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CONSERVATION STATUS AND RECOVERY STRATEGIES FOR ENDEMIC HAWAIIAN BIRDS

PAUL C. BANKO, REGINALD E. DAVID, JAMES D. JACOBI, AND WINSTON E. BANKO

Abstract. Populations of endemic Hawaiian birds declined catastrophically following the colonization of the islands by Polynesians and later cultures. Extinction is still occurring, and recovery programs are urgently needed to prevent the disappearance of many other species. Programs to recover the endemic avifauna incorporate a variety of conceptual and practical approaches that are constrained by biological, financial, social, and legal factors. Avian recovery is difficult to implement in Hawai'i because a variety of challenging biological factors limit bird populations. Hawaiian birds are threatened by alien predatory mammals, introduced mosquitoes that transmit diseases, alien invertebrate parasites and predators that reduce invertebrate food resources, and alien animals and plants that destroy and alter habitats. Life in the remote Hawaiian Archipelago has imposed other biological constraints to avian recovery, including limited geographical distributions and small population sizes. Recovery of the endemic avifauna is also challenging because resources are insufficient to mitigate the many complex, interacting factors that limit populations. Decisions must be made for allocating limited resources to species teetering on the brink of extinction and those in decline. If funds are spent primarily on saving the rarest species, more abundant species will decline and become more difficult to recover. However, critically rare species will disappear if efforts are directed mainly towards restoring species that are declining but not in immediate danger of becoming extinct. Determining priorities is difficult also because management is needed both to supplement bird populations and to restore habitats of many species. Rare species cannot respond quickly to management efforts intended only to improve habitat and reduce limiting factors. Recovery is slow, if it occurs at all, because years or decades are generally required for habitat rehabilitation and because small populations of birds initially increase slowly even when habitat conditions are favorable. Consequently, even as habitat conditions begin to improve, small populations may disappear unless they are supplemented directly. Hawaiian bird conservation is also affected by social and legal factors, including hunting alien game species, commercial land use practices, and lawsuits and policies concerning endangered species and critical habitat. Influenced by this mixture of conflicting and competing issues, Hawaiian bird recovery programs range from management of single species and some components of their habitats to limited forms of community or ecosystem management. Although the effectiveness of most programs is difficult to evaluate because of monitoring limitations, several programs exemplify species and community management. Programs primarily intended to recover single species include Hawaiian Goose or Nēnē (*Branta sandvicensis*), Hawaiian Crow or 'Alalā (*Corvus hawaiiensis*), and Palila (*Loxioides bailleui*). Programs attempting to manage entire communities of forest birds include Hakalau Forest National Wildlife Refuge and Hawai'i Volcanoes National Park on Hawai'i, and Waikamoi Preserve, Hanawī Natural Area Reserve, and Haleakalā National Park on Maui.

Key Words: conservation; extinction; habitat management; Hawaiian birds; recovery strategy; species management.

The Hawaiian avifauna is renowned for the spectacular radiation of specialized species evolving from relatively few founders, widespread extinctions of endemic forms following human colonization, and recent inundation by alien species. In the wake of sweeping changes to native ecosystems wrought by humans, biologists and resource managers must struggle just to protect remaining species from extinction and prevent further degradation to habitats. Restoring whole communities of birds and entire ecosystems seems only a distant hope. Only during the last several decades have conservationists begun to appreciate the complexity of factors limiting Hawaiian bird populations and threats to their habitats (see van Riper and Scott, *this volume*). Success in recovering the remaining avifauna depends on developing and implementing strategies that overcome problems inherent in managing small populations in fragmented, degraded ecosystems and that mitigate the effects of alien species.

THE HAWAIIAN AVIFAUNA AND ITS COLLISION WITH CIVILIZATION

Indigenous and alien bird species inhabit the entire length of the Hawaiian Archipelago from Kure Atoll to the still-growing island of Hawai'i (2,683 km); endemic species are distributed from Laysan to Hawai'i (1,925 km; Fig. 1). Nearly 150 native species occupied this remote island chain before humans arrived. Isolation from continents and other island groups led to a high degree of endemism of the nonmigratory, terrestrial avifauna prior to the introduction of many new bird species during the 1900s. In contrast, relatively few marine species nest exclusively in the Hawaiian Islands, and resident

