Conservation of Hawaii's Vanishing Avifauna

Hawaiian birds provide one of the best, and most spectacular, showcases of divergent evolution

J. Michael Scott, Cameron B. Kepler, Charles van Riper III, and Stewart I. Fefer

Of the thousands of islands in the world's oceans, those in the central and south Pacific have captured the fancy of adventurers and dreamers for centuries. These islands provide biologists with many fine examples of divergent evolution (adaptive radiation). The Hawaiian Islands, however, are the jewel in the crown that makes adaptive radiation on the other islands pale in comparison. Hawaiian birds, especially the honeycreepers (Drepanidinae) with their bright colors and exceptionally diverse bills, provide an evolutionary showcase for the world's ornithologists. If Darwin had visited Hawaii, he might well have written *The Origin of Species* a decade earlier and fostered an interest in the islands that could have prevented many of the stresses that now plague its biota.

A detailed database is aiding efforts to save what remains of Hawaii's avian communities

Today the Hawaiian archipelago (Figure 1) is primarily a tourist destination for those seeking a tropical paradise. Most assume that the lush lowland vegetation and bountiful flowers are native to Hawaii, rather than correctly recognizing them as a diverse collection of alien invaders (Smith 1985). In addition, few visitors realize that the Hawaiian archipelago includes numerous islands that stretch northwest of the main Hawaiian islands for more than 2200 kilometers. These northwestern Hawaiian islands include some of the largest, most diverse seabird colonies (Figure 2) in the world, and are also among the most fragile habitats.

In recent years biologists have shown an unprecedented interest in the biology of islands, especially Hawaii. For example, in the last two decades major field studies by state, federal, and university researchers have attempted to understand past distributions and present limiting factors of Hawaii's forest birds (Mueller-Dumbois et al. 1981, Scott et al. 1986a, van Riper 1984, 1987, van Riper et al. 1986, Weathers and van Riper 1982), seabirds (Fefer et al. 1984), and water birds (Griffin et al. in press, Harrison et al. 1984). The detailed database that resulted from these studies has promoted a renewed effort to save what remains of Hawaii's endangered avian communities (Scott et al. 1987b).

Hawaii's 84 species of endemic birds (44 known only from the subfossil record[1]) are thought to have originated from only 20 colonizations; the more than 47 drepanidinaes are thought to be derived from a single ancestor (Berger 1981, Olson and James 1982). Hawaii has 29 spe-

J. Michael Scott, a US Fish and Wildlife Service employee, is the unit leader at the Idaho Cooperative Fish and Wildlife Research Unit, US Fish and Wildlife Service, College of Forestry, Wildlife, and Range Sciences, University of Idaho, Moscow 83843. Cameron B. Kepler is a research biologist with the Southeast Field Station of Patuxent Wildlife Research Center, US Fish and Wildlife Service, School of Forest Resources, University of Georgia, Athens 30602. Charles van Riper III is a research ecologist with the Cooperative National Parks Studies Unit and the Department of Wildlife and Fisheries Biology, University of California, Davis 95616. Stewart I. Fefer is the refuge complex manager of the Hawaiian Islands and Wetlands Complex of National Wildlife Refuges, Pacific Islands Office, US Fish and Wildlife Service, P.O. Box 50167, Honolulu 96850. Each author has lived in the islands at least five years and has conducted research on distribution, ecology, and/or limiting factors of Hawaiian birds. All are working to increase the survival chances of this archipelago's fragile avifauna.

[1]H. F. James, 1987. Personal communication. Smithsonian Institute, Washington, DC.

The Hawaiian honeycreepers (right) provide the most impressive example among birds of adaptive radiation. Their bills include stout seed crushers, parrot shapes, crossed bills, warblerlike forceps, and decurved probes. First column (top to bottom): Iiwi, *Vestiaria coccinea*; Apapane, *Himatione sanguinea*; Akepa, *Loxops coccineus coccineus*; Maui parrotbill, *Pseudonestor xanthophrys*; Grosbeak finch, *Psittirostra kona*. Second column: Hawaii mamo, *Drepanis pacifica*; Crested honeycreeper, *Palmeria dolei*; Kauai akialoa, *Hemignathus procerus*; Common amakihi, *Loxops virens virens*; Ou, *Psittirostra psittacea*; Nihoa finch, *Telespiza ultima* (female). Third column: Ula-oihowane, *Ciridops anna*; Akiapolaau, *Hemignathus munroi*; Kauai creeper, *Oreomystis bairdi*; Poo-uli, *Melamprosops phaeosoma*. Painting: H. Douglas Pratt, Louisiana State University Museum of Zoology.


H. Douglas Pratt
1977

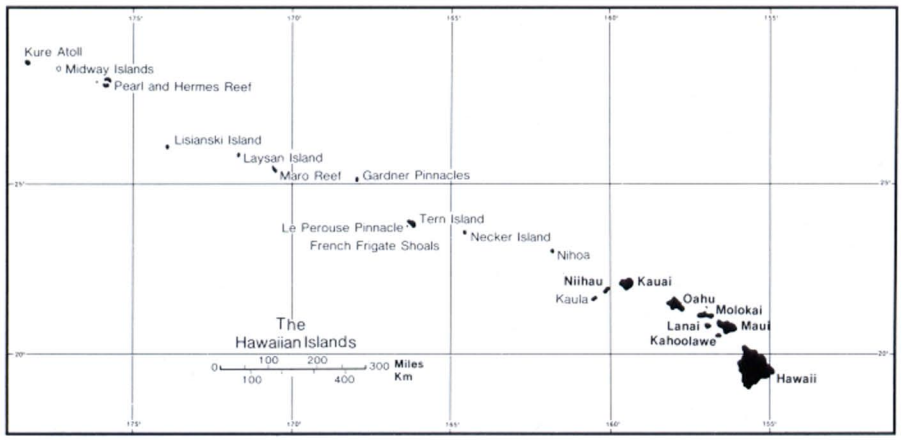

Figure 1. The Hawaiian Islands.

cies of birds listed as endangered by the International Council for Bird Preservation (ICBP) (King 1981). Rats, cats, dogs, and humans have been effective and ruthless predators on the main Hawaiian Islands (Atkinson 1977, Tomich 1986, van Riper and van Riper 1982).

At least 44 taxa have become extinct on the main islands as the result of actions by Polynesian man and his commensals before the arrival of European explorers in 1778.[2] Further deforestation by ranching, logging (Figure 3), and urban development activities, as well as constant browsing, grazing, and rooting by alien ungulates, continues today on all the main Hawaiian islands (Loope et al., page 272 this issue). On Laysan Island in the northwestern part of the archipelago, devegetation by introduced rabbits in the early part of this century led to the extinction of the Laysan rail, Laysan millerbird, and Laysan honeycreeper. Rats accidentally introduced on Midway Island in 1943 (Fisher and Baldwin 1946) led to the extinction of the translocated Laysan rail and Laysan finch as well as Bulwer's petrel. Severe reductions in the number of nesting Bonin petrels and wedge-tailed shearwaters also occurred on Midway at this time. In addition, introduced avian diseases limit the number and distribution of native birds on the main islands (van Riper et al. 1986), while alien plants and invertebrates are continuously modifying native ecosystems (Howarth 1985, Smith 1985).

Man-induced perturbations of the environment have extended into the pelagic world of seabirds. Persistent plastic items floating on the ocean in the vicinity of the Hawaiian Islands, especially those in the westernmost portion of the leeward islands, present hazards to seabirds that eat them and/or become entangled in them (Fry et al. 1987).

Hawaii's wetlands have not escaped modification by Hawaiian and European cultures. Only remnants of former wetland areas remain. More recent urbanization of lowland areas has accelerated the conversion of wetlands and loss of water-bird habitat. Taro fields, fish ponds, cane waste silting basins, and reservoirs have replaced many natural wetlands and are now of primary importance to water birds.

However, even in its depauperate state the avifauna of the island of Hawaii is spectacular. In the high forests of Hawaii, the observed forest-bird densities of 1500–3000 birds/km^2 (Scott et al. 1986a) represent the highest documented bird densities. One can only wonder at the nature of the avifauna prior to the waves of extinction and habitat modification that have swept over the islands. The diversity and numbers of seabirds are equally impressive. For example, on Laysan Island nearly one million seabirds of 17 species occupy virtually every available niche for nesting habitat, an incredible 224,000 birds/km^2. At dawn and dusk during the nesting season, clouds of seabirds fill the skies as they arrive and depart from the colony.

