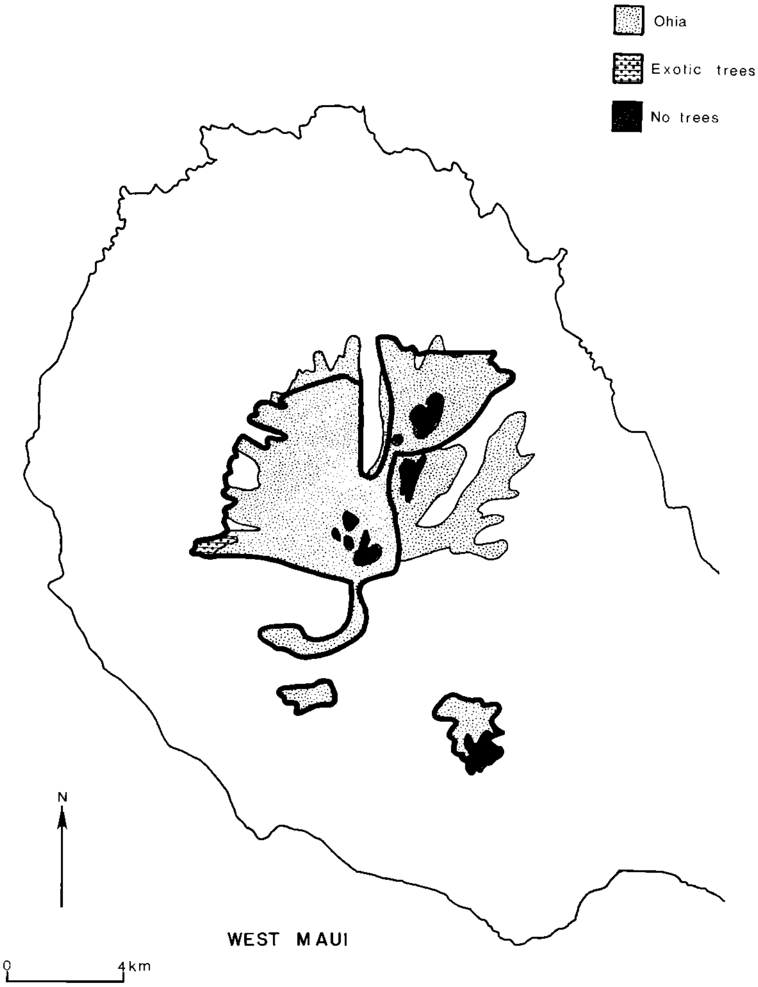

FIGURE 35. Habitat types in the West Maui study area.

FIELD METHODOLOGY

Establishment of Transects

A survey of the scope required to sample all Hawaiian forest bird habitat has never been attempted (Scott, Jacobi, and Ramsey 1981). The analysis presented in this monograph is based on 9940 stations surveyed during 20,789 count periods that recorded over 240,000 birds of 57 species across 4114 km^2 in 12 study areas on 5 islands (Tables 3, 4). Except for the Mauna Kea study area, we chose May–August as our sampling period because it provided reasonably fair weather, birds were conspicuous and vocal, and we were assured of a supply of experienced birders. We selected areas small enough so that they could be surveyed in three months. Our survey of the Mauna Kea study area was designed to maximize efficiency in determining densities of Palila (Scott et al. 1984).

Variation of bird behavior and plant phenology within a season was considered minor in comparison with geographic variation within a study area. The boundaries of each study area were determined from our knowledge of the distribution of native vegetation. The upper elevational limits for the study areas were determined by tree line or the highest point on the island. Lower and lateral boundaries were imposed by such factors as agricultural development, urbanization, or other habitat discontinuities. Because the forests of windward Hawaii were too extensive to survey in a single season, we surveyed the low elevation forest southeast of Route 11, the belt highway (Puna study area) and the dry forest west of Kilauea Crater (Kipukas study area) separately from the main block of generally wet forest that extended from Kilauea Crater to the northeast slopes of Mauna Kea (Hamakua study area).

The map locations of the initial transect in each study area were determined randomly and subsequent transects were systematically placed 1.6 or 3.2 km apart