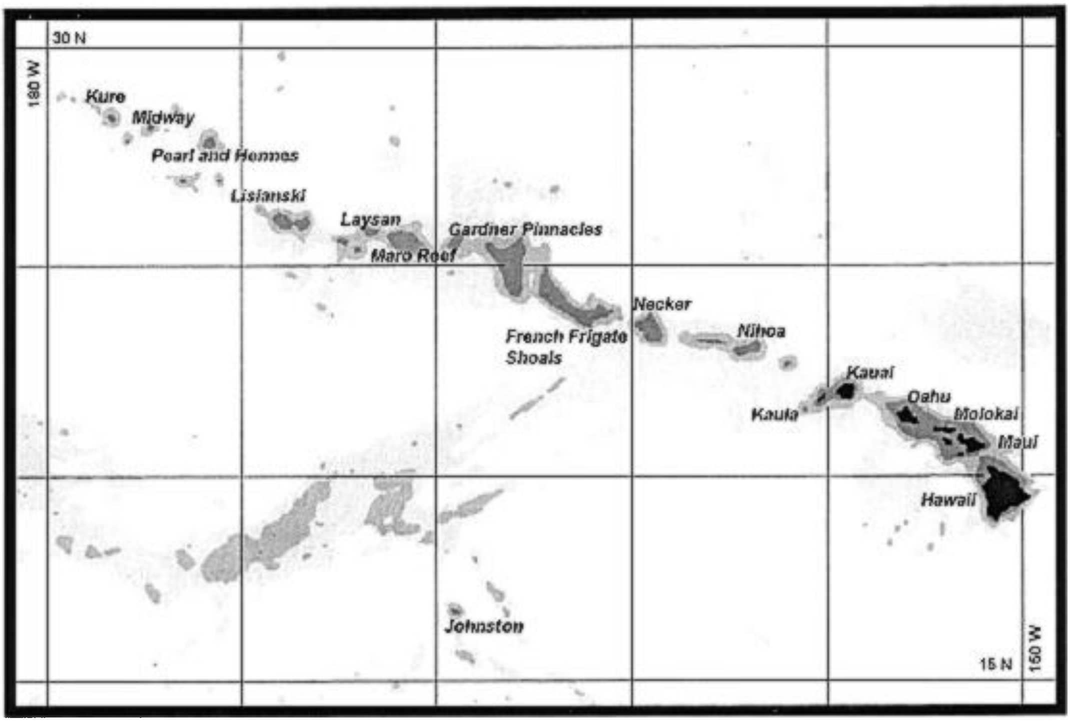

FIGURE 1. The Hawaiian Archipelago extends 2,683 km from Kure (the oldest island) to Hawai'i (the youngest island). Islands are formed and sustained sequentially as the Pacific lithospheric plate slides slowly over a "hot spot" (upwelling of magma) in the earth's mantle.

freshwater birds have differentiated only slightly from continental forms (Pratt et al. 1987, James and Olson 1991, Olson and James 1991, Pyle 1997). In addition, 51 species regularly or occasionally visit the islands and another 114 rarely occur but do not breed in the archipelago (Pyle 1997). More than 165 alien bird species have been introduced to the Hawaiian Islands, and at least 50 have established breeding populations persisting for 25 years or longer (Long 1981, Pyle 1997; R. E. David, unpubl. data).

The larger Hawaiian Islands, which extend 598 km from Kaua'i to Hawai'i, are home to most endemic terrestrial birds; however, marine species are more numerous in the smaller Northwestern Hawaiian Islands, which extend 1,837 km from Nihoa to Kure. Geological age of the archipelago increases with latitude, and island size and height decrease with age. The oldest major island, Kaua'i, is 5.1 million years old (K-Ar), whereas new land continues to be added to the youngest island, Hawai'i (Carson and Clague 1995). Two volcanic peaks rise over 4,100 m above sea level on Hawai'i, which is larger than all other remaining islands and atolls combined. Steep elevation and rainfall gradients, rugged topography, and a mosaic of substrate types resulting from lava flows of different ages characterize the major islands. In this setting, Hawaiian birds have become adapted to a variety of habitat types, foraging substrates, and food resources, resulting in a spectacular radiation of forms (Freed et al. 1987a).

Endemic species declined markedly in numbers and distribution following human colonization in approximately 400 AD (James and Olson 1991, Olson and James 1991). Since then, about 95 (67%) of the 142 endemic bird species and subspecies known from collected specimens (71 taxa; Pyle 1997) or nonmineralized fossils (71 taxa; James and Olson 1991, Olson and James 1991, Giffin 1993; J. G. Giffin, pers. comm.) have become extinct. About 50% (71/142) of the endemic taxa were extirpated during Polynesian colonization and were unknown to nineteenth century naturalists, while an additional 17% (24/142) were extirpated after 1825. About 69% (31/45) of the remaining endemic taxa are listed as endangered or threatened, and others are being considered for listing by the U.S. Fish and Wildlife Service. In addition, at least 11 taxa listed as endangered are unrecoverable because they are very rare or extinct.