In this article, we review the past and current status of Hawaii's birds in an effort to focus attention on the perturbations that have occurred in these distinctive island ecosystems. We show, through the use of modern biogeographic theory, that an appropriate management scheme can be developed to help ensure the continuation of this unique avifauna.

[2]See footnote 1.

Figure 2. Seabird colony, primarily Laysan albatrosses. Photo: S. I. Fefer.

Seabirds

Twenty-two species of seabirds breed in the Hawaiian Islands. All but three species nest on the leeward islands; however, while 86% of the species and 48% of the populations occur on

Frigate bird on Midway Island feeds chick. Photo: Robert J. Shallenberger, courtesy Defenders of Wildlife.

Figure 3. Heavily grazed and logged ohia-koa forest. Photo: James D. Jacobi.

Table 1. Number of surveyed colonies and breeding pairs of seabirds in Hawaii.*

Species	Number of populations	Number of nesting pairs	Percent of populations <500	Percent of populations <50
Black-footed albatross, *Diomedea nigripes*	9	55,586	33	0
Laysan albatross, *Diomedea immutabilis*	16	342,747	56	50
Dark-rumped petrel, *Pterodroma phaeopygia sandwichensis*	2	431	50?	?
Bonin petrel, *Pterodroma hypoleuca*	6	330,944	17	17
Bulwer's petrel, *Bulweria bulwerii*	20	203,853+	70	40
Wedge-tailed shearwater, *Puffinus pacificus*	45	307,270+	56	18
Christmas shearwater, *Puffinus nativitatis*	10	2,898	70	50
Townsend's shearwater, *Puffinus auricularis*	3	57+	100	67
Band-rumped storm petrel, *Oceanodroma castro*	1	?	100?	?
Sooty storm petrel, *Oceanodroma tristrami*	5	5,967+	20	20
White-tailed tropicbird, *Phaethon lepturus*	4	12+	100	100
Red-tailed tropicbird, *Phaethon rubricauda*	17	11,020+	53	36
Masked booby, *Sula dactylatra*	11	2,199	64	27
Brown booby, *Sula leucogaster*	10	590	100	30
Red-footed booby, *Sula sula*	15	8,657+	27	13
Great frigatebird, *Fregata minor*	10	9,208	30	10
Gray-backed tern, *Sterna lunata*	11	50,460	18	9
Sooty tern, *Sterna fuscata*	12	1,358,745	0	0
Brown noddy, *Anous stolidus*	13	106,028+	8	8
Black noddy, *Anous minutus*	14	15,947	57	21
Blue-gray noddy, *Procelsterna cerulea*	4	4,000+	50	50
White tern, *Gygis alba*	11	14,622+	63	27

*Data from S. I. Fefer, D. Hu, and M. B. Naughton, 1988. Manuscript submitted.

main islands, only 5% of the breeding pairs do (Table 1). The three species found only on the main islands are the band-rumped petrel, the threatened Townsend's shearwater, and the endangered dark-rumped petrel. Prior to the arrival of man and his commensals, the eight main islands were the sites of major seabird colonies.[3] However, taking of eggs and young by Polynesians and predation by introduced rats, pigs, and dogs probably extirpated many seabird colonies on the main islands before Europeans arrived. The Europeans' introduction of cats, two more species of rats, barn owls (*Tyto alba*), and the small Indian mongoose (*Herpestes auropunctatus*) eliminated all remaining seabird colonies except one multispecies colony on Kauai, one remnant booby colony on Oahu, and a few high-elevation petrel and shearwater colonies. The only other nesting seabirds on the main islands are presently restricted to vertical cliff faces or offshore islets where they are safe from introduced predators.

Townsend's shearwater. One of the surviving species, Townsend's shearwater, provides an excellent example of how researchers and managers can cooperate to restore a population. Earlier this century, this species was thought to be extirpated as a breeding bird on all islands except Kauai (King and Gould 1967). The breeding colonies in Kauai were not located until 1967 (Sincock and Swedberg 1969). However, many birds, especially fledglings, died when they became disoriented by urban and resort lighting as they flew from inland nesting areas to the coast. Birds that crashed in developed areas tended to be subsequently killed by dogs and cats or run over by cars (Telfer et al. 1987). Townsend's shearwaters were observed falling to the ground as early as 1961. The problem increased as tourist-related development increased in the 1970s and the lowlands grew progressively brighter.

Beginning in 1978, state and federal biologists initiated a Save-Our-Shearwater (SOS) campaign, asking the public to turn in fallen birds at 11 shearwater-aid stations. The response was impressive: each fall volunteers

[3]See footnote 1.

picked up fallen birds (mostly newly fledged young), rehabilitated them, and released them on the coast. From 1978 through 1985 more than 10,000 shearwaters were rescued (Telfer et al. 1987). The number needing help, however, increased each year. Picking up birds was time consuming, costly, and thus not a permanent solution to the problem.

Researchers at the University of Wisconsin in Madison joined federal and Hawaii state biologists to tackle the problem of light pollution. They found that placing shields over outdoor lights and replacing high-intensity phosphorus lamps with low-intensity sodium vapor lamps greatly reduced shearwater "fallout" at their experimental site. This management solution was implemented by the Fish and Wildlife Service (USFWS), The Nature Conservancy of Hawaii (TNCH), Kauai Electric Company, several hotels, and a host of dedicated volunteers (Reed et al. 1985). However, this effort has not completely eliminated shearwater fallout and present plans call for reducing glare by phasing in cutoff luminaire sodium vapor lights in public lighting islandwide over the next 20 years.

Dark-rumped petrel. The second endangered seabird nesting in the islands is the dark-rumped petrel, which nests primarily above 2500 meters within Haleakala National Park on Maui. Small colonies of unknown size are thought to exist on Kauai, Lanai, and the upper slopes of Mauna Loa, Hawaii. This relict distribution has resulted from predation at other colonies, most of which are now extirpated. The Maui colony numbers approximately 400 nesting pairs (Simons 1983). Simons determined that predation (rats and especially cats and mongooses) was the primary source of mortality in this population, and he recommended predator trapping as the preferred management action.

Simon's predator traplines have been maintained since 1983, resulting in a severalfold increase in petrel reproductive success. Goat control in Haleakala and The Nature Conservancy's adjacent Waikamoi Reserve (Figure 4) has resulted in fewer nesting burrows being trampled and has allowed the petrel colony to expand

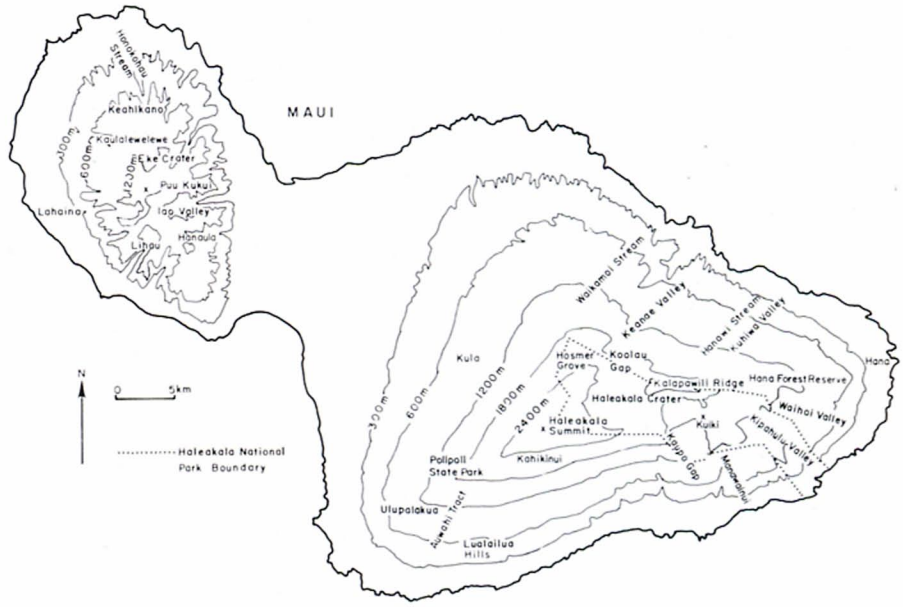

Figure 4. The island of Maui (Scott et al. 1986a).

in these areas. Trapping for mongoose at Waikamoi will begin as soon as goat removal is near completion in an effort to further expand the colony. To reduce the costs of predator control, researchers on Hawaii, funded by the US Fish and Wildlife Service and US Department of Agriculture, are developing an easy-to-handle, highly specific anticoagulant dropbait that is lethal to the mongoose.[4] The use of a dropbait is possible because the Hawaiian hoary bat (*Lasiurus cinereus semotus*) is the only native terrestrial mammal in the islands.

