(*Oxychilus alliarius*) suspected of preying on native snails, is abundant within the range of the Poo-uli, and may contribute to the declining numbers of that species. Data are presently too meager to assess fully the impacts of introduced invertebrates on the native biota, but effects include reduction not only of native invertebrate populations by predators and parasites (thereby seriously depleting the food resources of native birds), but also of native plant populations by herbivores, pathogens, and pathogen vectors (Howarth 1985). Although biomass trends of canopy arthropods along an elevational transect in Hawaii Volcanoes National Park (Gagné 1979) show little resemblance to elevational trends in native bird density (particularly in the drop-off below 1300 m elevation), more extensive studies are needed on the diets of native birds and the impact of introduced species on resource levels. The most cost-effective strategy to reduce problems caused by introduced invertebrates is (1) prevention of further introductions by strengthening quarantine procedures, (2) fumigation of imported biological material (e.g., Christmas trees, cut flowers), and (3) improvement of the surveillance of importations (Howarth 1985). Minimizing disturbances of native ecosystems (e.g., land clearing, grazing, pig rooting, invading weeds) that favor introduced invertebrates will also lessen their impact.

Disasters

Usually enough individuals survive hurricanes and heavy storms to perpetuate the population, but unfavorable events are potentially important when populations are extremely low. Laysan Island, 1500 km northwest of Honolulu, originally supported an endemic subspecies of Apapane, the Laysan Honeycreeper (*Himatione sanguinea freethii*). Laysan Honeycreepers frequented tall grass and low bushes (Fisher 1906). Unfortunately, rabbits were introduced in 1903 and by 1911 had destroyed most of the vegetation (Dill and Bryan 1912). By 1923 the rabbits had removed the last vestiges of vegetation, and members of the 1923 Tanager Expedition found only three Laysan Honeycreepers. These birds "perished during a three-day gale that enveloped everything in a cloud of swirling sand" (Wetmore 1925).

A severe tropical storm is thought to have been responsible for eliminating the Puerto Rican Bullfinch (*Loxigilla portoricensis grandis*) from the island of St. Kitts (Raffaele 1977). Cataclysmic storms could adversely affect other precariously low populations. Particularly vulnerable are those species having very small ranges. Broadside hits on the Alakai Swamp or the northeast slope of Haleakala could eliminate several species.

The island of Hawaii is the site of frequent volcanic eruptions and massive lava flows moving from volcano summits to the ocean. These flows are as wide as 1 km, destroy large tracts of native forest, and fragment the range of forest birds (see Fig. 48). Presently the greatest threat may be to nesting areas of the Hawaiian Crow; the 1984 Mauna Loa lava flow covered part of the area where Ou were most numerous in the 1977 survey. It has been 200 years since an eruption on Maui, but renewed eruptions are possible; the small range of Poo-uli could be demolished by a major eruption along the east rift zone of Haleakala, but this is quite unlikely. Fires resulting from volcanic activity are an additional threat in dry and mesic habitats.

CONSERVATION

History of Human Disturbance

The recent history of the Hawaiian biota may be divided into three cultural periods: the pristine period before Polynesian contact (ca. 400 A.D.); the Polynesian period before Western contact (1778); and the modern period to the present. The series of changes that Polynesians initiated drastically altered pristine ecosystems that had evolved in isolation for millions of years and were in fact older than the main islands themselves. The main Hawaiian islands are geologically young (0–6 million years) and transient, formed in succession as the Pacific Plate slowly slides northwest over a hot spot in the earth's mantle. In 8 to 10 million years, each island in turn moves over and past the hot spot to erode away, while the native birds colonize new islands emerging to the southeast. From Kure Atoll in the Northwestern Hawaiian Islands, a line of seamounts continues north until subducted near the Aleutians, with the northernmost over 70 million years old. Based on DNA hybridization studies, Sibley and Ahlquist (1982) inferred that the ancestral Hawaiian honeycreeper may have colonized the archipelago 15–20 million years ago on forested high islands that have since become low islands or seamounts. Thus the fauna and flora that Polynesians found on the young main islands may have had their origins back millions of years on now submerged islands. Existing in isolation for eons, free of many stresses faced by their continental ancestors, many species lost their defensive biochemistry, morphology, and behavior. Plants lost their alkaloids and thorns (Carlquist 1970), birds lost some of the immunity they had to disease, some birds became flightless (James and Olson 1983), and many insects lost their wings altogether (Zimmerman

1948). These species, successful in isolation, became increasingly vulnerable to alien influences poised around them on the Pacific rim and on islands to the south.

The Polynesian colonists brought with them a collection of plants and animals. Most of the plants, such as bananas, coconuts, taro, and yams, were food crops for their own consumption, but inadvertent introductions include weedy species such as *Ludwigia octivalvis, Oxalis corniculata, Urena lobata, Thelypteris interrupta, Waltheria americana, Merremia aegyptia* (Kirch 1982), and perhaps *Ipomoea congesta.* They also brought domestic animals such as dogs, pigs, and junglefowl, and such anthropophilic stowaways as the Polynesian rat, a gecko, a skink, and several snails. Most importantly, they transported with them a concept of landscape that would radically transform the pristine ecosystems into facsimiles of those of their home islands (Rappaport 1963, Kirch 1982). One of their tools was fire (Barrau 1961), and soon "the process of conversion of a natural ecosystem into an actively manipulated cultural landscape" began (Kirch 1982).

Archaeological evidence from dated village sites shows that the Hawaiian populations grew slowly for the first 600 years, then rose rapidly to a peak of over 200,000 people by about 1650 A.D. (Kirch 1982). This translates to an average density of about 22 people/km^2 in the habitable parts of the islands, and about 250 people/km^2 in heavily settled areas such as Halawa Valley on Molokai. All the islands except Oahu were more densely and uniformly settled than they are now! By the time of Western contact, populations were lower, and Kirch (1982) suggests the decline resulted from habitat destruction and a "consequent reduction in carrying capacity." The evidence for habitat destruction is compelling. Early explorers clearly described the lack of forest cover on the dry sides of all the islands, and descriptions such as "destitute," applied to Kahoolawe by missionary William Ellis (1827), were appropriate to much of Maui, Oahu, and Kauai as well. Extensive lowland grasslands in many areas were obviously anthropogenic; ash-laden soil underlying them has revealed fossil snails and birds that inhabited a pre-existing xeric forest (Kirch 1982, Olson and James 1982b). Interred with these materials are the bones of geckos and skinks that suddenly appeared on the islands with the Polynesian settlers. In many cases erosion was severe; Kirch (1982) reports finding buried irrigation systems and large alluvial basins of sediment interbedded with ash.

The dryland forests that succumbed to Polynesian fires may have been the richest terrestrial ecosystem in the islands. Rock (1913) estimates that 60% of all Hawaiian plants occurred there. More than 45 fossil bird species found by James and Olson (1983) were dryland species. These birds included at least 15 drepanidines, 35% of the known species in the subfamily. At least 11 additional species described in historic times also occurred in dry forests. Five of these are now extinct, suggesting that birds such as the Palila, Greater Koa-Finch, Lesser Koa-Finch, and Kona Grosbeak may have been represented by relictual populations, possibly in marginal habitat, in mid- and upper-elevation dry-forest refugia when discovered by Westerners.