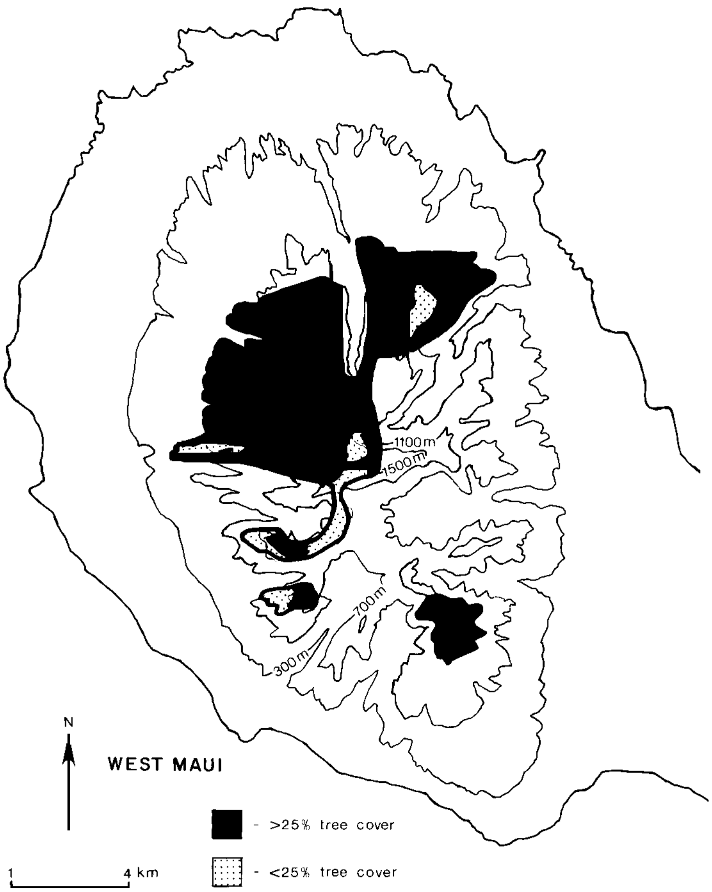

FIGURE 36. Canopy cover in the West Maui study area.

perpendicular to elevational contours. We deviated from this design only on Kauai and Mauna Kea where all transects were randomly located within the known distributional area of endangered species. The distance between transects was 1.6 km in areas where birds were known to have very localized distributions. Transect field locations were placed as close as possible to actual map positions. Two- and three-person teams laid the transects and established sampling stations using measuring tapes and compasses (for details see Ramsey et al. 1979 or Scott, Jacobi, and Ramsey 1981). We placed stations 100 m apart in Kau, 200 m apart on Mauna Kea, 250 m apart on Lanai, and 134 m apart in all other study areas (Table 3). The distance in Kau was based on preliminary estimates of effective detection distances. We increased the station distance to 134 m after analyzing the 1976 data. The greater distances on Mauna Kea and Lanai reflected the more open habitat in these areas. Stations were marked with numbered metal tags and flagging tape. Additional flagging was placed 9 and 18 m before and after each station. These flags alerted team members to an approaching station and were frequently used in calibrating distance estimates. The distance between stations was approximately twice the effective detection distance of the Omao, one of the most vocally conspicuous passerines, in order to provide a high degree of statistical independence among stations.

Observer Training

Ornithologists

We developed a training program to reduce variation among field ornithologists in their ability to detect and identify birds (Kepler and Scott 1981). In 1976 field workers were selected for their familiarity with Hawaiian birds: all but one had two or more years of experience. The least experienced individual underwent rigorous training prior to the survey. All observers spent one week immediately preceding the survey reviewing the forest birds that were more difficult to identify. We gave particular attention to the Hawaii Creeper, whose accurate identification had presented problems for years (Scott et al. 1979). In subsequent years we selected observers based on general birding experience, motivation, temperament, academic background, and physical condition. These ornithologists took part in two to three weeks of training that involved laboratory

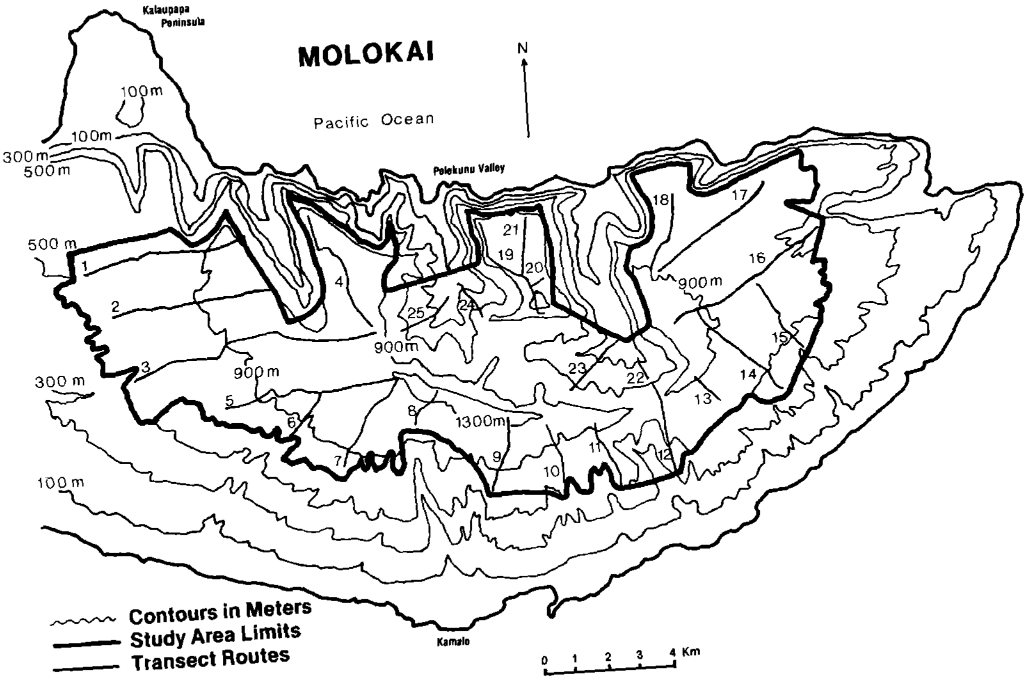

FIGURE 37. Transect locations in the Molokai study area.