Endemic waterfowl

Twenty-nine species of waterfowl have been recorded in Hawaii, but only five species of ducks and geese have nested in the islands (Pratt et al. 1986). The three endemic species (Hawaiian goose, Hawaiian duck, and Laysan duck) are all endangered (Table 2). The Laysan duck nests exclusively on Laysan Island, where its population has ranged from as few as 20 during 1910–1920 to several hundred during the last decade. The future of the wild population seems secure if alien predators and plants can be kept away from Laysan, and the mobile sand dunes currently threatening Laysan's central lagoon are stabilized (Moulton and Weller 1984). There are also several hundred birds in breeding facilities around the world (Giezentanner et al. 1982). Although these birds are not presently managed with the intent of returning them to the wild, the captive flocks provide additional long-term genetic safeguards for this species.

The largest Hawaiian duck (koloa) population is on mongoose-free Kauai, where there were an estimated 3000 birds in the mid-1960s (Swedberg 1967). There is no indication that present numbers have declined on this island, but there has been no complete survey of the streams of upland areas since Swedberg's study. Captive-reared koloa were released on Oahu, and approximately 240 koloa were recently counted there. Released birds are breeding and dispersing widely on the island of Hawaii.[5] This observation suggests a successful release program that has increased the numbers of birds breeding in the wild on these islands. However, interbreeding of koloa with mallard ducks (*Anas platyrhynchus*) is known to occur and poses a threat of unknown magnitude to the genetic integrity of the endangered koloa.

[4] J. Keith, 1987. Personal communication. USFWS, Volcano, HI.

[5] J. Giffin, 1987. Personal communication. Hawaii Department of Natural Resources, Waimea.

Table 2. Waterbird and waterfowl populations. Data from Hawaii Division of Forestry and Wildlife, Honolulu, and Scott et al. (1986a), Shallenberger (1977), and Swedberg (1967).

	Population sizes		Total number of birds	percent of populations <500	percent of populations <50	Number of populations
	Maximum	Minimum				
Black-crowned night heron* *Nycticorax nycticorax*	250+	2	450	100	71	7
Hawaiian goose *Nesochen sandvicensis*	300	125	425	100	0	2
Hawaiian duck *Anas wyvilliana*	3000	?	?	66	0	3
Laysan duck *Anas laysanensis*	500	500	500			1
Common moorhen *Gallinula chloropus*	500?	250?	750?	100	0?	2
American coot *Fulica americana*	1800	90	4500	60	20	5
Black-necked stilt *Himantopus mexicanus*	700	35	1500	60	40	5

*Maximal and minimal population numbers for black-crowned night heron are average annual counts, 1980–1985.

The Hawaiian goose (Figure 5), the last of at least eight species of geese, seven of them flightless, that once roamed Hawaii (Olson and James 1982), has been touted as a conservation success story (Ripley 1986). Indeed, because of a highly successful captive rearing and release program, it recovered from less than 50 geese in 1945 on the island of Hawaii to nearly 1000 birds on Maui and Hawaii in the 1970s (Kear and Berger 1980, Scott et al. 1986b).

Figure 5. Hawaiian goose or nene is the state bird of Hawaii. Photo © 1988 R. J. Shallenberger.

Elation at the recovery of this species was, however, premature. The 1980 population numbered only 400, and these numbers can apparently be maintained only through repeated captive releases (Scott et al. 1986b). On Hawaii, data indicate that the best nesting and feeding areas were in lowland areas that have been modified so severely that they are no longer suitable nene habitats.[6] Now, nesting wild geese are found only at upper elevations and are not reproducing successfully enough to replace those that die. Thus, the present population occupies marginal habitat. Within this marginal habitat, insufficient food and introduced predators are thought to be major reasons for poor reproduction, although genetics and behavior may also be involved (Stone et al. 1983). Conservationists hope that the dropbait being developed to kill predators at seabird colonies will also reduce predation at Hawaiian goose nests.

Rails

There were no fewer than 11 species of rails in the Hawaiian Islands when the first Polynesians arrived (ca. 500 A.D.). Only four rail species survived until the arrival of Europeans. The Hawaiian rail (*Porzana sandwichensis*) was last seen in 1884 (Perkins 1903), while the Laysan rail (*Porzana palmeri*) survived until perhaps 1944 (Baldwin 1947). Only the aquatic American "Hawaiian" coot (Figure 6) and common moorhen, subspecies of more common North American forms, survive in Hawaii today.

Both the moorhen and coot are endangered in Hawaii. Semiannual counts from 1980 to 1985 for the coot have averaged 1840 (range 4466–785) birds. The numbers for moorhen during 1980–1985 have averaged 176 (range 334–69) birds. However, because of the secretive nature of the moorhen, the total population is thought to number 750 birds, with perhaps 500 of them occurring on Kauai and the remaining 250 occurring on Oahu (Shallenberger 1977).

Recent efforts to set aside and manage wetland refuges have increased the long-term survival chances of both these species (Table 2). In spite of this, a large proportion of the coot population is not breeding.[7] Habitat quality is a key issue, because the wetlands are primarily in lowland areas where most developments and alien species occur. Predation by mongooses and other predators continue on all the islands except Kauai and Lanai.

Although there have been several recent efforts to document the breeding biology of coots (Byrd et al. 1985) and moorhens (Byrd and Zeillemaker 1981), far more needs to be known about habitat requirements and reproductive success if refuges are to be managed effectively. Improved methods of monitoring population trends, especially for moorhens, need to be developed. The anticoagulant dropbait under evaluation would undoubtedly aid these species, as would an expanded refuge system including Kealia Pond on Maui, Opaeula Pond on the island of Hawaii, and additional wetland habitat on the island of Oahu. In addition, full development of impoundments on existing refuges is required (e.g., Huleia Na-

[6]P. C. Banko, 1984. Personal communication. US National Park Service, Volcano, HI.

[7]C. Griffin, 1987. Personal communication. University of Massachusetts, Amherst.

tional Wildlife Refuge and Hanalei National Wildlife Refuge on Kauai).

Stilts and herons

The endangered Hawaiian subspecies of the black-necked stilt is the only representative of this family in Hawaii. The black-necked stilt occurs on all major islands except Lanai. Estimates of its population have varied from 1200 to 1500 birds since 1977. Like the extant rails, its population has become more secure with the creation of a wetland refuge system, and the subspecies appears to have established a new population on Hawaii (Paton et al. 1985).

The black-crowned night-heron nests in small numbers on all the main islands. It is not considered taxonomically distinct from the North American form. Statewide semiannual counts of black-crowned night herons between 1980 and 1985 averaged 367, ranging widely between 155 and 510 birds. Numbers have increased greatly during the past decade and pose a potential threat as predators to endangered endemic water birds.

Raptors

The Hawaiian Islands support one endangered raptor, the Hawaiian hawk (Figure 7), in addition to the widespread short-eared owl and the introduced barn owl. Several taxa of long-legged owls, one eagle, and one accipiter are known only from the subfossil record (Olson and James 1982). While the Hawaiian hawk occurs on only a single island, it still occupies about 95% of its historical range on Hawaii; when its former range on Molokai is considered, it is still found in more than 85% of its pre-Polynesian range (Figure 8). Its ability to feed and nest in forests of introduced species and feed on alien animals bodes well for its future (Griffin 1985, Scott et al. 1986a). The ground-nesting short-eared owl occurs on six islands, is vulnerable to introduced predators, and is less flexible in its habitat requirements than the Hawaiian hawk. There have been no attempts to estimate its population size on any of the islands, and much more information is needed on its reproduction and population dynamics.

Figure 6. The American "Hawaiian" coot is one of two remaining rail species in Hawaii. Photo © 1988 R. J. Shallenberger.