Damage to the mesic and wet Hawaiian forests was far less severe and restricted to their lower elevations, particularly the broader, more habitable valleys. The limited distribution of the Greater Amakihi above the upper level of Hawaiian cultivation on windward Hawaii may have resulted from habitat destruction in this area.

Walls around yam and taro patches on leeward Hawaii indicate that pigs occurred up to 1000 m elevation, and perhaps had penetrated even higher forests, although it is thought that Polynesian pigs had little effect upon pristine forest (Warshauer 1980; P. H. McEldowney, unpub. data).

In addition to eliminating most Hawaiian dry forests, Polynesians apparently hunted at least seven species of flightless geese (*Geochen rhuax, Thambetochen* spp.) and two species of flightless ibis (*Apteribis* spp.) to extinction (Olson and James 1982a). Discovery and interpretation of recent fossil findings are only partially complete at this time (S. L. Olson, pers. comm.), emphasizing our incomplete knowledge of the pre-Western periods.

Although Zimmerman (1963) stated that "fires of the early Polynesians swept vast areas of woodland away," such statements had been largely ignored until recently. It was assumed that the ancient Hawaiians were ardent conservationists, and that "extreme increases in instability did not occur until the advent of Western man and his advanced technology and civilization" (Murdock 1963). Carlquist (1970) reinforced these ideas by stating that "during the human occupation of the islands, especially by peoples other than the Polynesians, much dry forest was removed." Although these ideas are common in anthropological and ornithological works on Hawaii (Amadon 1950, Berger 1981), they are strangely at odds with descriptions of the islands by the first explorers. It is through the efforts of Olson and James (1982a, 1982b) and Kirch (1982) that we now know why many areas of the islands were barren when the first Europeans arrived.

When Captain Cook first sighted Kauai on 18 January 1778 he inaugurated the third or Western period in the ecological history of the Hawaiian Islands. After trading for provisions and collecting the type specimen of the Iiwi (Medway 1981), he sailed to Niihau and on 2 February released three goats on the island (Tomich 1969). Although his motives were humanitarian (to provide a new source of protein for the natives) and utilitarian (to ensure meat when ships returned), his understanding of the ecological consequences of his actions was poor indeed. During the Western period an inordinate number of introductions, coupled with commercial exploitation, led to progressively massive retreat and extinction among the native biota. Following introduction, feral ugulates such as cattle, sheep, goats, and pigs multiplied rapidly, and inexorably destroyed huge tracts of native forest by grazing, browsing, trampling or rooting up ground cover, and feeding on tree seedlings and understory plants (Tomich 1969, Kramer 1971, Baker 1979). Cattle in particular grazed what remained of the low-elevation dry forests and penetrated the wet forests; on Mauna Kea and Haleakala large numbers moved into subalpine woodlands and scrublands. The mesic koa forests provided ideal pastureland and were soon drastically reduced on Maui and heavily stressed on Hawaii. Goats rapidly penetrated dry and mesic forests throughout the islands, and European pigs invaded the pristine wet forest except where obstructed by impassable topography.

The forests also suffered from the direct impacts of man. The commercial harvesting of sandalwood began in 1790, and by 1820 the vast preponderance of sandalwood in the islands had been removed (Rock 1913, Judd 1927, A. Kepler 1984). Koa, the co-dominant tree in mesic forests, was rapidly removed to make way for cattle, and a koa timber industry developed on Hawaii that continues to this day. By the end of the 19th century, many of the forests extant when Cook arrived had been destroyed or severely degraded.

Animals were not the only group that became feral. An incredible diversity of foreign plants—now numbering over 4600 species, three times the number of native species (St. John 1973)—were brought to the islands for food, ornamentation, reforestation, or as weeds. About 10% of these introduced plant species have naturalized (St. John 1973), and 2% have become serious pests in native ecosystems, notably strawberry guava, banana poka, lantana, various blackberries and gingers, the melastome *Clidemia hirta,* and numerous grasses (Smith 1985).

The natural predators of native forest birds in pristine conditions included an extinct accipiter, the Hawaiian Hawk, and probably at least three extinct long-legged owls (Olson and James 1982b). The introduction of potential predators of native forest birds began with the Polynesian rat, a known bird predator (Kepler 1967; Atkinson 1973, 1977; Atkinson and Bell 1973). The list of new predators has since grown to include the black rat, Norway rat, mongoose, domestic cat, Common Barn-Owl, and Common Myna.

The Hawaiian Islands have had more bird introductions (162 species) and more exotic species established (45 definitely established, 25 probable) than any other area on earth (Long 1981). It has been suggested that competition for food between native birds and established introduced species has resulted in a decline of native species (Berger 1981, Mountainspring and Scott 1985). Far more importantly, introduced birds brought with them diseases that have probably had a severe impact upon native Hawaiian passerines (Warner 1968, van Riper et al. 1982).

The general trend from the pristine period to the present has thus been a steady retreat of the native biota into the least disturbed upland habitats. Montane rainforest and dry subalpine woodland provide the greatest "biological buffering" for the Hawaiian land birds. In effect, the initial patterns of species occurrence and response in a large hyperspace are destabilized, fragmented, and eroded away by an interminable procession of disturbance elements, much as ocean breakers wear down a headland, leaving the most resistant core community mainly intact. The relatively short history of human occupancy on the Hawaiian Islands has had a devastating impact far more severe than that of long-term human influence in continental tropical areas (Karr 1976b, Pearson 1977). Many endangered species that survive undoubtedly do so as relict populations in areas at the environmental extremes of their original range.

Conservation Strategies

Conservation strategies for individual species have been described in detail in U.S. Fish and Wildlife Service recovery plans for the Hawaiian Goose (Kosaka et al. 1983), Hawaiian Hawk (Griffin 1984), Hawaiian Crow (Burr et al. 1982), Palila (Berger et al. 1977), and the forest birds of Hawaii (Scott et al. 1983), Maui (Kepler et al. 1984), Molokai (Kepler et al. 1984), and Kauai (Sincock et al. 1984). Here we present an integrated overview of the strategies necessary to ensure the continued survival of Hawaiian forest bird species (Table 75). Many of the strategies will be appropriate to other parts of the world where major portions of avifaunas are threatened with extinction.