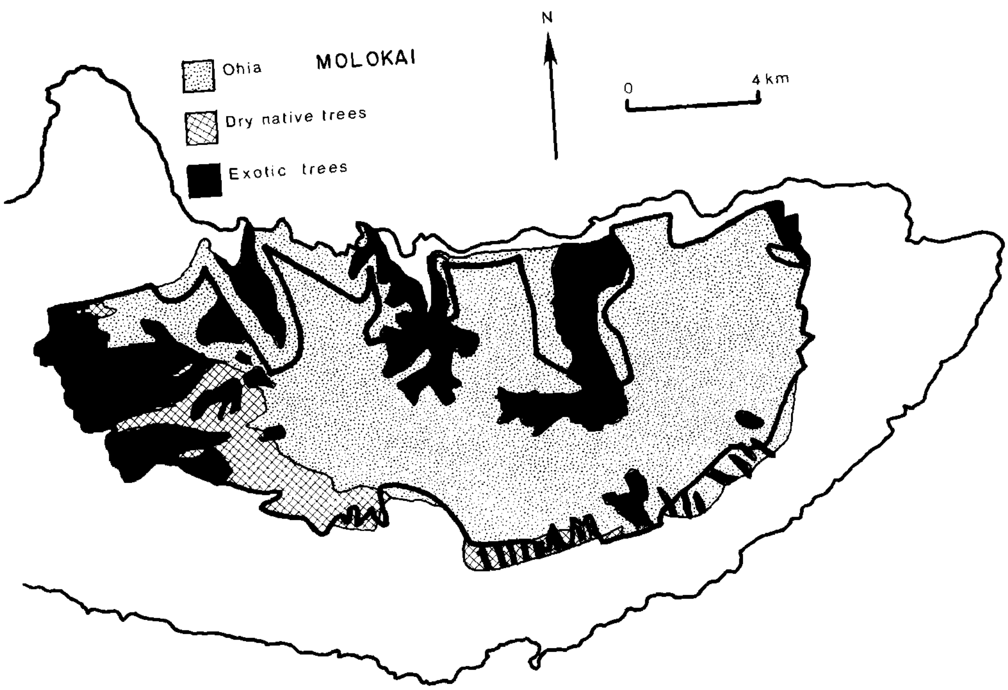

FIGURE 38. Habitat types in the Molokai study area.

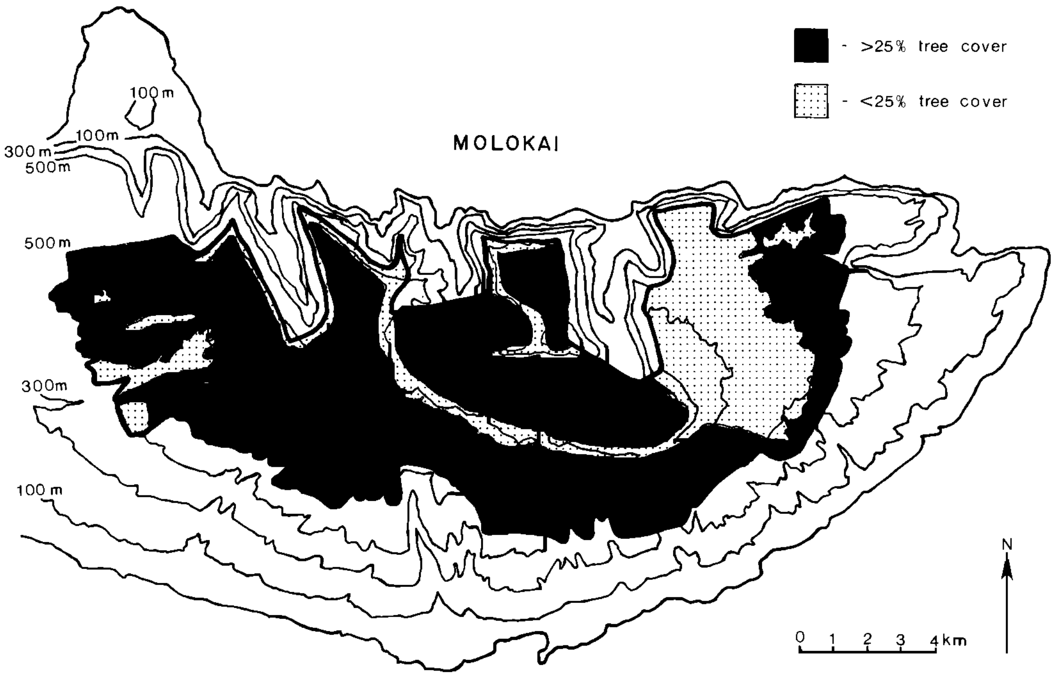

FIGURE 39. Canopy cover in the Molokai study area.

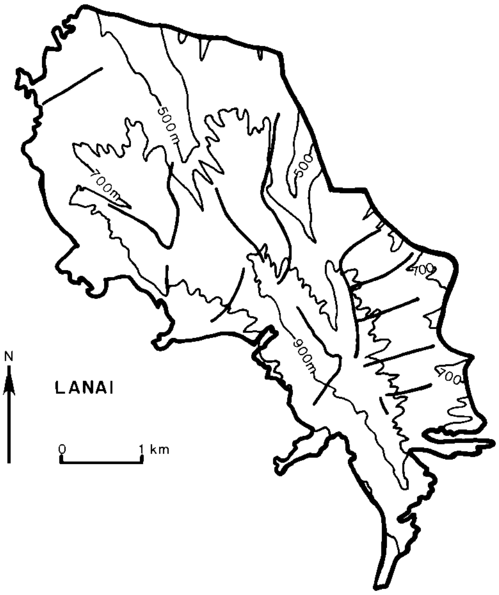

FIGURE 40. Transect segments in the Lanai study area.

