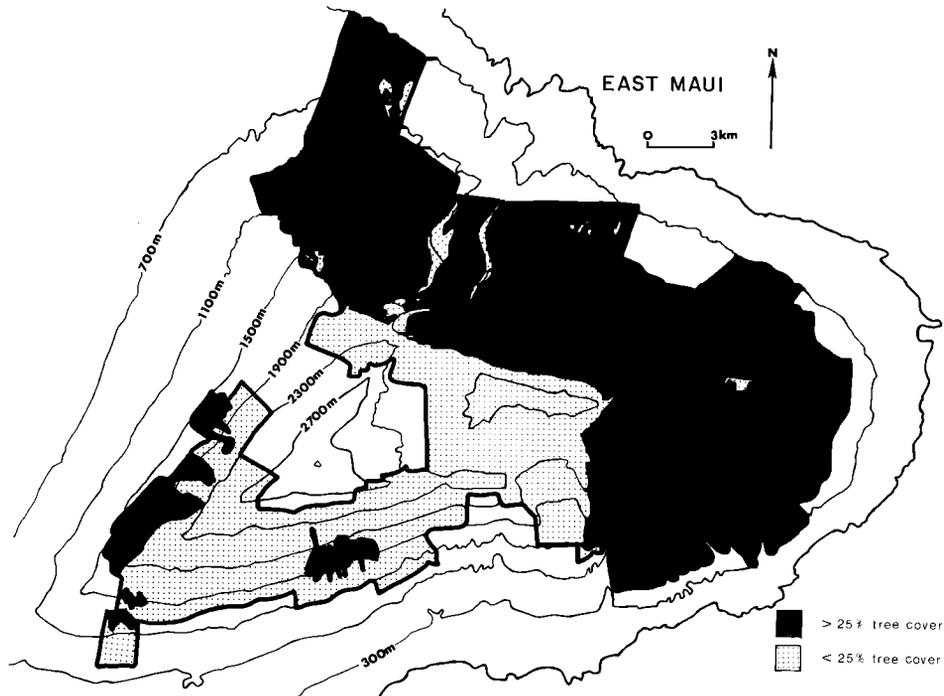


FIGURE 33. Canopy cover in the East Maui study area.

of koa-ohia forest occur northwest of Koolau Gap, in Kipahulu Valley, in Kaupo Gap, and as vestiges on the Kahikinui Tract. The western dry slopes of Haleakala formerly had extensive koa and sandalwood forests that were greatly disturbed by logging and grazing. One remnant area, the Auwahi Tract, is exceptionally rich in endemic dry forest plants (Table 2, Figs. 13, 32). The leeward slopes and crater district of East Maui have a much reduced canopy cover compared to the windward forests (Fig. 33).

Mamane is fairly common on the leeward side and in the cinder desert of the crater. Introduced trees, mainly guava, eucalyptus, and conifers, occur at lower elevations and along disturbed forest edges. Matted ferns are common in ohia dieback areas. Tree ferns are less common than on Hawaii, but still widespread. *Passiflora* outbreaks are small and confined to localized areas. Introduced grasses are common and widespread on ranchlands. Well-developed bogs occur locally near Lake Wai Anapanapa.

Many endemic birds occur only in the high montane rainforest on the northeast slopes of Haleakala. The Ou and Olomao were the only species lost from East Maui in historic times.

#### WEST MAUI

The West Maui study area covers 44 km<sup>2</sup> and extends from 250 m to the highest peak, Puu Kukui, 1764 m elevation (Figs. 10 and 34). The West Maui Mountains, a volcanic system separate from Haleakala, are incised by deep amphitheater-headed valleys (Stearns 1966). Puu Kukui does not rise above the inversion

layer, and very wet ohia rainforest covers most of the study area (Fig. 35). The many ridges, gulches, and bogs in the study area result in a variable canopy cover (Fig. 36).

We recorded no koa, mamane, or naio on West Maui. Forests of introduced trees, sugar cane fields, disturbed dry scrub, and pineapple fields border the area below. Bogs occur on Puu Kukui, its subsidiary ridges, and Eke Crater. Although West Maui has lost all except three native passerines common in historic times, evidence suggests the avifauna was originally as rich as on East Maui.