Legal habitat protection

Once key areas have been identified for most species, the primary conservation action needed

TABLE 75
STATUS AND MANAGEMENT RECOMMENDATIONS FOR NATIVE HAWAIIAN FOREST BIRDS

Island/species	Present status[a]	Total population	Management recommendations
Hawaii			
Hawaiian Crow (Alala)	E	75	Intensive management and captive propagation are absolutely essential in concert with habitat protection.
Ou	E	400	Probably little can be done in immediate future. Use of radio transmitters could prove useful in learning more about habitat requirements and limiting factors.
Hawaiian Goose (Nene)	E	340	Only current means of ensuring survival is captive propagation. Proposed research on food and predation may provide some relief.
Akiapolaau	E	1500	Long-term survival requires that several tracts of koa-ohia forest on windward Mauna Kea and Mauna Loa above 1500 m elevation be set aside and managed as ecosystem preserves.
Palila	E	2000	Removal of mouflon and implementation of fire management program should increase habitat quality. Long-term survival will be enhanced if width of mamane forest is increased.
Hawaiian Hawk (Io)	E	2000	Species is widespread, very adaptable in habitat and prey use; has good reproduction, high population densities for a raptor. In no immediate danger of extinction.
Hawaii Creeper	E	12,500	Large populations bode well for long-term survival, but habitat is declining in quality. Most severe habitat losses are in koa-ohia forests above 1500 m, where ecosystem preserves should be established and managed.
Hawaii Akepa	E	14,000	
Omao	N	170,000	Large numbers and broad distributions bode well for continued existence of these species. Mauna Kea Elepaio race, however, has restricted range, and small population (2500) should be monitored.
Elepaio	N	215,000	
Iiwi	N	340,000	
Common Amakihi	N	870,000	
Apapane	N	1,100,000	
Maui			
Hawaiian Goose (Nene)	E	50	Status is the same as on Hawaii.
Nukupuu	E	30	Pigs and goats have caused severe erosion on steep slopes above 1500 m, threatening long-term stability of forests and thus the future of all forest birds. Existing preserves are adequate for survival, if state forest reserves are included in a badly needed ungulate control program. Core habitat of Poo-uli should be fenced immediately and pigs removed. If habitat improvement does not result in increased numbers, captive propagation will be necessary. Research with radio-tagged birds has high potential in identifying additional limiting factors.
Poo-uli	E	140	
Maui Akepa	E	230	
Maui Parrotbill	E	500	
Crested Honeycreeper (Akohekohe)	E	3800	Large population and broad distribution bode well for continued existence. Management program for pigs and goats needed in essential habitat.
Iiwi	N	19,000	Large populations and broad distributions bode well for continued existence.
Maui Creeper	N	35,000	
Common Amakihi	N	47,000	
Apapane	N	110,000	
Molokai			
Molokai Creeper	E	?	The Nature Conservancy is actively managing significant proportion of essential habitat. Molokai Creeper may be extinct. See comments for Kauai birds.
Olomao	E	20	
Iiwi	N	80	
Common Amakihi	N	1800	Larger numbers and apparent disease resistance indicate no immediate threat of extinction.
Apapane	N	39,000	

TABLE 75
CONTINUED

Island/species	Present status[a]	Total population	Management recommendations
Lanai			
Common Amakihi	N	?	Possibility of using Molokai birds to reestablish population.
Apapane	N	540	Best hope is to control axis deer and prevent introduction of new exotics.
Kauai			
Kauai Akialoa	E	?	Only hope for long-term survival of endangered species on Kauai and Molokai is captive propagation. Disease appears to be the primary factor responsible for their desperate status and continued decline. Except for Ou, there may be no place to safely translocate birds within their historical ranges. Kauai Akialoa may be extinct.
Nukupuu	E	?	
Kauai Oo (Ooaa)	E	2	
Ou	E	<10	
Kamao	E	20	
Puaiohi[b]	E	180	
Kauai Creeper[b]	N	6800	Appears to have undergone significant decline in numbers and contraction in range in past 15 years.
Kauai Akepa[b]	N	5000	Large numbers and broad distribution bode well for continued existence.
Common Amakihi[b]	N	11,000	
Anianiau[b]	N	24,000	
Iiwi[b]	N	26,000	
Elepaio[b]	N	40,000	
Apapane[b]	N	163,000	

[a] Status: E = endangered; T = threatened; N = not endangered.
[b] Population numbers based on 1968–1973 survey by J. L. Sincock (unpub. data), for species known to occur widely outside our study area.

is habitat protection. A critical step in this process is consultation with the involved landowners to discuss management for natural values (Kepler and Scott 1985). Except for those species with desperately low populations, the most effective way to ensure the long-term survival of native birds is actively to protect intact ecosystems from further degradation and restore them as nearly as possible to their natural state. Commercial use and conservation management may be compatible on a rotational basis on rangeland (Scott et al. 1983); however, elimination of commercial activities in many areas of essential habitat in the Hawaiian Islands must precede intensive management of such areas. Because birds have the largest home ranges among the Hawaiian land biota, they provide a suitable base for deciding the minimum size of the managed area (see Eisenberg (1980) for a similar argument based on neotropical mammals).

Through the HFBS we have identified those areas most crucial to the long-term survival of native Hawaiian forest birds in the various recovery plans. The key areas on Maui, Kauai, and much of Molokai already enjoy legal protection as reserves. On much of Hawaii, however, the majority of the prime forest bird habitat has no protection, is threatened with commercial exploitation, and is declining in quality at an alarming rate. If the chance for long-term survival of forest birds is to be increased significantly, prime areas must be protected and managed for the benefit of their native ecosystems. Key areas that presently are not legally protected and that appear critical to the long-term survival of the Hawaiian Crow (Burr et al. 1982, Burr 1984) and Palila (Scott et al. 1984) have been identified on Hawaii and are reviewed below.

The best areas for Akiapolaau, Hawaii Creeper, and Akepa are the koa-ohia forests above 1300 m in the Hamakua, Kipukas, and Kau study areas; those in Hamakua are threatened by feral pigs, feral cattle, ranching, and planned timber harvest. The long-term survival chances of Akiapolaau, Hawaii Creeper, and Akepa would be enhanced significantly by legal protection of these lands. The information needed to design such a group of preserves is available. Action is needed by the concerned federal, state, and private agencies.

The relationship between montane forests and adequate water supply is a potent selling point for habitat protection. Agricultural, commercial, residential, and resort development on leeward Hawaii and Maui is impeded by inadequate water availability. A historical parallel occurred when many coastal Hawaiian villages were deserted after the water supply (streams, springs) failed.

At Lapakahi site on Hawaii and Nuu site on Maui, the water failure was connected with the clearing of dry and mesic woodlands above the sites on Kohala Mountain and on the Kahikinui Tract (Newman 1969). Preservation of forested areas on leeward Hawaii and eventual reforestation of areas like Kahikinui thus offer an economic incentive of a more dependable water supply, and would provide habitat suitable for native forest birds and other endemic plants and animals. The key selling point in negotiations for a conservation easement with the landowner over the Waikamoi Preserve on Maui was that the proposed conservation activities would improve water supply quality.

Habitat management

Once areas enjoy legal protection as conservation areas, they must be fenced, domestic and feral ungulates removed, introduced plants controlled or eradicated, and human access restricted. Although simple in principle, these four steps are often difficult to implement. Because of the vulnerability of native vegetation to destruction by introduced ungulates and plants, a policy of active management—not benign neglect (Soulé et al. 1971, Kepler and Scott 1985)—is imperative in some areas and desirable in most others to preserve the integrity of native ecosystems. Although we emphasize the importance of protecting montane forests to ensure the survival of endangered birds, natural communities at lower elevations often have significant biological value as well, and these communities may eventually be colonized by endangered birds as adaptations to introduced stress evolve.