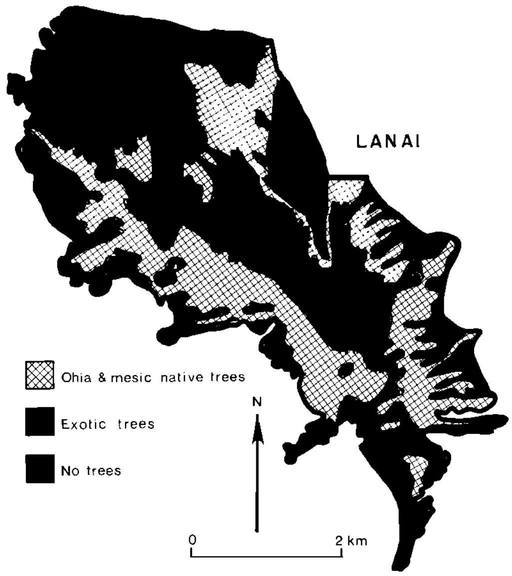

FIGURE 41. Habitat types in the Lanai study area.

TABLE 3
HAWAIIAN FOREST BIRD SURVEY STUDY AREAS

Study area	Survey dates	Distance between transects (km)	Length (km) of transects	No. of stations	No. of count periods	Distance between stations (m)	Observer sequences[a]
Kau	6/22/76–7/23/76	3.2	93	871	1742	100	1
Hamakua	6/18/77–9/1/77	3.2	357	2478	5598	134	2
Puna	5/17/79–6/14/79	3.2	90	669	1338	134	2
Kipukas	5/17/79–8/10/79	3.2	62	460	920	134	2
Kona	5/24/78–7/26/78	3.2	382	2847	5694	134	2
Mauna Kea	2/25/83–3/4/83	random placement, minimum 500 m	65	317	378	150	3
Kohala	7/28/79–8/9/79	3.2	29	215	430	134	2
East Maui	5/22/80–8/17/80	1.6 and 3.2	148	1104	2208	134	4
West Maui	7/27/80–8/21/80	1.6	26	194	388	134	4
Molokai	7/9/79–7/21/79; 8/2/80–8/8/80	1.6	76	568	1136	134	2 and 4
Lanai	5/2/79–5/10/79	N/A	10	77	154	250	2
Kauai	5/12/81–5/24/81	random placement, minimum 500 m	63	140	803	134	2 and 5
Totals			1401	9940	20,789		

[a] Observer sequence codes: 1 = second observer followed first with 5–15 min. delay; 2 = second observer followed first with 10–15 min delay; 3 = single observer 6 min. count period; 4 = specialists and generalists, 18 m apart; and 5 = 18 m apart and back to back.

training, simultaneous counts, pairing with experienced observers, and distance estimation (Kepler and Scott 1981; Scott, Ramsey, and Kepler 1981). The training program became more efficient and thorough with each passing year.

We tested all observers for hearing ability; all but two observers the first year and one in subsequent years met the criteria of Emlen and DeJong (1981) and Ramsey and Scott (1981b). Those with slightly impaired hearing were among the most experienced observers.

Thirty-four observers participated in the HFBS and individuals remained with the program from one to six years. The number of individuals participating in any given year ranged from six to twelve.

Ornithologists carried all their food and equipment in packs when working down a transect (Fig. 45) and remained in the forest until a transect was completed. This ordinarily took five to six days, but one transect took twelve days. Birds were counted only during periods of good weather when the wind registered no more than 4 on the Beaufort Scale (21 km/hr) and there was no appreciable noise from rain or water dripping from vegetation.

Botanists

As with the ornithologists, botanists underwent training prior to each field season. During training, emphasis was placed on calibrating plant cover, phenology categories, and height estimates. Field note formats were standardized to facilitate data transcription.

BIRD SAMPLING

We conducted bird counts during a four-hour sampling period (05:15–09:15 HST). The period was extended one hour on Maui where rainy weather often prevailed, but birders were not required to count for more than four hours.

The sampling period represented a compromise among the vocal conspicuousness of several bird species. As an example, Omao were more conspicuous during the first two daylight hours, whereas Akepa and other species were more conspicuous in the second half of the period. To compensate for this, observers spent four hours after the sampling period looking for endangered birds, observing their behavior, and recording the locations of species not found earlier in the day.