During Polynesian colonization, about 77%

TABLE 1. DECLINE OF ENDEMIC HAWAIIAN BIRD TAXA BY ORDER THROUGH TIME

Order	Prehistoric (<1778)	Historic (>1778)	Current (2000)
Procellariformes (petrels, shearwaters)	3	2	2
Ciconiiformes (ibises)	3	0	0
Anseriformes (geese, ducks)	13	3	3
Falconiformes (eagles, hawks)	4	1	1
Gruiformes (rails, gallinules, coots)	18	4	2
Charadriiformes (stilts)	1	1	1
Laridae	1	1	1
Strigiformes (owls)	5	1	1
Passeriformes (perching birds)	94	58	36[a]
TOTAL	142	71 [50%]	47 [33%][b]

[a] Includes four taxa that have not been seen for 10–30 years and are undoubtedly extinct, although they are still listed as endangered, and seven other taxa that are so rare that recovery is unlikely and extinction is imminent or may have already occurred. For specific details on recent sightings see Reynolds and Snetsinger (*this volume*).

[b] Percentage of total ancient taxa surviving shown in brackets.

(37/48) of the endemic nonpasserine taxa, mostly ground nesters and raptors, vanished; the 11 surviving forms are primarily wetland and marine birds (Table 1; Olson and James 1991). In contrast, about 38% (36/94) of endemic passerine taxa were extirpated, primarily in dry lowland habitats (James and Olson 1991, Giffin 1993; J. G. Giffin, pers. comm.). After 1825, another 23% (22/94) of endemic passerines disappeared from low and mid elevations, which were inundated by disease vectors, mammalian predators, food competitors, ungulates that destroyed and modified habitats, and weeds (Scott et al. 1986). About 61% (22/36) of all remaining endemic passerine taxa are endangered, and only half have any chance for recovery.

Naturalists explored the Hawaiian avifauna and investigated taxonomy and life history during the nineteenth and early twentieth centuries (Peale 1848, Wilson and Evans 1890–1899; Rothschild 1892, 1893–1900; Henshaw 1902a, Perkins 1903, Munro 1944). Following decades of neglect, modern Hawaiian ornithology began with investigations of the status, distribution, and ecology of native and introduced birds throughout the archipelago (Baldwin 1945, 1947a,b, 1953, 1969a,b; Fisher 1948a,b, 1949, 1951, 1965, 1967, 1968, 1969; Fisher and Baldwin 1945, 1946b, 1947; Richardson 1949, 1954, 1957, 1963; Richardson and Woodside 1954, Richardson and Bowles 1964).

Significantly, Baldwin (1953) conducted his detailed study of three common honeycreepers in Hawai'i National Park, which was established in 1917 to make available to the world the wonders of Kīlauea, Mauna Loa, and Haleakalā volcanoes. The Pacific Remote (formerly Hawaiian) Islands National Wildlife Refuge Complex was established in the same year to protect seabirds, migratory birds, and endemic landbirds of the tiny atolls and islands of the northwestern portion of the archipelago. These were the first areas in Hawai'i intended for conservation, and they have since become critical nodes for bird recovery and ecosystem management in the Pacific.

Despite a degree of legal protection and the establishment of conservation areas, it was clear that Hawaiian birds were becoming increasingly imperiled, prompting concern for at least some of the more conspicuous species. The first recovery efforts were directed at breeding and releasing Nēnē (*Branta sandvicensis*) or Hawaiian Geese after it was shown that their numbers and range had decreased precipitously (Baldwin 1945, Smith 1952, Elder and Woodside 1958, Scott 1962, Kear and Berger 1980). Today, Nēnē have been saved from extinction, but the species serves as a reminder that avian recovery in Hawai'i requires great persistence, effort, and resources to accomplish even modest gains.

AVIAN CONSERVATION ALONG THE ARCHIPELAGO

The distribution of avian habitats and breeding species varies considerably along the length of the Hawaiian Archipelago. Seabirds and shorebirds occur from Kure to Hawai'i, native passerines and waterfowl are found from Laysan to Hawai'i, and wetland birds and raptors are found primarily in the main islands from Kaua'i to Hawai'i. The largest tracts of forests, woodlands, shrublands, and grasslands occur on Hawai'i, followed by those on Maui, Kaua'i, and O'ahu. Wetlands are most available on Kaua'i, O'ahu, and Maui. Seabirds nest primarily on the small islands and atolls of the Northwestern Hawaiian Islands, where alien mammalian predators are absent, and relict populations persist in areas on the main islands where predators are locally absent or scarce.