Perching birds

Crows. Formerly at least three species of crows occurred in Hawaii (Olson and James 1982), but only one survived into the historic period. The Hawaiian crow was abundant on Hawaii in the 19th century, yet its numbers have steadily declined since at least 1900. From hundreds in the 1960s, numbers plummeted to 76 birds in 1978, and to perhaps 10 in 1986 (Giffin et al. 1987). Observers were able to locate only two crows in the wild in the spring of 1987 (Figure 8). Loss of habitat, introduced predators, and diseases have taken their toll. Eight birds in captivity on Maui provide a minimal core population for a breeding program, and efforts have begun to secure habitat for them with the creation of a 1740-hectare state sanctuary for forest birds on Hualalai, Hawaii (Giffin et al. 1987).

Monarch flycatchers. The elepaio is the only known monarch flycatcher (monarchinae) in Hawaii. No fossils for other members of this subfamily have been found (Olson and James 1982). Although there are no known extirpations of elepaio in the Hawaiian Islands, its absence from Maui, Molokai, and Lanai is a zoogeographic peculiarity that could indicate extinctions there. The elepaio is found on Hawaii, Oahu, and Kauai. Recently Pratt (1980) revised the taxonomy of this group and identified three subspecies on the island of Hawaii. One of these (*Chasiempis sandwichensis bryani*), restricted to the upper slopes of Mauna Kea, has a smaller range, and only a slightly larger population, than the endan-

Figure 7. The Hawaiian hawk is one of two native raptors in the islands. It is found only on the island of Hawaii. Photo © 1988 R. J. Shallenberger.

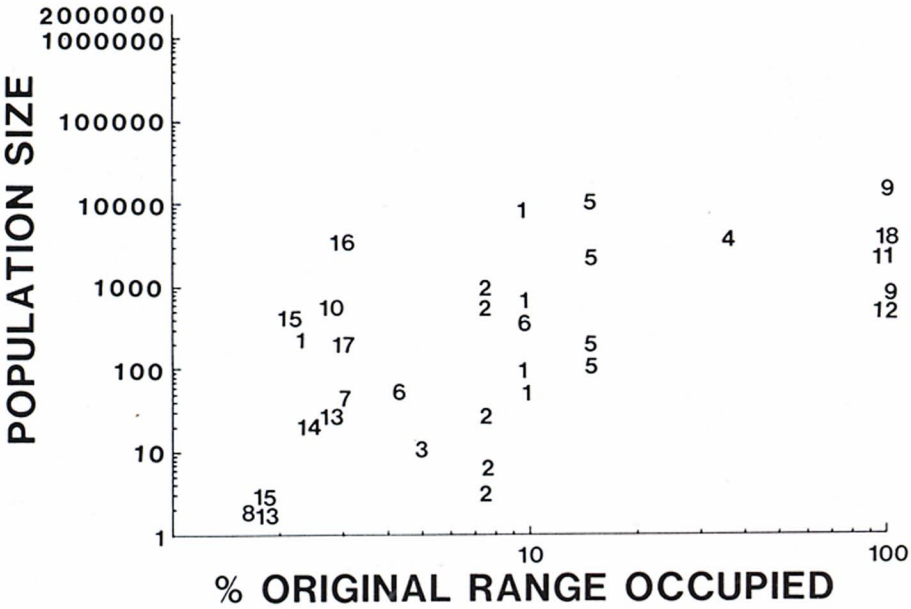

Figure 8. Population sizes of and percent of historical range occupied by endangered forest birds on the islands of Hawaii, Maui, Molokai, Lanai, and Kauai. A population is defined as an isolated group of breeding birds. 1=akepa, 2=akiapolaau, 3=Hawaiian crow, 4=crested honeycreeper, 5=Hawaii creeper, 6=Hawaiian goose, 7=kamao, 8=Kauai o'o, 9=Laysan finch, 10=Maui parrotbill, 11=Nihoa finch, 12=Nihoa Millerbird, 13=nukupuu, 14=olomao, 15=ou, 16=palila, 17=puaiohi, and 18=Hawaiian hawk. The horizontal and vertical scales are logarithmic.

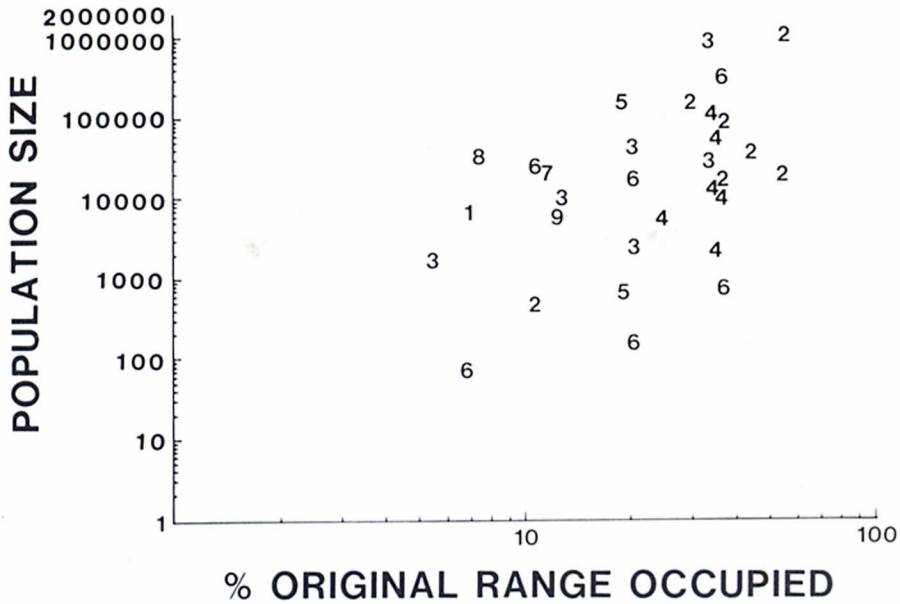

Figure 9. Population sizes of and percent of historical ranges occupied by nonendangered forest birds on the islands of Hawaii, Maui, Molokai, Lanai, and Kauai. 1=Kauai creeper, 2=apapane, 3=common amakihi, 4=elepaio, 5=omao, 6=iiwi, 7=anianiau, 8=Maui creeper, and 9=akepa (data from Scott et al. 1986a)

gered palila. Population sizes range from 2500 to 115,000 (Figures 8 and 9). A recent court decision (Palila 1986) requiring the removal of mouflon (*Ovis musimon*) from Mauna Kea should aid this population by protecting the mamane-naio (*Sophora chrysophylla-Myoporum sandwicense*) ecosystem that it occupies. Other subspecies of elepaio, thought to be surviving well even at low elevations on Oahu (Conant 1977), are apparently not adapting to alien plants, vertebrates, and diseases in the islands.[8]

Thrushes. A recent taxonomic revision of the Hawaiian thrushes (Pratt 1982) identified six species as having occurred in the Hawaiian Islands. While a subfossil occurrence of a species has been recorded for Maui, its taxonomic status has not been determined.[9] Three (those on Lanai, Oahu, and Maui) are extinct, and all the others except the omao are considered endangered. Population sizes for the extant Hawaiian thrushes range from less than 20 on Molokai to 170,000 on Hawaii (Table 3, Figures 8 and 9). The species on Molokai (olomao) and Kauai (kamao and puaiohi) are missing from a major part of their former ranges, are found in single declining populations, and are in imminent danger of extinction (Figures 8 and 9). The Hawaii Island birds, which number more than 140,000, range over a much larger area and are found in two populations (van Riper and Scott 1979). However, even this species occurs in less than 25% of its former range.

Honeyeaters. Originally this family was represented by five widespread species in Hawaii. Today only one species, the Kauai oo, is known to survive; its population was estimated at two in 1980 (Scott et al. 1986a). Subsequent studies have been unable to locate more than a single individual deep in the heart of the Alakai Swamp. This bird is perhaps the last survivor of a formerly dominant group in the forest canopies of 19th century Hawaii, although there are putative records of Bishops' oo (*Moho bishopi*) on Maui (American Ornithologists Union [AOU] 1983).

Hawaiian honeycreepers. This family was once comprised of a minimum of 47 species (Olson and James 1982). At least 18 species were extirpated

[8]S. Conant. 1988. Personal communication. University of Hawaii, Honolulu.

[9]S. L. Olson, 1987. Personal communication. Smithsonian Institute, Washington, DC.

Only two oo birds are thought to survive. Photo: Robert J. Shallenberger, courtesy Defenders of Wildlife.