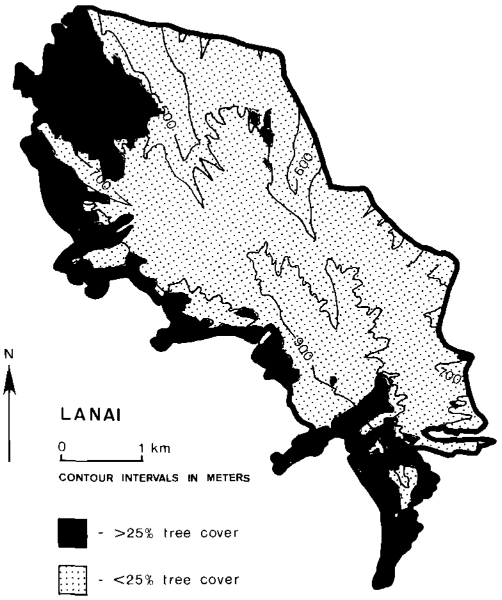

FIGURE 42. Canopy cover in the Lanai study area.

These data were used in determining species ranges and in constructing habitat response graphs.

Observers worked in pairs during the actual survey work. This permitted comparisons between observers and was necessary for safety reasons due to extremely hazardous terrain and volcanic activity in the Puna District of Hawaii. Ornithologists alternated daily being first down a transect. Results of studies of observer variability and sequence effects will be presented elsewhere.

The variable circular-plot method was used to record the occurrence of birds (Reynolds et al. 1980). All birds heard or seen during a count period were recorded as being an aural, visual, or combined detection. The estimated distance to each bird when it was first detected was also recorded. Birds judged not to be utilizing the area surveyed (e.g., flying high over the area) were not recorded (Reynolds et al. 1980). In test conditions, the variable circular-plot method compared in accuracy with spot-map and transect techniques (Anderson and Ohmart 1981, DeSante 1981, Edwards et al. 1981, Szaro and Jakle 1982).

We selected eight minutes as our count period. This period was short enough that our assumption of an instantaneous count was not seriously violated but still long enough to allow an observer to accurately record all birds observed (Scott and Ramsey 1981a).

We used three different sampling designs to avoid

TABLE 4
NUMBER OF STATIONS SAMPLED BY ELEVATION, HABITAT, AND STUDY AREA

	Kau	Hamakua	Puna	Kipukas	Kona	Mauna Kea	Kohala	East Maui	West Maui	Molokai	Lanai	Kauai
Elevational strata												
100–300 m	...	...	...	...	...	...	...	...	...	12	...	...
300–500 m	...	25	138	...	18	...	4	13	...	44	...	...
500–700 m	5	205	189	...	171	...	14	58	18	96	10	...
700–900 m	66	383	181	...	335	...	20	112	53	149	41	...
900–1100 m	135	428	134	...	322	...	42	147	39	150	26	...
1100–1300 m	155	449	26	28	402	...	66	148	44	105	...	75
1300–1500 m	158	423	...	72	565	...	55	126	20	17	...	65
1500–1700 m	142	300	...	94	448	...	14	114	18	...	...	...
1700–1900 m	136	161	...	109	266	...	...	111	11	...	...	...
1900–2100 m	66	54	...	148	198	43	...	121	...	...	...	...
2100–2300 m	4	5	...	33	117	39	...	97	...	...	...	...
2300–2500 m	...	...	...	...	24	74	...	38	...	...	...	...
2500–2700 m	...	...	...	...	...	85	...	10	...	...	...	...
2700–2900 m	...	...	...	...	...	65	...	2	...	...	...	...
2900–3100 m	...	...	...	...	...	11	...	...	...	...	...	...
Habitat types												
Ohia	610	1295	642	294	1593	...	204	532	183	424	...	139
Koa-ohia	257	925	...	74	652	...	...	158	...	...	...	...
Koa-mamane	...	32	...	82	209	...	...	...	...	...	...	...
Mamane-naio	...	...	...	...	27	163	...	...	...	...	...	...
Mamane	...	...	...	...	195	154	...	7	...	...	...	...
Other natives	...	45	...	30	62	...	...	127	...	45	16	...
Intro. trees	...	126	...	...	89	...	11	88	2	99	54	...
Treeless	...	10	26	4	39	...	...	185	18	5	7	1

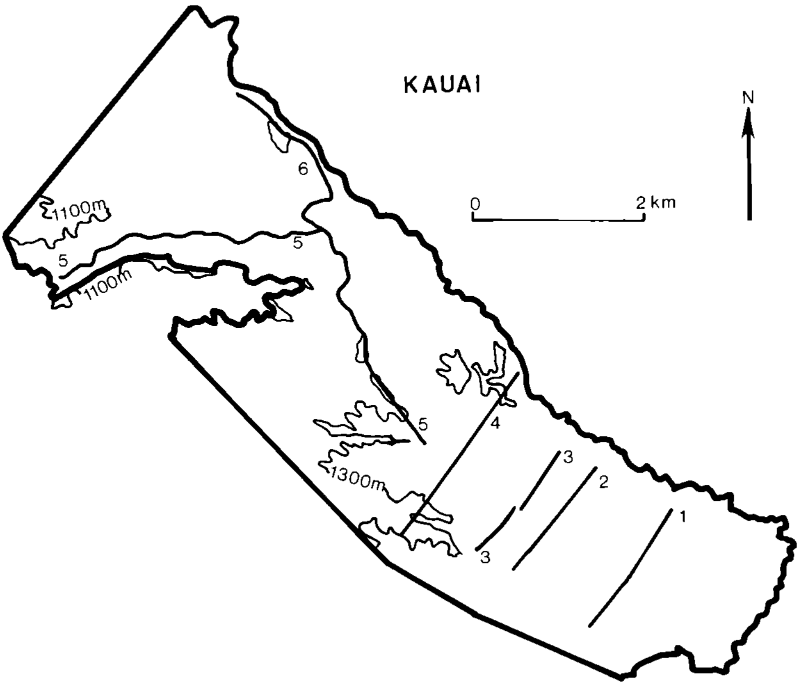

FIGURE 43. Transect locations in the Kauai study area.