Endangered bird species frequently occur on ranchlands, suggesting that they have a fair degree of adaptability to habitat modification, at least in its initial stages. However, the history of many of these lands is one of steady loss of canopy cover and native understory species while the number and impact of introduced plants increase (Warshauer and Jacobi 1982). Thus disturbed areas that now harbor endangered birds are not stable habitats and may not be suitable for endangered species indefinitely.

The lands of the U.S. National Park Service and The Nature Conservancy are the only major forest bird habitats in the Hawaiian Islands that are actively managed to protect native ecosystems. State activities on the Mauna Kea Game Management Area have resulted in the removal of goats, sheep, banana poka, and *Eupatorium riparium* and in limited control of mouflon. Other areas designated as state natural area reserves or forest reserves have no program to control introduced species, except public hunting. The need to control feral ungulates and exotic plants in existing preserves cannot be overstated. It is the most cost-effective way to increase the survival chances of native species and to reduce the number of extinct, endangered, and threatened species 100 years from now. Preserving native ecosystems now would avoid overwhelming conservation agencies in the future with species requiring clinical management to prevent extinction.

Intensive management of individual species

Manipulation of vegetation configuration, predator control, nest site manipulation, captive propagation (Conway 1980, Carpenter and Derrickson 1981), and translocation are costly but usually effective measures appropriate as a last resort for populations facing imminent extinction (Temple 1978). For species not yet on the brink, management dollars would be better spent on habitat protection and management.

Planting food crops has been proposed as a management strategy for the Hawaiian Goose (Kosaka et al. 1983) and Hawaiian Crow (Burr et al. 1982). Planting succulent grasses and fruit trees would benefit these species only in the long-term and only in conjunction with other intensive management measures. Moreover, the modification of an ecosystem for the benefit of one species and possible detriment of several other native species, possibly even endangered ones, raises philosophical concerns.

Control of predators, especially cats and mongooses, can be effective when concentrated in the area of nest sites. Mongoose predation of young takes a significant toll of Dark-rumped Petrels, Townsend's (Newell's) Shearwaters, Hawaiian Geese, endemic waterbirds, and Hawaiian Crows. For these species, saturating breeding sites with traps or poison bait may be an effective control measure.

Nest site manipulation includes multiple clutching (removing one clutch to obtain another), removing young from the nest and raising them in captivity, vaccinating birds against disease, and providing nest sites for cavity breeders. The key consideration is whether increased reproductive success will mitigate the factors limiting the population. On Kauai, for example, our data suggest that many species may become extinct by the year 2000 if avian disease has recently penetrated the Alakai Swamp. Funds and manpower would be ill-spent attempting to increase reproductive output of endangered passerines on Kauai if this is the case. The only clear case we see where nest site manipulation is justified is that of the Hawaiian Crow, and even here it is best combined with captive propagation to get through a population bottleneck (Burr 1984). These measures will not increase the survival chances for the Hawaiian Crow in the wild, however, unless there is a commitment to habitat protection and management.

Captive propagation has proved successful in reviving the Hawaiian Goose population (Kear 1975, Kear and Berger 1980); however, a self-sustaining natural population has not yet resulted (Devick 1981a, 1981b). Temple (1978) recommended captive propagation as the last resort for wild populations with little immediate hope of improving their reproductive output through habitat improvement, and for repopulating the original range. Because of the lack of success in reestablishing extirpated bird populations from captive-bred birds, captive propagation should proceed while endangered populations are still available to receive captively produced stock that can augment an existing population through cross-fostering. Among Hawaiian honeycreepers, the Nihoa Finch, Hawaii and Kauai races of Common Amakihi, Anianiau, Kauai Creeper, and Apapane have been kept in captivity (Berger 1981). Perkins (1903) noted that Hawaii Oo could easily be kept in captivity indefinitely. Hawaiian Crows have been bred in captivity and are prime candidates for captive propagation. For rare species, such as the Akiapolaau, for which probable stresses have been identified and which are subject to control, populations may increase sufficiently with habitat improvements so as to make captive propagation unnecessary. Habitat improvement for the Akiapolaau would also improve survival chances for other endangered native species. Captive propagation in connection with translocation may be feasible to reestablish the Ou from the windward Hawaii population to areas of its former range, such as Kona, Kau, and East Maui.

The extremely endangered birds on Kauai and Molokai are on a runaway course to extinction. If these species are to be preserved, extraordinary efforts are necessary. Captive propagation may be the only way to ensure survival of the Kamao, Olomao, and, if not too late, the Kauai Oo, Kauai Akiloa, Kauai Nukupuu, and Molokai Creeper. There is little hope that these species will survive without a commitment to this type of intensive management, and no guarantee that they will survive with it.

The New Zealand Wildlife Service has developed a successful strategy of transferring birds to new islands where the critical limiting factors are absent (Williams 1977); this strategy was pioneered with the Kakapo (*Strigops habroptilus*) (Oliver 1955), a flightless lekking parrot (Merton et al. 1984). Interisland transfer is unequivocally credited with saving the Saddleback (*Creadion carunculatus*), one of the two extant species of wattlebird, from extinction (Merton 1966, 1975; King 1978) and almost certainly the Black Robin (*Petroica traversi*) as well (Flack 1978, Diamond 1984). Transfers that are possible for this type of recovery effort among Hawaiian species include the Hawaiian Crow to Kau; Olomao to East Maui; Ou to Kona, Kau, and East Maui; Nihoa Millerbird to Laysan Island; Nihoa Finch to Necker Island; Common Amakihi to Lanai; Palila to Kona and the northern slopes of Mauna Kea; Maui Parrotbill, Nukupuu, Maui Creeper, and Akepa to Kahikinui; and Akiapolaau, Hawaii Creeper, and Akepa to koa forests in Hawaii Volcanoes National Park. By analyzing vegetation structure, resource levels, and natural history, the probability of a successful transplant can be increased by identifying optimal release sites.

Public education

Public support for conservation is essential for ultimate success in restoring native ecosystems. This has been strongly stated in all recovery plans prepared for Hawaiian birds. Radio and television spots, newspaper releases, filmstrips, brochures, and other printed materials are currently used to raise public awareness. A 30-min film for elementary and secondary schools would be very helpful. Professional wildlife biologists need to explain their perspective in non-technical terms to state legislators, regulatory officials, and the general public. Hunters need to understand that the endemic geese, hawks, owls, and crows are inappropriate targets. Visitors and travelling residents need to understand that thoughtless or inadvertent importations of organisms alien to the islands may create disastrous problems of enormous proportions. In the final analysis it is the people of the Hawaiian Islands who will save the forest birds, but they need to become better informed of the natural heritage under their stewardship. Informing the public may be our biggest challenge in attempting to save native Hawaiian ecosystems.