Table 3. Terrestrial bird populations on islands other than Oahu. There are no estimates of the numbers of native forest birds on Oahu. But a single population was assumed for those species known to occur there. Data from Griffin and Scott et al. 1986a.

	Population sizes		Total number of birds	Percent of populations <500	Percent of populations <50	Number of populations
	Maximum	Minimum				
Hawaiian hawk *Buteo solitarius*	2700	2700	2700	0	0	1
Short-eared owl† *Asio flammeus*			no estimate			6
Hawaiian crow *Corvus hawaiiensis*	8	2	12	100	100	1
Elepaio† *Chasiempis sandwichensis*	191,127	857	213,289	0	0	6
Millerbird *Acrocephalus familiaris*	577	577	577	0	0	1
Omao *Myadestes obscurus*	170,525		170,525	0	0	1
Olomao *Myadestes lanaiensis*	19	19	19	100	100	1
Kamao *Myadestes Myadestinus*	24	24	24	100	100	1
Puaiohi *Myadestes palmeri*	176	176	176	100	0	1
Bishops oo *Moho bishopi*	?	?	?	100?	100?	1?
Kauai oo *Moho braccatus*	2	2	2	100	100	1
Laysan finch *Telespyza cantans*	14,786	900	15,686	0	0	2
Nihoa finch *Telespyza ultima*	2227	2227	2227	0	0	1
Ou *Psittirostra psittacea*	394	3	397	100	50	2
Palila *Loxioides bailleui*	2200	2200	2200	0	0	1
Maui parrotbill *Pseudonestor xanthophrys*	500	500	500	100	0	1
Common amakihi† *Hemignathus virens*	840,673	1834	926,612	0	0	6
Anianiau *Hemignathus parvus*	24,000	24,000	24,000	0	0	1
Kauai akialoa *Hemignathus procerus*	<10	<10	<10	100	100	1
Nukupuu *Hemignathus lucidus*	28	<25	50	100	100	2
Akiapolaau *Hemignathus munroi*	891	10	1494	60	60	5
Kauai creeper *Oreomystis bairdi*	6800	6800	6800	0	0	1
Hawaii creeper *Oreomystis mana*	10,100	25	24,780	50	25	4
Maui creeper *Paroreomyza montana*	34,200	600	34,800	0	0	2
Molokai creeper *Paroreomyza flammea*	?	?	?	100	100	1
Oahu creeper† *Paroreomyza maculata*	?	?	?	100	100	1
Akepa† *Loxops coccineus*	7938	50	15,793	14?	14	7
Iiwi† *Vestiaria coccinea*	339,615	80	413,485	33	17	6
Crested honeycreeper *Palmeria dolei*	3753	3753	3753	0	0	1
Apapane† *Himatione sanguinea*	1,077,574	540	1,277,100	0	0	7
Poo-uli *Melamprosops phaeosoma*	141	141	141	100	0	1

*C. Griffin, 1987. Personal communication. University of Massachusetts, Amherst.
†Species with populations on Oahu.

prehistorically, and another 8 were eliminated after Captain Cook's arrival in 1778. Despite these losses, the 20 extant species still provide the most impressive example of adaptive radiation among birds, with their bills ranging from stout seed crushers (palila) through parrot-shapes (Maui parrotbill), crossed-bills (akepa), warblerlike forceps (Maui creeper), to decurved probes (iiwi) (Figure 10) that, in the Kauai akialoa, span one-third the bird's overall length (see Raikow 1976).

The stresses that have plagued the drepanidines for centuries continue at present, with devastating effect. Of the 20 surviving species, 6 species number fewer than 500 birds, and 3 species number 50 or fewer. The population size of the Oahu creeper is unknown, but it is very rare and probably numbers fewer than 100. Nearly half the species rely upon a single population for their survival (Table 3). Eleven of the 53 drepanidine populations (21%) number less than 500 individuals (Figures 8 and 9). Fourteen of the 18 species on the main islands are restricted to ohia (*Metrosideros polymorpha*) or ohia-koa (*Acacia koa*) forests, which are subject to accelerating degradation due to domestic cattle, feral pigs, and the more subtle effects of the invasion of alien insects (including *Culex quinquefasciatus*, which carries avian malaria; van Riper et al. 1986), plants, and competing birds. The range of problems facing the honeycreepers can be demonstrated with a few species.

Three species (apapane, iiwi, and amakihi) account numerically for approximately 95% of all the extant honeycreepers. But even within this triumvirate all is not well. The most successful drepanidine is the nectarivorous apapane, distributed over six islands, with densities in places exceeding 1600 birds/km^2, and a population in excess of 1,000,000 birds on Hawaii. Yet even this successful species is represented by fewer than 1000 birds on Lanai and a small, unknown number on Oahu.

Two other species (common amakihi and iiwi) number in the hundreds of thousands with a range that spans several islands. The common amakihi disappeared from Lanai in the 1970s (Hirai 1978), and three of its current

Figure 10. The iiwi; a common honeycreeper of the Hawaiian islands. Photo © 1988 R. J. Shallenberger.

populations each have fewer than 3000 individuals. The iiwi, with over 400,000 individuals, is extinct on Lanai; the Molokai and West Maui populations each contain fewer than 200 individuals and it is extremely rare on Oahu. Both the amakihi and iiwi were formerly much more widespread.

In contrast to the 3 abundant species, there are 15 species with more specialized habitats and ranges restricted to only one or two islands. Those most seriously threatened include the Molokai creeper (last seen in 1962), akialoa (last seen in 1965), Oahu creeper (probably fewer than 100), Nukupuu (perhaps less than 100 birds total on Kauai and Maui), poo-uli (numbers greatly reduced from the 140 estimated in 1980), and o'u (fewer than 400). They are all candidates for extinction.

The poo-uli is an excellent example of what is happening in the forests of Hawaii. It is restricted to 13 km^2 on Haleakala's wet northeast slope. Its population was estimated at 140 in 1980 (0.03 birds/count period), a decline of 85% from densities found in 1975 (0.18 birds/count period) (Mountainspring et al. in press). The population had experienced a further decline by 1986; no birds were detected during 77 eight-minute station counts, and sightings were restricted to incidental observations of the bird.[10]

Why is the poo-uli declining so precipitously when it occurs in a highly remote ohia forest far from direct human impacts? Feral pig activity, as measured by rooting, increased 473% from 1975 to 1985. Increased pig activity encourages the spread of mosquitoes by creating breeding sites. Loss of understory, including a dense mossy layer harboring snails and insects, important poo-uli foods (Baldwin and Casey 1983), has resulted in accelerated erosion on the steep slopes. The introduced garlic snail (*Oxychilus alliarius*), predatory on other land snails, is now firmly established within the poo-uli's range and may compete for food. *Rattus rattus* and *Rattus exulans* are both abundant. Avian diseases, especially malaria, continue as important stresses below about 1500-meter elevation (van Riper et al. 1986).

The myriad stresses afflicting poo-uli are active throughout the islands of Hawaii. Small and declining populations of the poo-uli, whether of nonendangered or endangered species, share two prominent features: they all have a sharply reduced distributional range and less than 50% of their population occurs below 1500-meter elevation. What can be done to halt the apparently irreversible decline of these birds?

[10]C. Kepler, 1987. Personal communication. USFWS, Athens, GA.

Management of small populations

In reviewing the status of Hawaii's birds, we have focused on populations rather than species, and for the terrestrial birds we have also considered the percentage of historical range occupied (Figures 8 and 9). Only the translocated Laysan finch occupies more than its historical range at the time of the Polynesians' arrival. Figures 8 and 9 show that only 5 of the remaining 25 species (20%) occupy more than half their historical range on all islands.

Gilpin and Soule (1986) suggest that an effective population size of 500 is the minimal viable population (MVP) necessary for long-term genetic survival of a population and an effective population size of 50 is the MVP for short-term survival (Gilpin and Soule 1986). However, more recent works (see papers in Soule 1987) use MVP couched in terms of 95% probability of a population surviving 100 or 1000 years (Shaffer 1987). Many of Hawaii's bird populations number less than 500. The akepa and creeper number more than 5000 but are still considered endangered because of the threat of alien species and habitat loss.

In many instances, conservationists and managers are considering a recovery goal of the MVP level. Indeed, in the case of the spotted owl (*Strix occidentalis*) in North America, a candidate endangered species, there has been discussion of reducing the population to the level of MVP. This strategy could ultimately prove to be a costly mistake. Managers must consider striving for sustainable population levels that have a high probability of surviving 100 generations or more. In many instances, these levels will be at least an order of magnitude greater than 500.