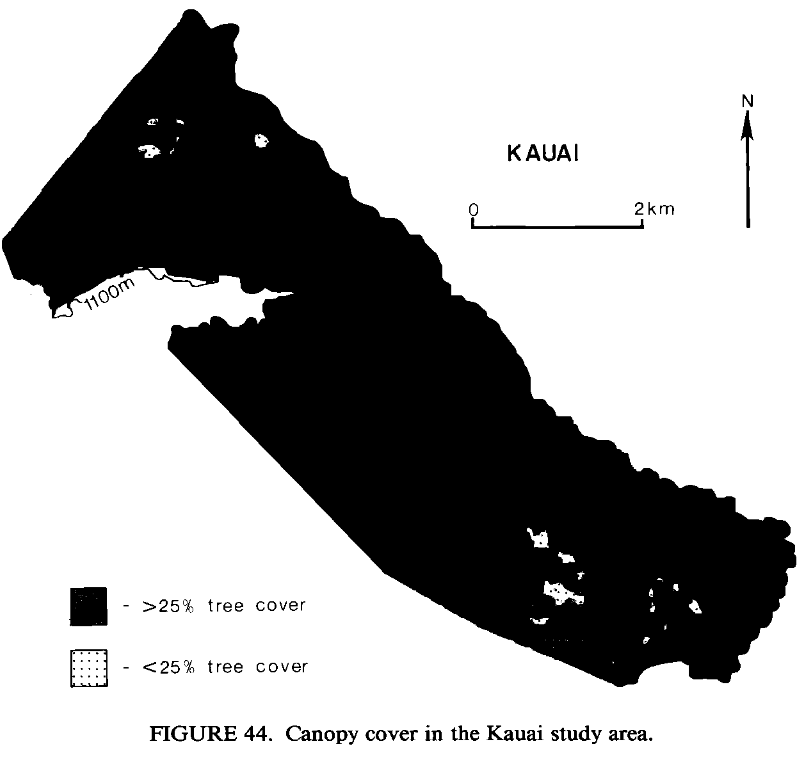

FIGURE 44. Canopy cover in the Kauai study area.

FIGURE 45. Observer at top of transect prepared for ten-day bout in the rainforest in Hamakua study area. Note dense matted fern vegetation. (Photograph by C. B. Kepler)

bias resulting from sequence effects, observer boredom, or observers that were overwhelmed by the number of birds (Scott and Ramsey 1981b): (1) two observers separated by 5–15 min, observers recording all birds observed on all stations; (2) observers placed 9 m before and 9 m after a station, recording simultaneously, and comparing species lists and numbers at the conclusion of counts but making no changes on the data sheets; and (3) observers as in 2, but each observer recording all of the species except one of the two most common species. In all three designs observers counted birds independently of each other (Scott and Ramsey 1981b).

VEGETATION SAMPLING

Botanical survey

We sampled the vegetation in each study area to determine the habitat requirements of the bird species and the factors that affected the distribution and stability of their habitats.

The vegetation was described in three ways. First, detailed descriptions of the vegetation and habitat features were made at each station. Then, at irregular intervals, the vegetation structure and floristic composition were described in intensive detail. Finally, detailed vegetation maps were prepared for each study area.

Field vegetation sampling was done by two-person teams. Vegetation structure was usually sampled at each station within two weeks of the date that bird populations were censused to minimize temporal change in vegetation structure, particularly in flowering and fruiting phenology. Botanists quantified vegetation structure within an estimated 50 m of the station. Since the botanical teams were not limited to a four-hour sampling period, they covered about twice as many stations daily as the bird survey teams. A ratio of one botanical team to two bird survey teams was therefore ideal for this survey.

Detailed habitat description

A habitat description format was developed for the survey, which allowed a rapid, detailed, and consistent assessment of the major habitat features in the field. Habitat information recorded along the transects included (1) general description of the vegetation type;

FIGURE 46. Ecotone between wet ohia forest and mesic native subalpine scrub dominated by *Sadleria, Vaccinium, Styphelia,* and *Coprosma* at 2100–2200 m elevation on East Maui. Note isolated patches of alpine *Deschampsia* grassland, steepness of terrain, and cloud formation marking inversion layer. Entire range of Poo-uli lies in back and to the right of oval-shaped grassy area. (Photograph by T. L. C. Casey)

FIGURE 47. Dry ohia woodland with native shrub understory at 1500 m elevation near Puu Lehua, Hawaii, with Hualalai in the background. (Photograph by C. B. Kepler)

FIGURE 48. Aerial view of kipukas of mesic ohia forest surrounded by dry ohia scrub pioneering 1852 lava flow from Mauna Loa in background. (Photograph by W. E. Banko)

FIGURE 49. Dry mamane woodland with patchy introduced grass understory at 2400 m elevation on south slope of Mauna Kea. (Photograph by J. D. Jacobi)

FIGURE 50. Closed canopy ohia rainforest with olapa, *Vaccinium,* and *Dubautia* understory at 2000 m elevation along [Lake] Wai Ele'ele on East Maui. (Photograph by J. D. Jacobi)

(2) phenological data for selected plant species; (3) a detailed description of the vegetation structure and floristic composition at selected stations; (4) estimates of maximum, minimum, and modal tree diameter at selected stations; (5) tree stand vigor; (6) occurrence of aggressive weedy plant species; (7) signs of feral ungulate presence and damage to the vegetation; and (8) substrate type.