Importation control

Many of the stresses experienced by native bird populations derive from such introduced organisms as aggressive plants, pathogens, insects, predatory molluscs, and competing birds. Solving such problems usually entails a substantial commitment of resources. A cost-effective strategy to prevent the occurrence of these problems is to place more rigorous and restrictive controls on importations to ensure that organisms potentially disruptive to native ecosystems or detrimental to native birds are not permitted to enter the Hawaiian Islands. Many of the most serious problems are caused by deliberate, thoughtless importations (e.g., fountain grass, banana poka)

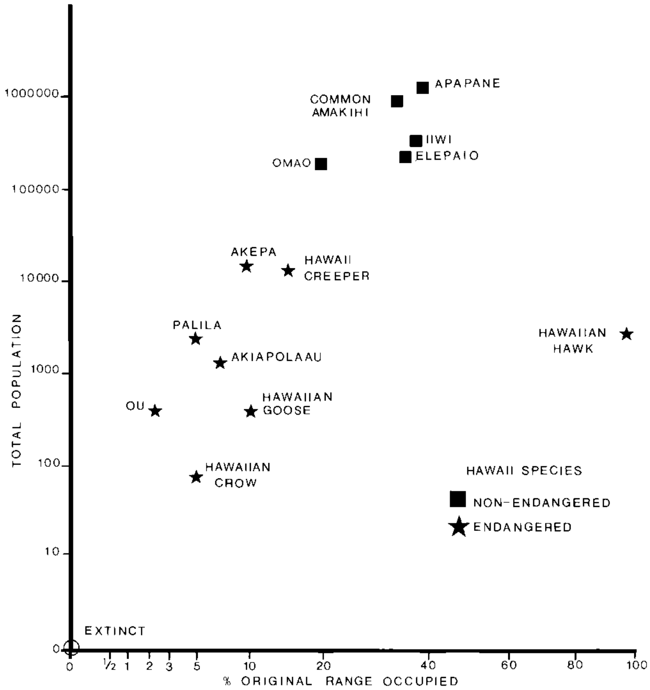

FIGURE 334. Extinction model for bird species on Hawaii.

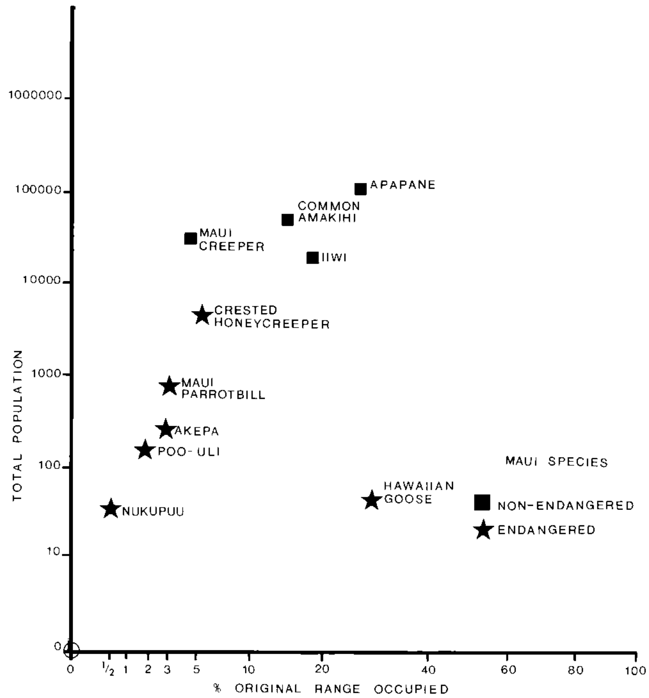

FIGURE 335. Extinction model for bird species on Maui.

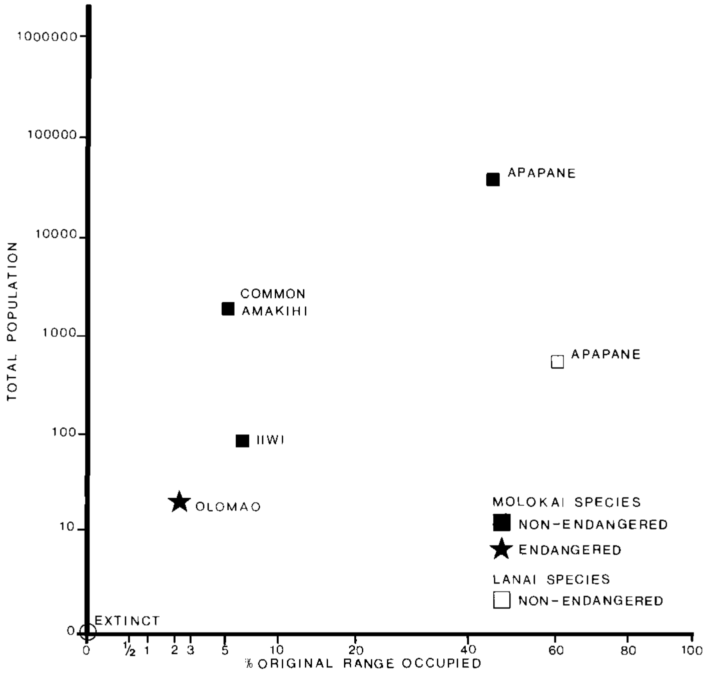

FIGURE 336. Extinction model for bird species on Molokai and Lanai.

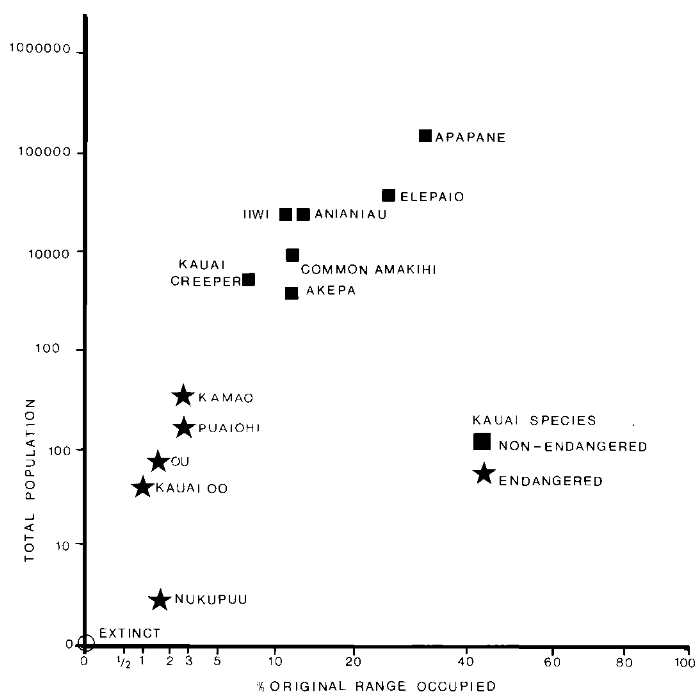

FIGURE 337. Extinction model for bird species on Kauai.

that could have been avoided had state officials looked beyond narrow agricultural interests in permitting these organisms entry. A comprehensive, well designed, fully implemented system of importation controls is of a high priority in averting unnecessary future problems.