In situ recovery efforts

During the past decade, there have been impressive strides in learning about the distribution, abundance, habitat requirements, and limiting factors of Hawaii's avifauna (Conant 1977, Fefer et al. 1984, Griffin et al. in press, Harrison et al. 1984, Mountainspring and Scott 1985, Reed et al. 1985, Scott et al. 1984, 1986a, Simons 1983, Telfer et al. 1987, van Riper 1984, van Riper and Scott 1979, van Riper et al. 1986, Weathers and van Riper 1982). Although recovery efforts for all Hawaiian species would benefit from more detailed information, enough is presently known to permit the intelligent management of this fragile resource. Extensive, explicit recovery plans have been written for all the endangered birds except the forest birds of Oahu, and these plans in large part are being implemented (see Scott et al. 1986a for a review). Even so, because the stresses to Hawaiian ecosystems are persistent and pervasive, they will continue cumulatively to affect native species, many of which may yet be lost without ex situ management.

Seabirds. Breeding colonies of dark-rumped petrels could be increased through an active predator control program at high-elevation sites on Hawaii, Lanai, and Molokai and extended efforts at peripheral colonies on Maui. Predator control programs to guard Townsend's shearwaters should be applied to all known Kauai colonies and should include pig control where necessary. Translocation of young birds and the use of taped calls to attract breeding birds may speed colonization.

Efforts on behalf of nonendangered seabirds have focused on development of a seabird monitoring program for the major seabird colonies within the Hawaiian Islands National Wildlife Refuge (NWR) (Fefer et al. 1984). Such a program should detect changes due to environmental alterations on land or sea. An active fisheries industry, for example, could affect the birds by reducing their food supply. Managers have attempted to ensure that alien plants and animals are not introduced by island visitors. These steps also protect the three endangered land birds inhabiting the Hawaiian Islands NWR. Specific regulations designed to minimize the potential for alien introductions have recently been implemented (USFWS 1986).

Elimination of rats and cats and reduction of human disturbance are needed on seabird islets off the main islands as well as on the more remote leeward islands. Equally important are systematic monitoring programs to ensure that predators will be quickly discovered and eradication programs implemented.

Water birds. Because the original conditions for many water-bird habitats are not known, conservation efforts have concentrated on the birds themselves rather than on restoring native habitats. To produce the greatest number of endangered water birds possible, intensive management is underway in manmade or highly altered natural impoundments, containing species alien to Hawaii. The challenge in Hawaii and elsewhere is to minimize the number of other species that must be managed in this manner.

Restoring Hawaiian water birds requires additional wetlands on Maui, Hawaii, and Oahu, as well as nesting islets, predator control programs, and manipulation of water levels and food availability to increase the numbers of breeding birds. Effective habitat enhancement programs for water birds become more important as unprotected wetlands continue to diminish in extent and quality. Because of financial constraints and increasing competition for land that is already exorbitantly expensive, it is imperative that wetland managers become more aware of critical habitats and management options.

Land birds. The eight-year Hawaiian Forest Bird Survey (Scott et al. 1986a) sampled 9940 stations along 1400 kilometers of transects and recorded more than 240,000 birds during 20,789 count periods on Hawaii, Maui, Molokai, Lanai, and Kauai. Therefore, detailed information is available on distribution abundance and limiting factors of Hawaiian forest birds, and these data have been used to identify potential reserve areas. Large tracts of forest have been dedicated as reserves on Hawaii, Maui, and Molokai by the state of Hawaii, US National Park Service, USFWS, and The Nature Conservancy of Hawaii (Scott et al. 1987b). Still more needs to be done.

It is on Hawaii and Maui that the largest acreages of forest-bird habitat remain without legal protection and without management to sustain native bird populations. The majority of areas, especially the ohia and ohia-koa forests upon which most endemic

species are dependent, are being seriously degraded by humans and their commensals. Many of these areas are above 1500-meter elevation, above which the threats from avian malaria and pox are presumed to be significantly less. It is these areas that provide the greatest opportunity for increasing the population sizes of many of Hawaii's endangered forest birds.

On Hawaii we envision a continuous band of forest-bird refuges, beginning in the cloud-enshrouded forests of windward Mauna Kea (Hakalau National Wildlife Refuge), then wrapping southeast around Mauna Loa through Hawaii Volcanoes National Park to the ohia-koa forests of Kau (Figure 11). Such a system would link presently disjunct populations of akepa, creeper, and akiapolaau in Kau with those of windward Mauna Kea. If the pasturelands between 1800- and 2400-meter elevations on Mauna Kea were also reforested, the former ecotone between the dry mamane and moist koa-ohia forests would be reestablished. Widening the forest, and improving its quality by removing all ungulates and planting native trees, would be a long-term recovery effort that could double the numbers of endangered forest birds in upper Mauna Kea in an area that is well above the elevation where disease is presumed to be a major limiting factor.

On Maui, similar habitat restoration efforts are possible in the high elevation koa-ohia forests of Haleakala. Relinking the ohia-koa forests of Kuiki to those of Kahikinui, through the Kaupo Gap, and reforesting the damaged koa-ohia forests on the windward side and those above Kula would be a major step in the recovery effort for Maui's endangered forest-bird community (Figure 4). Restoration efforts need to be coupled with greatly expanded efforts for control of alien ungulates, especially pigs, in order to maximize chances for successful reforestation of critical upland areas (Stone and Loope 1987).

The restoration of upland ohia and ohia-koa forests on Maui and Hawaii will require an aggressive control program for alien ungulates, invertebrates, and plants, as well as the elimination of domestic stock from many of these areas. Such a program will also increase the numbers of endemic invertebrates and plants that will survive into the 22nd century.

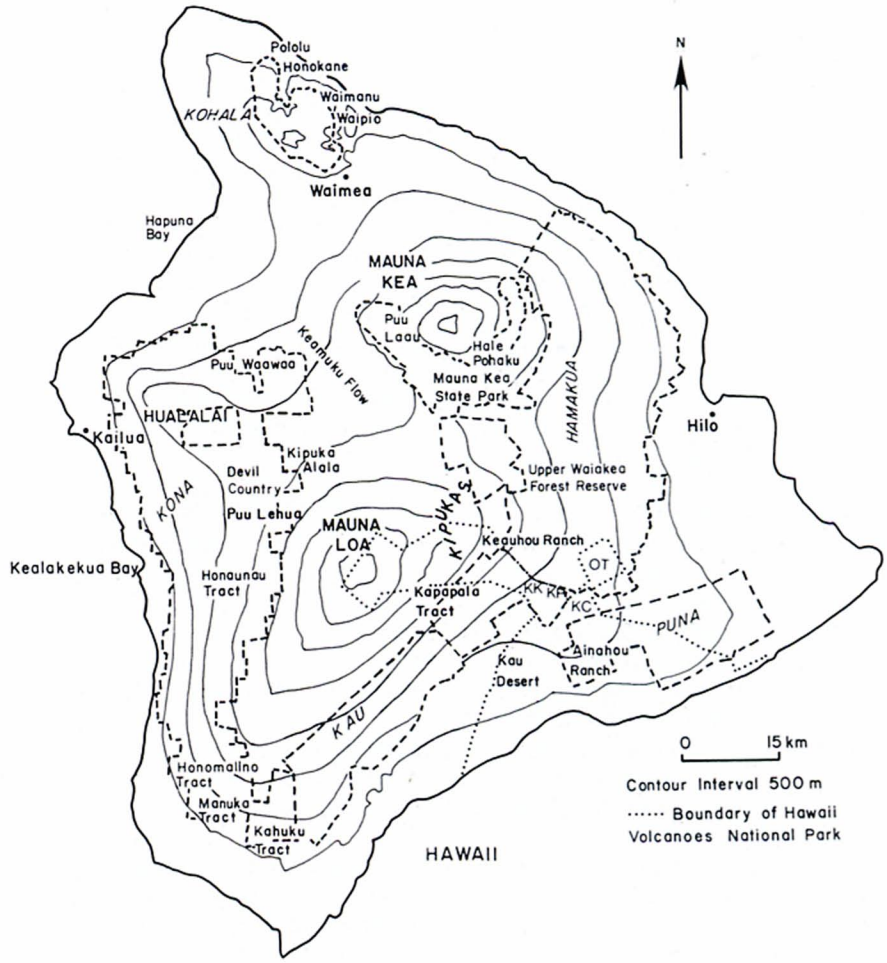

Figure 11. The island of Hawaii.