Bird species are protected by state and federal

TABLE 2. MANAGERIAL JURISDICTION OF AVIAN HABITATS IN HAWAI'I

Jurisdiction	Wet forest, shrubland & bog	Mesic forest & shrubland	Dry forest, shrubland & grassland	Coastal wetlands	Shoreline	Small islands & atolls
National Park Service	X	X	X	X	X	
U.S. Fish & Wildlife Service	X	X		X	X	X
Military[a]		X	X	X	X	
Natural Area Reserve	X	X	X			
Forest Reserve & Wilderness	X	X	X			
Game Management Area	X	X	X			
The Nature Conservancy	X	X			X	
Private	X	X	X			
Government & Private Partnership	X	X				

[a] Excludes areas used for active training and operations.

laws, but habitats are managed by a variety of jurisdictions and organizations, each with somewhat different objectives (Table 2). The Hawaii Department of Land and Natural Resources, the National Park Service, and the U.S. Fish and Wildlife Service manage most Hawaiian bird habitat, including forests and shrublands, wetlands, and small islands and atolls used by seabirds.

The most significant gaps in habitat protection occur in areas essential to endemic forest birds. Scott et al. (1986) delineated areas on Hawai'i, Maui, Moloka'i, and Kaua'i as being essential for long-term survival of native forest birds. These areas represented the core and surrounding habitat where native bird communities were most intact and where the rarest species were found during the Hawai'i Forest Bird Surveys. On Hawai'i, four such areas were identified: the māmane (*Sophora chrysophylla*) and naio (*Myoporum sandwicense*) forest on the southern and southwestern side of Mauna Kea, the windward rain forest, the Ka'ū forest, and the remaining mesic to wet forest in South Kona (Fig. 2). On Maui, essential habitat included the higher-elevation rain forest on the northeastern slope of Haleakalā and the upper reaches of Kīpahulu Valley (Fig. 3). On Moloka'i, the forest of Kamakou Preserve and Oloku'i plateau were considered essential (Fig. 3). On Kaua'i, essential habitat consisted of the core of the Alaka'i Swamp (Fig. 4).

Most essential forest bird habitats on Maui, Moloka'i, and Kaua'i fall within areas that are primarily intended for conservation management, but on Hawai'i there are extensive areas that lack even nominal protection, especially in leeward locations. Preserving and restoring native biodiversity in additional areas of essential habitat would greatly benefit bird conservation. Critical habitat has been designated only for the Palila (*Loxioides bailleui*). Unlike critical habitat, essential habitat has no legal definition or implications.

On Hawai'i, endemic passerine populations and efforts to recover them are mostly restricted to highland native forest, because lowland areas have less remaining native habitat and more problems associated with alien species and disease (Scott et al. 1986, van Riper et al. 1986). Therefore, opportunities for avian recovery have been limited to areas that for many species represent the upper range of their historical distribution. Some of these areas may be marginal due to cooler temperatures and lower richness of food resources.

Endemic birds have persisted with varying degrees of success on different islands (Table 3). The present number of endemic species and subspecies on each island ranges from 26% to 67% of what existed prehistorically. Although much of this range simply reflects differences in the completeness of fossil and historical records, it is clear that endemic birds have declined dramatically throughout the archipelago. Even on Kaua'i, where about 62% of the known prehistoric avifauna survives, bird species are disappearing.

HAWAI'I

The island of Hawai'i presently supports 20 endemic bird species, of which 13 are listed as endangered or threatened (USFWS 1996a). Of the 11 surviving endemic forest passerines, 6 are endangered. The 'Alalā (*Corvus hawaiiensis*), or Hawaiian Crow, is nearly extinct in the wild but may be saved by captive breeding and release. Prospects for recovering the 'Ō'ū (*Psittirostra psittacea*) are hopeless because wild populations on all islands are exceedingly rare or extinct, and there are there are no birds in captivity. The other four species, Palila, 'Akiapōlā'au (*Hemignathus munroi*), Hawai'i Creeper (*Oreomystis mana*), and Hawai'i 'Ākepa (*Loxops coccineus*),