Future research needs

The major refugia for native forest birds should be surveyed at least decennially to monitor long-term population trends. Surveys to study seasonal and annual variation in distribution and habitat response are also important. A systematic survey of forest bird habitats on Oahu would be desirable. These efforts should be planned so that useful information is gathered on the behavior, habitat response, and biology of the rarer species. Research on the diet and habitat response patterns of the Puaiohi would help to maximize the chances of a successful captive propagation program for that species. Paired high- and low-elevation tests manipulating food sources and predators would yield insight on the limiting factors of the Hawaiian Goose. More information is needed on the regeneration patterns and role of introduced organisms in native ecosystems once feral ungulate pressure is removed.

Radiotelemetry studies on endangered passerines have high potential for yielding valuable insights on breeding behavior, movement patterns, limiting factors (in conjunction with translocation), optimal preserve designs, and the most appropriate management techniques. Radiotelemetry studies are needed on the Hawaiian Crow to compare habitat utilization and resource availability on a seasonal basis, to maximize reproductive output, and to determine the effectiveness of disease vaccinations. Studies on seasonal movement patterns with radiotagged Ou, Palila, Maui Parrotbill, Akiapolaau, and Crested Honeycreeper would also aid in the development of optimal management strategies. An intensive study of distributional anomalies identified in this study would be valuable in further determination of limiting factors of endangered Hawaiian forest birds. Endangered and surrogate species translocated to areas of unexpectedly low densities in aviaries or released with radio transmitters can have their behavior and survival rates easily compared with birds similarly treated in occupied areas.

Extinction Models

As a means of identifying those species most in need of attention, we constructed "status graphs" for the native avifauna of each island (Figs. 334–337). These graphs plot the current population of each species against the percent of the species' range still occupied. At a glance the graphs show how many birds are left and how restricted their ranges have become. The species nearest the lower left-hand corner (the point of extinction) are the most endangered; those farther away are less threatened, while those appearing in the upper right-hand corner are fairly safe.

Island Recommendations

Hawaii

The native avifauna is most intact in four refugia: the Mauna Kea mamane-naio woodland, the windward rainforest, the Kau forest, and the mesic forest on the north slopes of Hualalai (Fig. 338). In addition, the main population of the Hawaiian Crow and very low populations of other endangered species inhabit the mesic to wet forest of central Kona. The habitat response graphs (Fig. 331) show that koa-ohia forest above 1500 m elevation supports the highest density of endangered birds, with a secondary population center lying in the mamane-naio woodland. Endangered bird density declines dramatically with decreasing vegetation biomass within a habitat type.

Hawaiian Geese populations are presently maintained principally by releases of captive-bred birds. Captive propagation has begun and will be essential for the Hawaiian Crow; it may also prove necessary for the Ou. Our status graph (Fig. 334) indicates that these species are the ones most threatened with extinction on Hawaii.

The main threats to the mamane and naio woodland on Mauna Kea are fire and feral ungulates (mouflon and formerly sheep, goats, and cattle). Removal of mouflon and the few remaining sheep from the upper elevations of Mauna Kea is recommended, as is developing a fire management program that includes eliminating fountain grass, establishing fire breaks, controlling activity in the Hale Pohaku corridor, educating the public, and increasing surveillance during high-risk periods.

Management of the Kau Forest Reserve epitomizes benign neglect. Fencing the forest reserve above 1300 m elevation and removal of feral pigs are recommended. The mouflon and feral sheep at timberline should be extirpated. Feral cattle are found in Kau at higher elevations within and above the koa-ohia forest. Long-term stability of the forest requires that domestic and feral cattle be eliminated from the area. The long-term survival chances of the endangered birds in Kau would be further increased if feral ungulates were removed from the Kapapala Forest Reserve. That area would then serve as a corridor linking the Kau and Hamakua populations of Akiapolaau, Hawaii Creeper, and Akepa. This

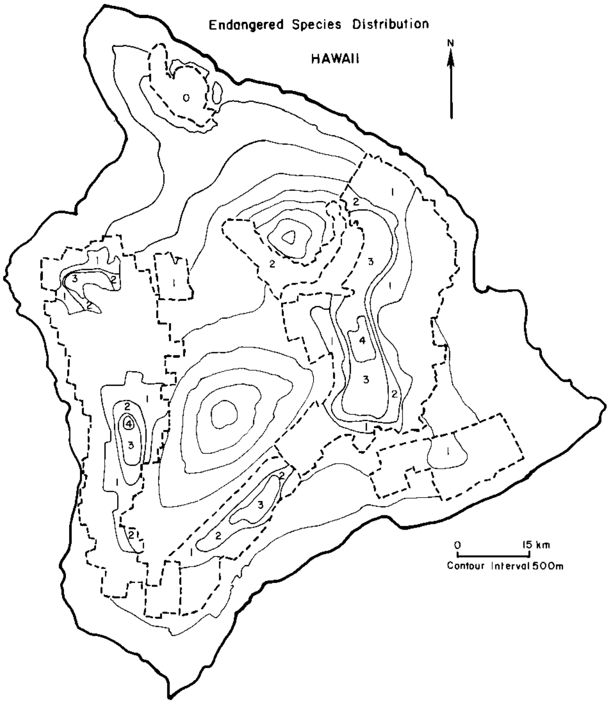

FIGURE 338. Distribution of endangered passerine bird species richness on Hawaii.

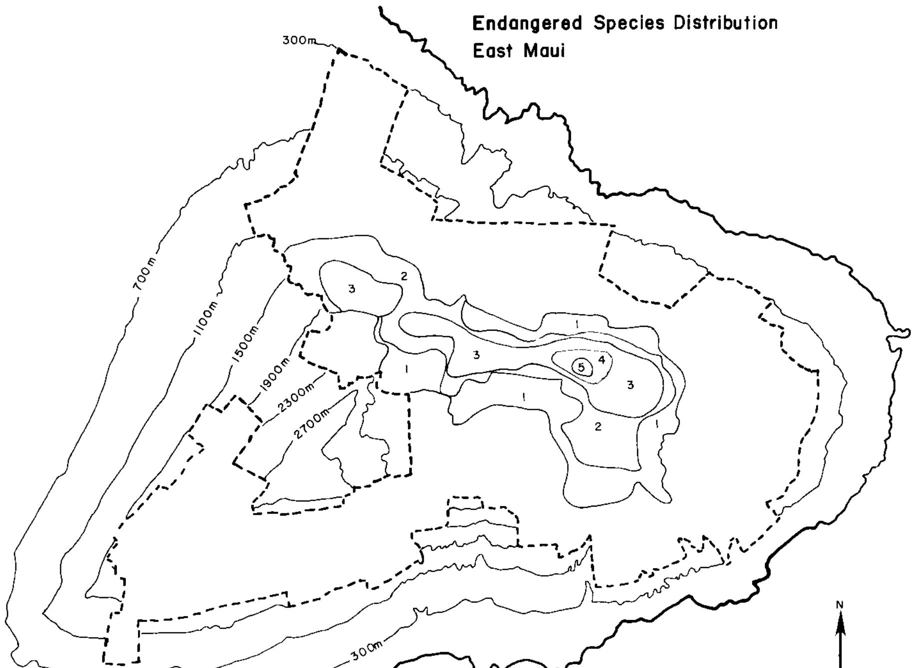

FIGURE 339. Distribution of endangered passerine bird species richness on East Maui.