Protection and restoration of forests above 1500-meter elevation will increase the numbers of forest birds (Scott et al. 1983, 1986a). It will also preserve large numbers of native plants and invertebrates that also occupy those habitats in the Hawaiian Islands. This system approach should also prevent many other taxa from declining to such low numbers that they will ultimately be considered endangered.

Ex situ recovery efforts

In recent years there have been intense debates in the conservation and scientific communities on the need, timing, and wisdom of removing some or even all remaining individuals of a bird species from the wild as a last resort to save the species from extinction (James 1980, Ogden and Snyder 1981, Pitelka 1981). In the case of the dusky seaside sparrow (*Ammodramus maritimus nigrescens*) and several Guamanian species, the action came too late. It remains to be seen whether action was taken in time to save the California condor (*Gymnogyps californianus*). However, recoveries of New Zealand's Chatham Island robin (*Petroica traverse*), North America's whooping crane (*Grus americana*), and the Puerto Rican parrot (*Amazona vittata*) suggest that recoveries can be made from populations of less than 20, if limiting factors in the environment have been effectively controlled (Lewis 1986, Merton 1983, Snyder et al. 1987).

Captive propagation of endangered species was pioneered on Hawaii with the extensive breeding and release program for the Hawaiian goose. Begun in 1950, this program has not resulted in a self-sustaining wild population of the Hawaiian goose, but it is rightfully acclaimed as having saved the species from extinction.

Cross-fostering of Townsend's shearwater eggs into the nests of wedge-tailed shearwaters has been attempted in order to establish lowland breeding colonies of Townsend's shearwater (Byrd et al. 1984). Townsend's shearwaters have returned to these experimental colonies, but none are known to have nested there. Present plans are to continue the shearwater translocation efforts using eggs, chicks, and tape-recorded calls. Captive propagation efforts on behalf of the Hawaiian goose, Hawaiian crow, and the two endangered ducks will continue, but none are underway for any other Hawaiian species.

Despite the efforts at habitat protection and improvement, it seems unlikely that the kamao, poo-uli, or ou will survive without massive captive-rearing programs. Although such programs would not guarantee their survival as self-sustaining wild populations, such efforts must be started soon if there is to be any reasonable chance of saving these species. The Kauai oo, the nukupuus on Kauai and Maui, the Molokai creeper, and the olomao are perhaps beyond the point where even captive propagation can save them.

For those species occurring on islands with small acreages above 1500-meter elevations (Kauai, Molokai, and Oahu), the prospects for successful reintroductions or augmentation of existing populations from captive flocks seem minimal. The only means of saving these species outside a zoo environment may be the development of disease-resistant strains.

Conclusions

State, federal, and private researchers are further identifying population-limiting factors by studying surrogate species and distributional anomalies. They are investigating the importance of disease, predation, and parasites as limiting factors for the endemic birds of Hawaii. While this work goes on, conservationists should act on what is already known, while continuously monitoring numbers of selected species. Doing so will increase the survival chances of Hawaii's fragile avifauna, which is still the world's best example of adaptive radiation and an evolutionary showcase for the ornithologists of the world.

The experience in Hawaii provides a view of the future of other ecosystems if biological diversity is not successfully protected (Scott et al. 1987a). The issue of how to allocate limited fiscal and intellectual resources among clinical and systems approaches to protecting biological diversity is perhaps in sharpest focus in Hawaii. It is only through the system approach that is presently being used in Hawaii that we have any chance of preserving Hawaii's unique avifauna for future generations.

Acknowledgments

We thank David Ainley, Sheila Conant, Reid Goforth, Curt Griffin, Alan Holt, A. Kay Kepler, Allan Marmelstein, A. Newman, Charles P. Stone, and R. J. Shallenberger for providing thoughtful comments on early drafts of this manuscript. We thank H. F. James and S. L. Olson for use of unpublished data and Lee Cantrell, Allan Jokisaari, and R. L. Walker for preparing the line drawings. Maureen Edwards provided thoughtful editorial assistance and typed various drafts of the manuscript.

The Idaho Cooperative Fish and Wildlife Research Unit is funded and supported by Idaho Department of Fish and Game, University of Idaho, USFWS, and the Wildlife Management Institute. This is contribution number 349 from the University of Idaho, Forestry and Wildlife Resources Experiment Station.

References cited

American Ornithologists Union (AOU). 1983. *Check-list of North American Birds*. Allen Press, Lawrence, KS.

Atkinson, I. A. E. 1977. A reassessment of factors, particularly *Rattus rattus* L. that influenced the decline of endemic forest birds in the Hawaiian islands. *Pac. Sci.* 31: 109–133.

Baldwin, P. H. 1947. The life history of the Laysan rail. *Condor* 49: 14–21.

Baldwin, P. H., and T. L. C. Casey. 1983. A preliminary list of foods of the Po'o-uli. *'Elepaio* 43: 53–56.

Berger, A. J. 1981. *Hawaiian Birdlife*. University Press of Hawaii, Honolulu.

Byrd, G. V., R. A. Coleman, R. J. Shallenberger, and C. S. Arune. 1985. Notes on the breeding biology of the Hawaiian race of the American coot. *'Elepaio* 45: 57–63.

Byrd, G. V., J. L. Sincock, T. C. Telfer, P. I. Moriarty, and B. G. Brady. 1984. A cross-fostering experiment with Newell's race of manx shearwater. *J. Wildl. Manage.* 48: 163–168.

Byrd, G. V., and C. F. Zeillemaker. 1981. Ecology of nesting Hawaii common gallinules at Hanalei, Hawaii. *West. Birds* 12: 105–116.

Conant, S. 1977. The breeding biology of the Oahu elepaio. *Wilson Bull.* 89: 193–210.

Fefer, S. I., M. B. Naughton, C. S. Harrison, and R. J. Shallenberger. 1984. Synopsis of results of recent seabird research conducted in the northwestern Hawaiian Islands. Pages 9–76 in R. W. Grigg and K. Y. Tanoue, eds. Proceedings of the Symposium on Resource Investigations in the Northwestern Hawaiian Islands, University of Hawaii Sea Grant Program, Honolulu.

Fisher, H. I., and P. H. Baldwin. 1946. War and the birds of Midway Atoll. *Condor* 48: 3–15.

Fry, D. M., S. I. Fefer, and L. Sileo. 1987. Ingestion of plastic debris by Laysan albatrosses and wedge-tailed shearwaters in the Hawaiian Islands. *Mar. Pollut. Bull.* 18: 339–343.

Giezentanner, B. D. Woodside, J. Sincock, and E. Kridler. 1982. *Laysan Duck Recovery Plan*. US Fish and Wildlife Service, Portland, OR.

Giffin, J. G., J. M. Scott, and S. Mountainspring. 1987. Habitat selection and management of the Hawaiian crow. *J. Wildl. Manage.* 51: 485–494.

Gilpin, M. E., and M. E. Soule. 1986. Minimum viable populations: processes of species extinction. Pages 19–34 in M. E. Soule, ed. *Conservation Biology*. Sinauer Assoc., Sunderland, MA.

Griffin, C. R. 1985. *Hawaiian Hawk Recovery Plan*. US Fish and Wildlife Service, Portland, OR.

Griffin, C. R., R. J. Shallenberger, and S. I. Fefer. In press. Hawaii's endangered waterbirds: a resource management challenge. In R. R. Sharitz and J. W. Gibbon, eds. Proceedings Synopsis on Freshwater Wetlands for Wildlife, Savannah River Ecology Laboratory, Aiken, SC.

Harrison, C. S., M. B. Naughton, and S. I. Fefer. 1984. The status of seabirds in the Hawaiian Archipelago and Johnston Atoll. Pages 513–526 in J. P. Croxall, P. G. H. Evans, and R. W. Schreiber, eds. *Status and Conservation of the World's Seabirds*, International Council for Bird Preservation Tech. Publ. 2, Cambridge, UK.

Hirai, L. T. 1978. Native birds of Lanai, Hawaii. *West. Birds* 9: 71–77.

Howarth, F. G. 1985. The impacts of alien land arthropods and molluscs on native plants and animals. Pages 149–179 in C. P. Stone and J. M. Scott, eds. *Symposium on Protection and Management of Terrestrial Hawaiian Ecosystems*. University of Hawaii Press, Honolulu.