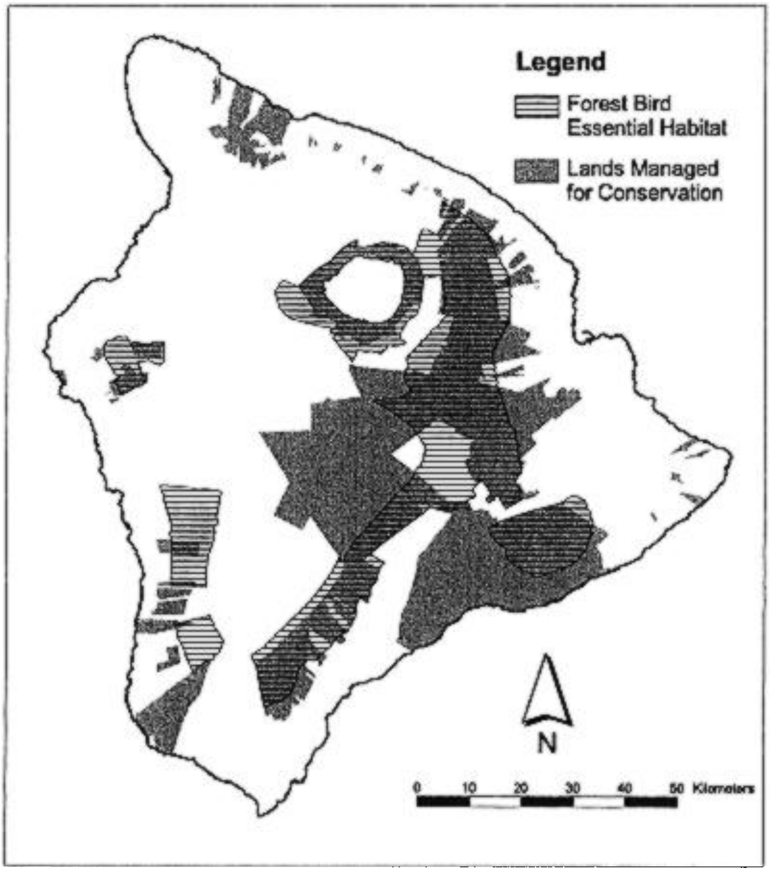

FIGURE 2. Essential forest bird habitat on Hawai'i requires additional protection in many areas but especially on the western side of the island.

are likely to persist for decades longer, but their recovery cannot be taken for granted. Even among the five species not considered endangered, there are troubling downward trends. For example, the 'I'iwi (*Vestiaria coccinea*) has disappeared or is declining in many areas. Nonetheless, Hawai'i is the only island where there is a viable population of endemic thrush, the 'Ōma'o (*Myadestes obscurus*). Although today most passerines occupy wet and mesic native forests, many extinct species occurred in dry forest, formerly the most botanically rich habitat on the island (Rock 1974; Wagner et al. 1990a,b; James and Olson 1991, Olson and James 1991). Dry forests now exist mainly as highly altered remnants, but portions receive limited protection.

The 'Io (*Buteo solitarius*), or Hawaiian Hawk, the sole surviving falconiform species in the islands, is a widely distributed hawk in forests and woodlands. It is limited to Hawai'i, although fossil evidence indicates a wider range prehistorically, and it is listed as endangered. The endemic subspecies of the Short-eared Owl (*Asio flammeus sandwichensis*), or Pueo, is the only other surviving raptor of the nine known to have occurred prehistorically or historically (Olson and James 1991). The Short-eared Owl occurs in forests, woodlands, and shrub-grasslands on Hawai'i and all the other major islands.

The endangered Nēnē inhabits agricultural lands and managed grasslands in addition to native shrublands and grasslands. Three endangered waterbirds, the Koloa (Koloa maoli, *Anas wyvilliana*), or Hawaiian Duck; Hawaiian Coot ('Alae ke'oke'o, *Fulica alai*); and an endemic subspecies of the Black-necked Stilt, the Hawaiian Stilt (Ae'o, *Himantopus mexicanus knudseni*), survive primarily in the small wetlands along the western coast. In recent years, populations of Hawaiian Coot and Black-necked Stilt have increased significantly in the Kona area due to the construction of aquaculture ponds at