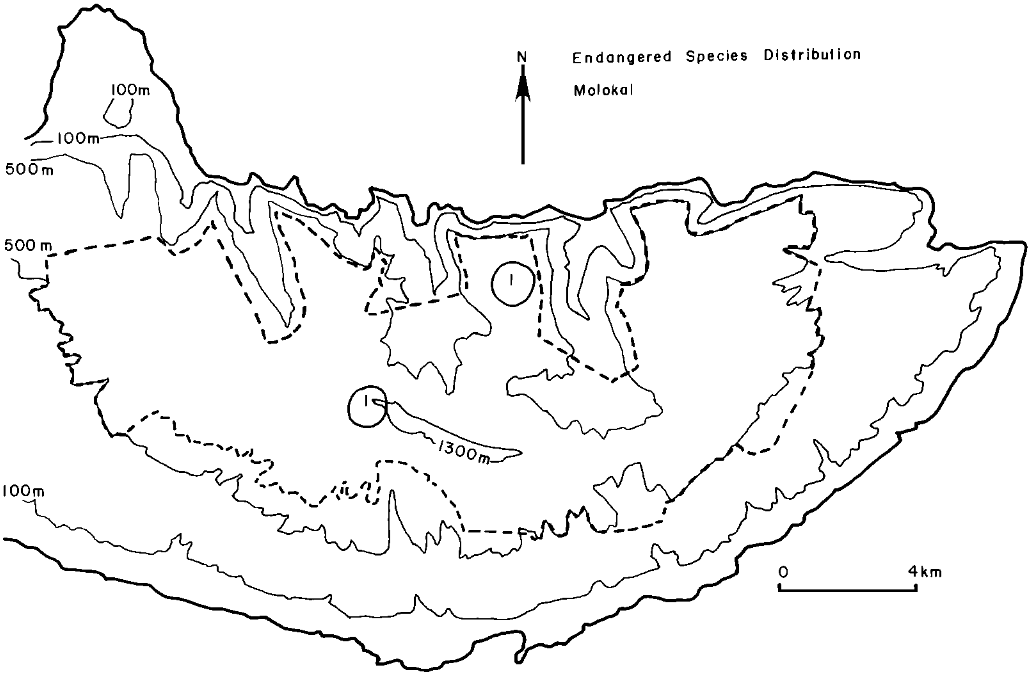

FIGURE 340. Distribution of endangered passerine bird species richness on Molokai.

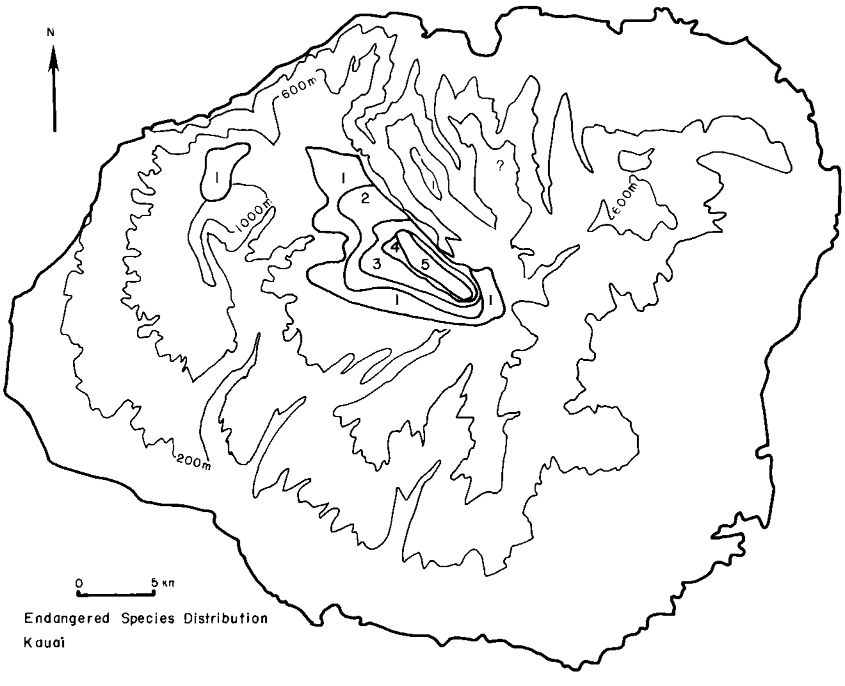

FIGURE 341. Distribution of endangered passerine bird species richness on Kauai.

management strategy would be strengthened if the lands of Keauhou above 1500 m north of Hawaii Volcanoes National Park were similarly managed. Their suitability as forest bird habitat, however, has steadily declined during the last 30 years, because of ranching and clearing (Warshauer and Jacobi 1982).

On windward Hawaii, acquisition of a long-term mandate for conservation management is especially important for the montane forests above 1300 m elevation. Koa-ohia forests at 1500–2000 m on Mauna Kea and northwest of Kilauea Crater are threatened with commercial harvesting. These areas support the core of the Akiapolaau, Hawaii Creeper, and Akepa populations. Reforesting the mesic koa-ohia forests on the windward slopes of Mauna Kea may make it possible to reestablish the link between the populations of Akiapolaau in the Hamakua and Mauna Kea study areas. Extensive areas of well-managed habitat in Hawaii Volcanoes National Park benefit many native biota, including Hawaiian Geese and Hawaiian Hawks, but other than an occasional Ou, virtually no endangered passerines occur within the park boundaries. Control measures are needed for banana poka, which threatens significant portions of essential forest bird habitat on windward Hawaii. High priority should be placed on controlling further spread of banana poka in the vicinity of Hawaii Volcanoes National Park.

On leeward Hawaii, the koa-ohia forest on Hualalai that supports Hawaiian Crows, Hawaii Creepers, and Akepa is heavily grazed and portions were unlawfully logged. A reserve is being established in this area, as has long been proposed by the Hawaii Division of Forestry and Wildlife. In central Kona, the koa-ohia forests that Hawaiian Crows occupy are a mosaic of grazed and undisturbed lands. Portions of the prime Hawaiian Crow habitat in this area are being logged at present. Dedicating some of these lands to conservation management is essential in the near future, or Hawaiian Crows and much of the koa-ohia forest ecosystem in central Kona will disappear.

In conclusion, the top priorities on Hawaii are (1) securing ownership of, conservation easements to, or management agreements for several koa-ohia forest areas that are essential for the survival of the Hawaiian Crow, Akiapolaau, Hawaii Creeper, and Akepa; (2) removal of feral ungulates from the Mauna Kea Game Management area; (3) intensive management of the Hawaiian Crow population; (4) control of banana poka in essential habitat; and (5) control of pigs in essential habitat.