James, F. C. 1980. Miscegenation in the dusky seaside sparrow. *BioScience* 30: 800–801.

Kear, J., and A. J. Berger. 1980. *The Hawaiian Goose: An Experiment in Conservation*. Buteo Books, Vermillion, SD.

King, W. B. 1981. *Endangered Birds of the World: The ICBP Bird Red Data Book*. Smithsonian Institution Press, Washington, DC.

King, W. B., and P. J. Gould. 1967. The status of Newell's race of the manx shearwater.

Living Bird 6: 163–186.
Lewis, J. C. 1986. The whooping crane. Pages 657–676 in R. L. DiSilvestro, ed. *Audubon Wildlife Report—1986*. R. R. Dunnelley & Sons, New York.
Loope, L. L., O. Hamann, and C. P. Stone. 1988. Comparative conservation biology of oceanic archipelagoes. *BioScience* 38: 272–282.
Merton, D. V. 1983. Chatham Island black robin. *Wildl. Rev. N. Z. Wildl. Serv.* 12: 12–49.
Moulton, D. W., and M. W. Weller. 1984. Biology and conservation of the Laysan duck. *Condor* 86: 105–117.
Mountainspring, S., T. L. C. Casey, C. B. Kepler, and J. M. Scott. In press. Ecology, behavior, and conservation of the poo-uli. *Wilson Bull.*
Mountainspring, S., and J. M. Scott. 1985. Interspecific competition among Hawaiian forest birds. *Ecol. Monogr.* 55: 219–239.
Mueller-Dombois, D., K. W. Bridges, and H. L. Carson, eds. 1981. *Island Ecosystems: Biological Organization in Selected Hawaiian Communities*. Hutchinson Ross, Stroudsburg, PA.
Ogden, J. C., and N. F. R. Snyder. 1981. The view from Ventura . . . . *Pt. Reyes Bird Observatory Newsl.* 53: 11–15.
Olson, S. L., and H. F. James. 1982. Prodromus of the fossil avifauna of the Hawaiian Islands. *Smithson. Contrib. Zool.* 365.
Palila (*Loxioides bailleui*) et al. vs. Hawaii Department of Land and Natural Resources et al. 649 F. Supp. (D. HI, 18 Nov. 1986).
Paton, P. W. C., J. M. Scott, and T. A. Burr. 1985. American coot and black-necked stilt on the island of Hawaii. *West. Birds* 16: 175–181.
Perkins, R. C. L. 1903. Vertebrata. Pages 365–466 in D. Sharp, ed. *Fauna Hawaiiensis*. vol. 1, part IV. The University Press, Cambridge, UK.
Pitelka, F. A. 1981. The condor case: An uphill struggle in a downhill crash. *Auk* 98: 634–635.
Pratt, H. D. 1980. Intra-island variation in the elepaio on the island of Hawaii. *Condor* 82: 449–458.
_____. 1982. Relationships and speciation of the Hawaiian thrushes. *Living Bird* 19: 73–90.
Pratt, H. D., P. L. Brunner, and D. G. Bennett. 1986. *A Field Guide to the Birds of Hawaii and the Tropical Pacific*. Princeton University Press, Princeton.
Raikow, R. J. 1976. The origin and evolution of the Hawaiian honeycreepers. *Living Bird* 15: 95–117.
Reed, J. R., J. L. Sincock, and J. P. Hailman. 1985. Light attraction in endangered procellariiform birds: Reduction by shielding upward radiation. *Auk* 377–383.
Ripley, D. S. 1986. The Smithsonian's role in US cultural and environmental development. *BioScience* 36: 153–157.
Scott, J. M., B. Csuti, J. D. Jacobi, and J. E. Estes. 1987a. Species richness: a guide to protecting future biological diversity. *BioScience* 37: 782–788.
Scott, J. M., C. B. Kepler, P. Stine, H. Little, and K. Taketa. 1987b. Protecting endangered forest birds in Hawaii: the development of a conservation strategy. Pages 348–363 in R. T. McCabe, ed. *Transactions of the 56th North American Wildlife and Natural Resources Conference*, Wildlife Management Institute, Washington, DC.
Scott, J. M., S. Mountainspring, F. L. Ramsey, and C. B. Kepler. 1986a. Forest bird communities of the Hawaiian Islands: their dynamics, ecology and conservation. *Stud. in Avian Biol.* No. 9.
Scott, J. M., S. Mountainspring, C. van Riper III, C. B. Kepler, J. D. Jacobi, T. A. Burr, and J. G. Giffin. 1984. Annual variation in the distribution abundance and habitat of the palila (*Loxioides bailleui*). *Auk* 101: 647–664.
Scott, J. M., C. P. Stone, and R. L. Walker. 1986b. Of geese and faulty sentences. *BioScience* 36: 412–413.
Shaffer, M. 1987. Minimum viable populations: coping with uncertainty. Pages 69–86 in M. C. Soule, ed. *Viable Populations for Conservation*. Cambridge University Press, New York.
Shallenberger, R. J. 1977. An ornithological survey of Hawaiian wetlands. US Army Corps of Engineers, Honolulu.
Simons, T. R. 1983. Biology and conservation of the endangered Hawaiian dark-rumped petrel (*Pterodroma phaeopygia sanwichensis*). National Park Service, Cooperative Park Studies Unit, College of Forestry Resources, University of Washington, CPSU/YW 83–2, Seattle.
Sincock, J. L., and G. E. Swedberg. 1969. Rediscovery of the nesting grounds of Newell's manx shearwater (*Puffinus puffinus newelli*) with initial observations. *Condor* 71: 69–71.
Smith, C. W. 1985. Impact of alien plants on Hawaii's native biota. Pages 180–250 in C. P. Stone and J. M. Scott, eds. *Hawaii's Terrestrial Ecosystems: Preservation and Management*. University of Hawaii Press, Honolulu.
Snyder, N. F. R., J. Wiley, and C. Kepler. 1987. The Parrots of Luquillo: Natural History and Conservation of the Puerto Rican Parrot. Western Foundation of Vertebrate Zoology, Los Angeles, CA.
Soule, M. E., ed. 1987. *Viable Populations for Conservation*. Cambridge University Press, New York.
Stone, C. P., and L. L. Loope. 1987. Reducing negative effects of introduced animals on native biota in Hawaii: what is being done, what needs doing, and the role of national parks. *Environ. Conserv.* 14: 245–258.
Stone, C. P., R. L. Walker, J. M. Scott, and P. C. Banko. 1983. Hawaiian goose management and research—where do we go from here? *'Elepaio* 44: 11–15.
Swedberg, G. E. 1967. *The Koloa*. Department of Land and Natural Resources, Honolulu.
Telfer, T. C., J. L. Sincock, G. V. Byrd, and J. A. Reed. 1987. Attraction of Hawaiian seabirds to lights: conservation efforts and effects of moon phase. *Wildl. Soc. Bull.* 15: 406–413.
Tomich, P. Q. 1986. Mammals in Hawaii: a synposis and notational bibliography. B. P. Bishop Museum Special Publication 76.
US Fish and Wildlife Service (UFSWS) 1986. Hawaiian Islands National Wildlife Refuge Master Plan/Environmental Impact Statement. FES 86/11. Region 1, Portland, OR.
van Riper, C., III. 1984. The influence of nectar resources on nesting success and movement pattern of the common amakihi (*Hemignathus virens*). *Auk* 101: 38–46.
_____. 1987. Breeding ecology of the Hawaiian common amakihi. *Condor* 89: 85–102.
van Riper, C., III, and J. M. Scott. 1979. Observations on distributions, diet, and breeding of the Hawaiian thrush. *Condor* 81: 65–71.
van Riper, C., III, S. G. van Riper, M. L. Goff, and M. Laird. 1986. The epizootiology and ecological significance of malaria in Hawaiian landbirds. *Ecol. Monogr.* 56: 327–344.
van Riper, S. G., and C. van Riper. 1982. *A Field Guide to the Mammals in Hawaii*. Oriental Publ., Honolulu.
Weathers, W. W., and C. van Riper III. 1982. Temperature regulation in two endangered Hawaiian honeycreepers: the palila (*Psittirostra bailleui*) and the Laysan finch (*Psittirostra cantans*). *Auk* 99: 667–674.