The vegetation type description included categories for tree crown cover, tree height, tree species composition, and ground cover or understory type (Jacobi 1978). Crown cover was estimated in the following classes: closed canopy (> 60% cover), open canopy (25–60% cover), scattered trees (5–25% cover), and very scattered trees (< 5% cover, trees widely spaced). Tree canopy height was estimated in three classes: tall stature (> 10 m), medium stature (5–10 m), and low stature (2–5 m). When the canopy was distinctly multi-layered, the cover, height, and species composition were noted separately for individual stories.

Vegetation structure and floristic composition were sampled at irregular intervals along the transects using the relevé method (Mueller-Dombois and Ellenberg 1974). Sampling points were taken at the start of each transect and additionally wherever a major change in the vegetation occurred. Total plant cover was estimated to the nearest 10% for all recognizable vegetation layers: ground cover (0–0.5 m), small shrubs (0.5–2 m), tall shrubs (2–5 m), small or sub-canopy trees (5–10 m), and tall trees (> 10 m). Additionally, all species within a vegetation layer were listed and their cover rated, using a modification of the Braun-Blanquet (1932) cover-abundance scale. Although our method was based on estimation rather than actual measurement, semi-quantitative methods have sufficient accuracy and far greater efficiency compared with more detailed measurements for characterizing vegetation profiles (Braun-Blanquet 1932, Moore et al. 1970, Mueller-Dombois and Ellenberg 1974, Barbour et al. 1980) and are effective in analyzing avian habitat response (Sabo 1980).

Vegetation mapping

Vegetation maps of the study area were prepared in order to relate the bird survey information to the distribution of plant communities. Vegetation map units described the vegetation in a similar but less detailed

FIGURE 51. Dieback of wet ohia forest showing tree fern understory on east slope of Mauna Loa in Hamakua study area. (Photograph by J. D. Jacobi)

FIGURE 52. Remnant dry forest dominated by koa, ohia, mamane, and sandalwood, confined to vicinity of gulch, and surrounded by open eroded pasture at 1400 m elevation on Kahikinui Tract of East Maui. Area formerly inhabited by Maui Parrotbill, Nukupuu, and Akepa. (Photograph by J. D. Jacobi)

FIGURE 53. Mesic koa-ohia forest in Waikamoi Preserve, East Maui, at 1600 m elevation. This forest was more extensive 100 years ago and harbored Ou, Maui Parrotbill, and Nukupuu. The Ou is now extinct on Maui. (Photograph by C. B. Kepler)

manner than field descriptions along transects. Moisture regime, tree canopy cover, tree height, tree species composition, and ground cover type were distinguished.

The distributions of the vegetation units were initially interpreted on aerial photographs at the approximate scale of 1:45,000 using a mirror stereoscope with 3× and 6× magnification. These preliminary map units were then verified on the ground during the field season by the botanical teams. An overview of the area from a small airplane or helicopter helped resolve interpretation problems in areas not covered on the ground. Finally, the corrected map unit boundaries from the aerial photographs were compiled on a U.S. Geological Survey 7.5′ quadrangle topographic map base using a Kern PG-2 plotter.

Vegetation map units were the foundation for the habitat response graphs and for determining areas within the range of a species. From the vegetation map units we also constructed eight general habitat types reflecting dominant tree species (ohia, koa-ohia, koa-mamane, mamane, mamane-naio, other native trees, introduced trees, treeless; see Figs. 46–60) for use in stratifying population estimates.

Phenology

We determined the flowering and fruiting phenology for three tree species that were important sources of food for native birds: ohia, olapa, and mamane (Perkins 1903). The 10 trees of each species nearest to the sampling station were scored on a 0–4 scale for the presence of flowers (ohia, mamane) or fruit (olapa, mamane) as follows: 0 = none; 1 = <1% of crown covered; 2 = 1–5% covered; 3 = 5–25% covered; 4 = >25% covered. On Mauna Kea we also determined the phenology of naio fruit.