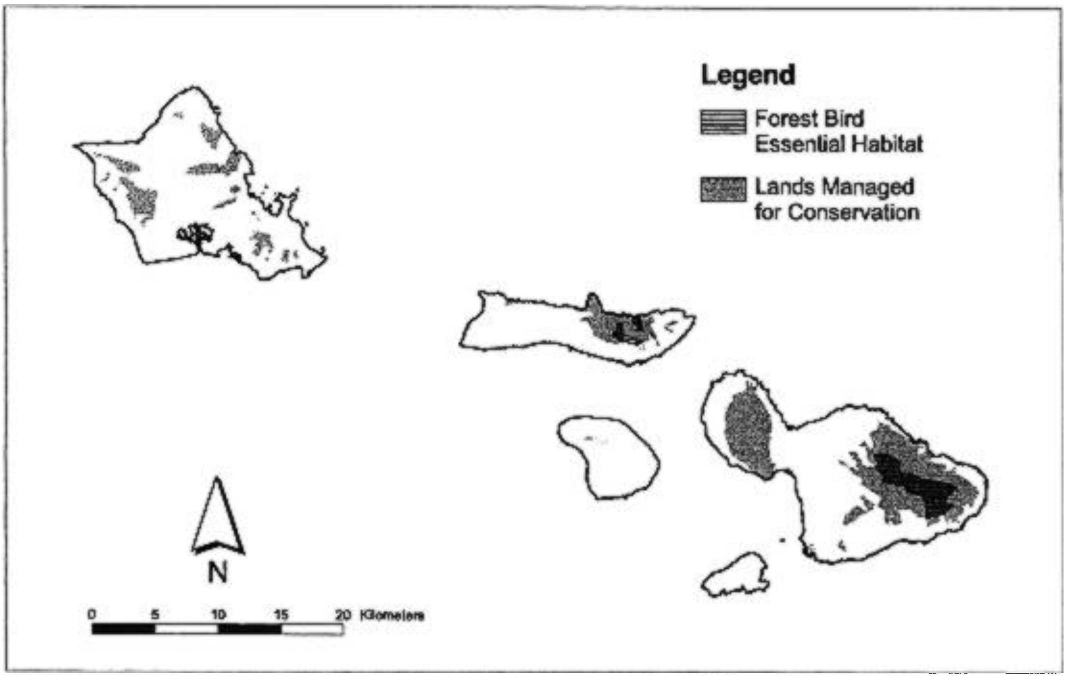

FIGURE 3. Essential forest bird habitat on Maui and Moloka'i are designated for conservation, but essential habitat was not identified on O'ahu, Lāna'i, or Kaho'olawe.

the Natural Energy Laboratory at Keāhole and sewage treatment ponds.

The endangered Dark-rumped Petrel ('Ua'u, *Pterodroma phaeopygia sandwichensis*), or Hawaiian Petrel, once abundant on the island, now is limited to relic nesting colonies in remote lava fields at high elevation (Hu et al. *this volume*). The remoteness of these sites inhibits predation by introduced small mammals that long ago overran lowland breeding sites on the island (Simons and Hodges 1998). The threatened endemic subspecies of Townsend's Shearwater, here-

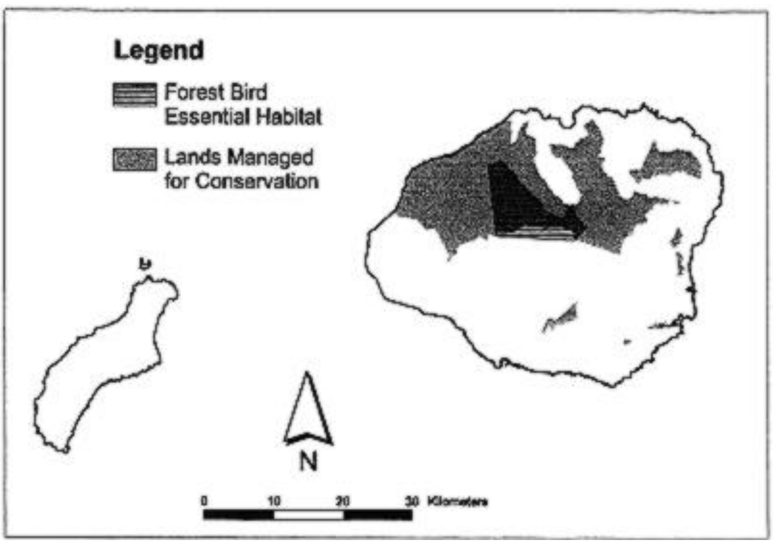

FIGURE 4. Essential forest bird habitat on Kaua'i is designated for conservation.

TABLE 3. Distribution and survival of endemic taxa (including subspecies) in the Hawaiian Archipelago through time

Island	Prehistoric (<1778)	Historic (>1778)	Current (2000)
Northwestern Islands	9	9	6 [67%][a]
Kaua'i	34	22	22 [65%]
O'ahu	43	17	11 [26%]
Moloka'i	37	18	11 [30%]
Lāna'i	11	11	6 [55%]
Maui	48	19	16 [33%]
Hawai'i	46	31	20 [43%]

Notes: Data adapted from James and Olson (1991), Olson and James (1991), Giffin (1993, pers. Comm.), and Pyle (1997). Values for prehistoric and historic avifauna on different islands will increase as fossils continue to be identified, revealing new species and range extensions of already-described species.

[a] Percentage of surviving prehistoric taxa are shown in brackets.

after referred to as Newell's Shearwater ('A'o, *Puffinus auricularis newelli*), has been reduced to tiny, relic colonies nesting in pit craters in low- and mid-elevation forest on the southern and eastern portions of the island and along cliffs in the northern Kohala mountains (Ainley et al. 1997b, Reynolds and Ritchotte 1997, Ainley et al. *this volume*). The Hawaiian subspecies of the Black Noddy, or Hawaiian Noddy (Noio; *Anous minutus melanogenys*), nests along sea cliffs on the eastern and southern coasts.