Maui

The native avifauna of Maui is best represented in the high-elevation rainforest of northwest Haleakala and upper Kipahulu Valley (Fig. 339). The Olomao and Ou have apparently become extinct. The habitat response graphs (Fig. 331) indicate that the montane ohia rainforest supports the highest density of endangered birds. Nukupuu, Maui Akepa, and Poo-uli are the species most threatened with extinction on Maui (Fig. 335). The Hawaiian Goose population on Haleakala is maintained chiefly by release of captive bred birds (Devick 1981b).

We would expect to see a significant increase in the densities of the Maui Parrotbill and Poo-uli by fencing and then eliminating feral pigs and goats from the high montane rainforest in the Hanawi and Kuhiwa watersheds. These areas are national park and state forest reserve lands; recently, Haleakala National Park has begun fencing essential forest bird habitat. The area with the highest priority for fencing is the watershed between the two forks of the Hanawi, where the greatest numbers of Poo-uli are known to occur. All other endangered Maui forest birds also occur in this area. The Waikamoi Reserve supports a fairly intact koa-ohia forest west of Koolau Gap with key populations of Maui Parrotbill, Maui Akepa, and Crested Honeycreeper; management rights to this area have been recently acquired by The Nature Conservancy, which will be fencing it and eliminating feral ungulates. Management rights to the Haiku Uka lands, owned by East Maui Irrigation Co. and lying between Waikamoi Reserve and the Koolau Forest Reserve, also need to be acquired so that this essential connecting forest can be similarly managed.

The dry side of East Maui, Kahikinui, has been overgrazed to a scrubland with vestiges of the original forest. Portions of Kahikinui were fenced in 1983 by the Hawaii Department of Land and Natural Resources and the National Park Service as the first step in regenerating this ecosystem. Here the plan is to enlist the cooperation of local hunters to radically reduce goat herds on the south slope of Haleakala (W. Wong, L. Loope, pers. comm.). The revegetation of Kahikinui offers an exciting prospect in the management of endangered species. As earlier mentioned, the dry koa-mamane-ohia woodland that would eventually develop above 1400 m elevation would provide good habitat for Maui Parrotbill, Nukupuu, and Akepa. The Kahikinui forest would connect to the koa forests on Kuiki Peak by a corridor of dry forest in Kaupo Gap. Because Maui Parrotbill and Nukupuu often flock with Maui Creeper, which tend to wander, we would expect Maui

Creeper flocks to repopulate the regenerated Kahikinui woodland in time, and that some of the flocks would include birds of the two endangered species, thus seeding new populations.

Perhaps as much as 80% of the benefits that are to be derived from management efforts would result from exclusion of feral ungulates and prevention of the establishment of new populations of exotic plants and animals. Additional research is needed in the montane rainforest of East Maui on seasonal and annual variation in distribution, abundance, and habitat response of the endangered passerines. The results of these studies should help in the design and management of reserves. They should also help us to gain a more detailed understanding of the operation of the factors that limit the rarest species.

Molokai

The avifauna of Molokai is much reduced, but Olomao and possibly Molokai Creeper still survive (Fig. 340). These species and the Iiwi are near extinction (Fig. 336) and are confined to remote rainforests. Captive propagation and translocation are the best hope for the continued survival of the endangered Molokai forest birds. The Nature Conservancy has begun active management to preserve the native forest on its Kamakou Preserve, but the area needs to be expanded eastward to include all the remnant rainforest. The Olokui Plateau is almost inaccessible to feral ungulates and supports the least disturbed native forest in Hawaii (Fig. 329); a short stretch of fencing across a certain treacherous ridge would close the only possible access for pigs and axis deer. The native vegetation on vast tracts of east Molokai and the southwest edge of our study area is utterly devastated. If our assessment of the impact of avian disease is correct, the outlook for the long-term survival of Olomao and Molokai Creeper, even with intensive habitat protection and management, seems bleak.

Lanai

The Lanai avifauna has been almost totally extirpated by habitat destruction and probably avian disease. The Apapane may be the only native passerine extant (Fig. 336). Fencing would help protect the remaining forest. If, as we suspect, disease is the principal factor responsible for the massive extinctions on Molokai and Lanai, then the long-term survival chances for reintroduced native species are negligible. One bright spot would be reintroducing Common Amakihi on Lanai, using birds from the apparently disease-resistant lowland populations on Molokai.

Kauai

Most of the native birds of Kauai have retreated to the Alakai Swamp since the 1890s (Fig. 341). After the 1960 survey (Richardson and Bowles 1964), it was hoped that the Alakai would serve as a permanent refuge for the six endangered species, but Kauai Akialoa were last sighted in 1965, and Nukupuu in 1975 (Sincock et al. 1984). Our survey shows that none of the endangered Kauai passerines has a population of even 50 birds; we estimated fewer than 10 Kauai Oo and Ou. In addition, the Kauai Creeper population appears to have declined in the past decade (Fig. 337). Disease is one probable cause for these declines. Distribution and density maps for the endangered passerines show a general retreat to the remote south edge of the Alakai, suggesting that an inimical factor is entering from the lower north edge. If present trends continue unabated, by the year 2000 several of the six endangered Kauai passerines could be extinct in the wild. Captive propagation seems to be the only way to sustain these species. In many ways the situation on Kauai replays the pattern of retreat and extinction that must have occurred on Molokai, Lanai, and Oahu. Despite the continued declline of endangered birds, the Alakai Swamp should be protected from introduced plant invasion and feral ungulates because of its rich diversity of native plants and the outside chance that some species may yet evolve genetic resistance to avian diseases. Dams, ditches, and other potential breeding sites for mosquitoes should not be permitted on the high plateau.

Conclusion

Much has been learned about endangered Hawaiian forest birds in the last decade. Available information is now adequate to define essential habitat. Although numerous factors may have potential negative impacts on Hawaiian species, we feel that those having the greatest impact are clearly identified on each island. In many cases, the management actions and means to eliminate or significantly reduce these negative factors are known. Implementation of these actions should result in significant increases in the numbers of many endangered birds while increasing the long-term survival chances of the native ecosystems in which they live. For some limiting factors such as mosquito-borne diseases, effective means of abatement may not exist, although reduction in exposure may be possible and effective control techniques may be discovered. The long-term survival chances of Palila, Maui Parrotbill, Maui Nukupuu, Akiapolaau, Hawaii Creeper, Akepa, Crested Honeycreeper, and Poo-uli can be increased significantly by protection, restoration, and management of their essential habitat. If we fail to act on available information, their survival chances will be reduced significantly. Other species will require intensive management with no guarantee of success. For some species little can be done beyond maintaining a captive population, and for birds like Olomao, Kauai Oo, Kauai Akialoa, Maui and Kauai Nukupuu, and Molokai Creeper, it may be too late to establish a captive flock. Much progress has been made through the combined actions of federal, state, and private agencies, as well as by university workers and concerned individuals. Much more needs to be achieved. We hope that the data presented in this monograph will encourage the cooperation of all interested parties towards further conservation action in the Hawaiian Islands.

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