Insect Observations

Stations were baited and visual searches made for the carnivorous ant *Pheidole megacephala* at each camp site on Hawaii (approximately every 15th station), because this species may compete for food with insectivorous birds (Perkins 1903, Banko and Banko 1976). During the 1976 survey, light traps and casual obser-

FIGURE 54. Dry lama-ohia woodland with understory completely dominated by fire-adapted fountain grass at 1000 m elevation near Puu Waawaa, Hawaii. Hawaiian Crow formerly bred in this area. (Photograph by J. D. Jacobi)

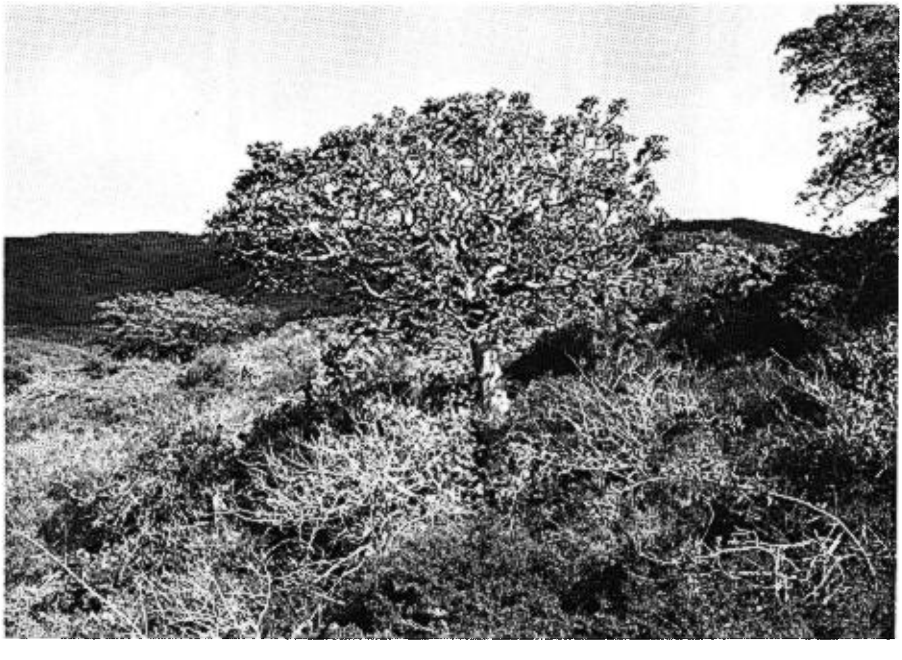

FIGURE 55. Remnant arid *Erythrina-Reynoldsia* woodland at 150 m elevation, Ulupalakua area, East Maui. Once extensive before Polynesian and western disturbance, woodlands like this one hosted over a dozen species of extinct honeycreepers. (Photograph by C. B. Kepler)

FIGURE 56. Greensword (*Argyroxiphium virescens*, Compositae) bog with native sedges surrounded by ohia rainforest at 1650 m elevation on East Maui. (Photograph by C. B. Kepler)

FIGURE 57. Alpine *Deschampsia* grassland with admixture of introduced grass (*Holcus lanatus*) and native shrubs on ridge at 2300 m elevation on windward East Maui. (Photograph by C. B. Kepler)

FIGURE 58. Remnant woodland on the Auwahi Tract, an area at 1200 m elevation on East Maui with an exceptionally rich assemblage of xerophytic species. Arborescent monocot in foreground is halapepe (*Dracaena aurea*). (Photograph by R. Hobdy)

vation at campsites were used to document the occurrence of *Culex quinquefasciatus* and other mosquito species. We used only casual observations at campsites in subsequent years.

DATA ANALYSIS

Estimation of Effective Area Surveyed

Bird densities were determined from the field data using "plotless" or "variable area" survey procedures, where estimation of the area surveyed poses a statistical problem. The theory of variable area techniques originated with studies of line transect surveys (Emlen 1971, Seber 1973, Burnham and Anderson 1976, Ramsey 1979), and was extended to more general survey methods (Ramsey et al. 1979, Ramsey and Scott 1981a), including the variable circular-plot method (Reynolds et al. 1980). Ramsey and Scott (1979, 1981a) outlined the methods to obtain smoothed estimates.

Raw estimates of effective area

Each station was assigned to one of 13 detectability classes (Table 5) based on canopy and understory conditions that affected visibility. Twelve of these classes represented the factorial combinations of crown cover (closed, open, scattered), canopy height (tall, short), and understory (closed, open); class 13 designated treeless stations. Detections were grouped into data cells by species, observer, detectability class, and study area.

Detection distances D were converted to the area X that was searched to obtain that detection as $X = \pi D^2$. Detection areas in each cell were arranged in order of increasing magnitude from 1 to N and then used to construct a cumulative distribution curve (Fig. 61). A line from any point P_1 at (x_1, y_1) to another point P_2 at (x_2, y_2) on the cumulative distribution function has slope equal to the density of detections in area (see Ramsey and Scott 1981a). We constructed the convex envelope of the cumulative distribution function by drawing a straight line from the origin (0, 0) to the point P_1 at (x_1, y_1) that gave the greatest slope of all

TABLE 5
Adjustment Factors for the Effects of Habitat Configuration on Effective Area

Detectability class	Multiplicative factor
Closed canopy (>60% cover)	
Open understory, height >10 m	1.00
Open understory, height 2–10 m	1.46
Closed understory, height >10 m	0.87
Closed understory, height 2–10 m	0.98
Open canopy (20–60% cover)	
Open understory, height >10 m	1.24
Open understory, height 2–10 m	1.89
Closed understory, height >10 m	1.02
Closed understory, height 2–10 m	1.10
Scattered canopy (<20% cover)	
Open understory, height >10 m	1.84
Open understory, height 2–10 m	3.38
Closed understory, height >10 m	0.85
Closed understory, height 2–10 m	1.16
Treeless	6.79