Maui

Maui, to the northwest of Hawai'i, is older and smaller, and this geochronological trend continues northwestward along the archipelago. Although once much larger, these older islands now support relatively reduced areas of forest, thereby limiting opportunities for avian recovery. Nevertheless, a moderately large proportion of high-quality native forest on Maui is protected and supports ten endemic bird taxa; of these, five are endangered. Three of these taxa, Maui Nukupu'u (*Hemignathus lucidus affinus*), Maui 'Ākepa (*Loxops coccineus ochraceus*), and Po'ouli (*Melamprosops phaeosoma*), are so rare that recovery seems highly improbable (Reynolds and Snetsinger *this volume*). Although Maui Parrotbill (*Pseudonestor xanthophrys*) and 'Ākohekohe (*Palmeria dolei*) populations and ranges are relatively small, their remaining habitat is at least minimally protected and managed. Populations of three endangered endemic wetland birds, Koloa, Hawaiian Coot, and Black-necked Stilt, occur in the wetlands on the isthmus between east and west Maui. The two largest wetlands, Kanahā and Keālia, are protected and managed. As on the island of Hawai'i, the Dark-rumped Petrel nests primarily in high-elevation habitats within Haleakalā National Park (Simons and Hodges 1998, Hodges and Nagata *this volume*, Krushelnycky et al. *this volume*), and the Black Noddy nests along sea cliffs and offshore sea stacks.

Lāna'i

Lāna'i, once connected to Maui and Moloka'i, now contains only a tiny area of forest. The 'Apapane (*Himatione sanguinea*), one of the most abundant forest birds on the major islands today and in the past, is the only endemic passerine surviving on Lāna'i. Even the once common Maui 'Amakihi (*Hemignathus virens wilsoni*) is no longer found on Lāna'i (Lindsey et al. 1998). However, the Short-eared Owl still occurs on the island (Scott et al. 1986). In addition, two endangered wetland birds, Hawaiian Coot and Black-necked Stilt, are observed rarely at sewage treatment ponds. The colony of Dark-rumped Petrels that once nested on Lāna'i (Simons and Hodges 1998) has recently disappeared. Black Noddies, however, continue to nest in small numbers on the island (Harrison 1990).

Moloka'i

The native forest on Moloka'i is much reduced, and no more than five endemic forest bird species remain. However, the Moloka'i Oloma'o or Moloka'i Thrush (*Myadestes lanaiensis rutha*) was last seen in 1979–1980 (Scott et al. 1986), and the Kākāwahie or Moloka'i Creeper (*Paroreomyza flammea*) was last seen in 1963 (Pekelo 1963). Both species are almost certainly extinct, although they continue to be listed as endangered (but see Reynolds and Snetsinger *this volume*). Only 'Apapane and Maui 'Amakihi are relatively common. 'I'iwi are very rare today, although they were once abundant on this and other major islands (Scott et al. 1986). Two endangered endemic wetland birds, Hawaiian Coot and Black-necked Stilt, still survive. The Short-eared Owl is the only survivor of the five raptorial taxa formerly known from Moloka'i. The Dark-rumped Petrel and Newell's Shearwater still nest in the valley walls deep in the interior of the island. The Black Noddy nests along the ocean cliffs.

O'ahu

Five endemic forest bird species remain on O'ahu; however, populations generally are in decline (VanderWerf and Rohrer 1996, VanderWerf et al. 1997). Although listed as endangered, the O'ahu 'Alauahio (*Paroreomyza maculata*), or O'ahu Creeper, is probably extinct. The O'ahu 'Elepaio (*Chasiempis sandwichensis ibidis*) is being considered for listing as an endangered species (Conant 1995), although subspecies on Hawai'i and Kaua'i are still relatively common. The O'ahu 'Amakihi (*Hemignathus flavus*) is still relatively common and is even reappearing in some lowland habitats after decades of absence (VanderWerf 1997). 'Apapane are now scarce, and 'I'iwi are very scarce. Four species of endangered endemic waterbirds still occur on O'ahu: Common Moorhen (Hawaiian Gallinule, 'Alae'ula; *Gallinula chloropus sandvicensis*), Hawaiian Coot, Black-necked Stilt, and Koloa, which was reintroduced from releases of captive stock. Mallards (*Anas platyrynchos*) have genetically swamped Koloa on O'ahu through extensive hybridization (Browne et al. 1993). The Short-eared Owl is the only endemic raptor and the Black Noddy is the only endemic seabird still nesting on O'ahu.

Kaua'i

The endemic avifauna on Kaua'i is somewhat more intact than on other islands, but many forest bird species are declining or have recently become extinct. Of the seven forest bird species not listed as endangered, the 'Akikiki (*Oreomystis bairdi*), or Kaua'i Creeper, has declined significantly and become uncommon. Of the six forest bird species listed as endangered, recovery may be possible only for the Puaiohi (Small Kaua'i Thrush, *Myadestes palmeri*). Kāma'o (Large Kaua'i Thrush, *Myadestes myadestinus*), 'Ō'ū, and Kaua'i Nukupu'u (*Hemignathus lucidus hanapepe*) are too rare to be recovered. The 'Ō'ō'ā'ā (*Moho braccatus*), or Kaua'i 'Ō'ō, was last observed in 1987 (Pyle 1987a, Conant et al. 1998) and the Kaua'i 'Akialoa (*Hemignathus ellisianus procerus*) was last seen in 1969 (P. Bruner in Pyle 2000); both are almost certainly extinct (Reynolds and Snetsinger *this volume*).