#### MOLOKAI

The Molokai study area is located in the forests on the eastern half of the island (Figs. 10 and 37). The area covers 131 km<sup>2</sup> and extends from 250 m to the highest peak, Kamakou, 1515 m elevation. East Molokai consists of eroded lava flows that slope southward and are bounded by sheer seacliffs along the northern shore; these cliffs are punctuated by deep amphitheater-headed canyons. An interior plateau, Olokui, is bounded by cliffs on all sides and is virtually inaccessible to feral ungulates. Molokai does not rise above the inversion layer, and windward areas support rainforest. A rainshadow occurs toward the southwest part of the study area, where mature dry forest remnants occur (Table 2). Naio, mamane, and koa are restricted to this area. Conifers and eucalyptus are common in the western half of the study area. Guava and other introduced trees are common in Pelekunu and Wailau Valleys (Fig. 38), but *passiflora* was found only in Wai-

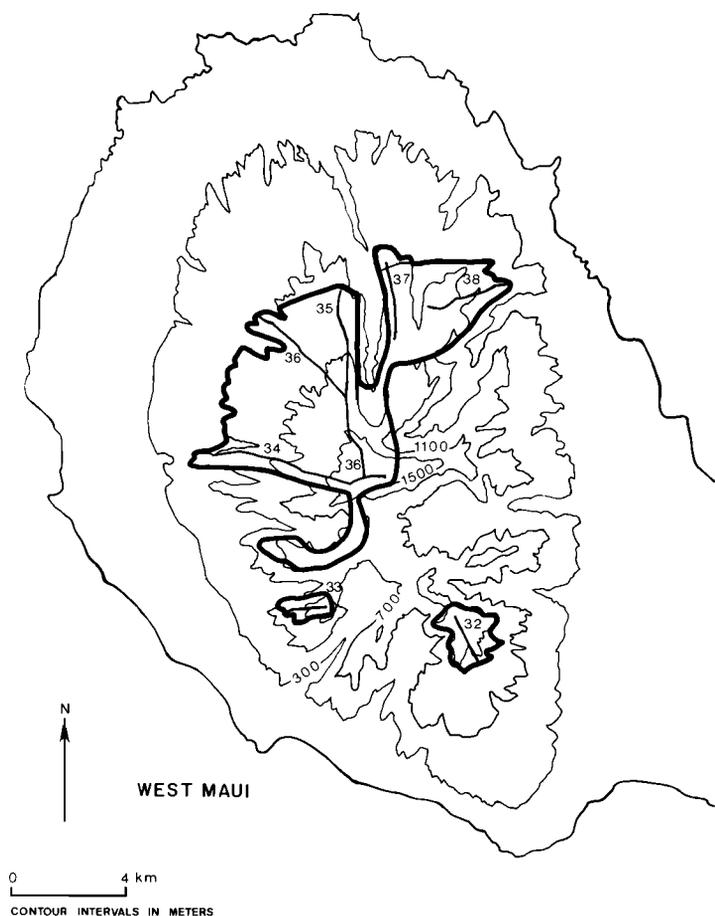


FIGURE 34. Transect locations in the West Maui study area.

lau. Canopy cover in the study area is most open in the southwest and in the east (Fig. 39), where axis deer, feral pigs, and cattle have completely devastated large forest tracts. Many bird species have been lost in historic time, including the Bishop's Oo, Black Mamo, Crested Honeycreeper, and perhaps the Molokai Creeper.

#### LANAI

The Lanai study area is situated on the slopes of the high north caldera rim (Figs. 10 and 40) where a small remnant of native forest occurs (Fig. 41). The study area covers 20 km<sup>2</sup> and extends from 300 m to the highest peak, Lanaihale, 1027 m elevation. The crest of the caldera has wet forest due to fog interception (Blumenstock and Price 1967) and a weak trade wind effect, but the forest sharply grades into arid habitat at lower elevations. No significant amounts of koa, naio, mamane, tree ferns, ieie, passiflora, or native grasses were recorded. Canopy cover on Lanai (Fig. 42) has been greatly influenced by past land use practices and the impacts of cattle, goats, deer, and sheep, although the low cover on Lanaihale corresponds to an intact

native shrub community. All native passerines are extinct except the Aupane and possibly the Common Amakihi.

#### KAUAI

The Kauai study area is located in the Alakai Swamp region, a high montane plateau dissected by numerous valleys and bordered by sheer canyons (Figs. 11 and 43). The area covers 25 km<sup>2</sup> and extends from 1000 to 1500 m elevation. Mount Waialeale, elevation 1569 m, lies 1 km east of the study area and has the highest mean annual precipitation on earth, exceeding 1500 cm in some years. The study area vegetation consists of very wet, dense ohia forest, and includes few introduced species. Ohia is the only forest type within the study area, although bogs are scattered throughout and a large area of mesic koa-ohia forest occurs northwest of the study area. The canopy cover in the study area is dense (Fig. 44). No koa, naio, mamane, introduced trees, or passiflora were recorded. All 10 bird forms endemic to Kauai occur in the study area, but the Kauai Akialoa may have become extinct since the last sighting in 1965 (Berger 1981, Sincovick et al. 1984).