Endemic nonpasserines on Kaua'i include two seabirds that nest in forest habitats: the endangered Dark-rumped Petrel and the threatened Newell's Shearwater. The Black Noddy nests along sea cliffs. Four endangered wetland birds also reside on Kaua'i: Koloa, Common Moorhen, Hawaiian Coot, and Black-necked Stilt. The Short-eared Owl inhabits forests and shrubgrasslands. The Nēnē has been reintroduced to Kaua'i, and populations are growing rapidly in and around agricultural lands and golf courses (Banko et al. 1999).

SPECIES AND HABITAT APPROACHES TO AVIAN CONSERVATION

The Hawaiian avifauna has become so depleted and habitats have been destroyed and altered on such a large scale that designing and implementing recovery programs is daunting, especially given the limited resources available for conservation in Hawai'i. As a consequence, recovery actions in Hawai'i are often opportunistic and seldom reflect a coherent, overall strategy (van Riper and Scott *this volume*). Avian conservation in Hawai'i, therefore, is attempted along a continuum of levels, including individuals, populations, species, communities, habitats, and ecosystems. Although recovery of species is mandated by the Endangered Species Act of 1973, avian recovery in Hawai'i requires habitat management. Degradation of native plant communities and introductions of alien predators, disease vectors, and food competitors have caused widespread and pervasive problems for Hawai'i's avifauna (Warner 1968, Atkinson 1977, Banko and Banko 1976, Ralph and van Riper 1985, Scott et al. 1986, van Riper et al. 1986, Pratt 1994, Atkinson et al. 1995, Jacobi and Atkinson 1995, van Riper and Scott *this volume*). Recovery plans have been developed for most species (USFWS 1982a,b,c,d, 1983a,b,c, 1984a,b,c, 1985, 1986), but specified recovery actions have not been fully implemented.

The "species approach" often involves monitoring populations, studying life history and limiting factors, protecting species from predators, providing artificial nest sites and supplemental food, manipulating habitat or enhancing nesting or feeding opportunities, translocating species, captive breeding and release, and rehabilitating injured individuals. Species management should start when populations begin to decline, not when they are listed as endangered. By this criterion, nearly all endemic species in Hawai'i birds require some level of management; however, there are too many species requiring management to devote resources to each one. Resource managers are quickly overwhelmed even if they concentrate their efforts on the most critically endangered birds, the ones at the very end of the "extinction conveyor belt." In addition, by trying first to save the most endangered birds, managers are unable to stop the decline of the many less-threatened species. This results in desperate, if not hopeless, attempts to restore primarily "species on the brink" while reducing opportunities for recovering species for which there is a greater chance of success. Focusing avian recovery at the species level also diverts resources and attention from improving the quality of habitats.

The "habitat approach" assumes that bird communities are sustainable in the long-term when suitable resources are adequately distributed along appropriate environmental gradients and in large areas. It also assumes that bird populations will respond positively to changes in their habitat and that there is sufficient habitat to sustain bird communities for the long-term. For example, we know that seabirds thrive when predators are removed, and removing rats (*Rattus* spp.) may benefit forest bird species. However, we do not yet know that birds respond to changes we observe in plant communities following pig (*Sus scrofa*) removal. Nevertheless, we believe pig removal will result in fewer disease-transmitting mosquitoes, and it may result indirectly in more food resources for birds. Therefore, we should manage habitats before birds become uncommon, because a long time may pass before populations respond. In addition, we should manage large areas of habitat for the long-term. The habitat approach often incorporates removing or controlling alien species, such as ungulates, predators, disease vectors, and food competitors, and it should involve monitoring bird abundance to evaluate progress.

EXAMPLES OF SPECIES CONSERVATION

How do we allocate research on the endemic taxa that remain? The greatest effort is spent on studying nesting, food habits, movements, territory, limiting factors, habitat use, and population monitoring. We still know little about the nine species that are very rare or functionally extinct. The most intensively studied species include: Dark-rumped Petrel (Hodges and Nagata *this volume,* Hu et al. *this volume,* Krushelnycky *this volume*), Nēnē, 'Alalā, O'ahu 'Elepaio (VanderWerf *this volume*), Palila, Laysan Finch (*Telespiza cantans*), and Hawai'i 'Ākepa (Freed *this volume,* Hart *this volume*). Considerable research has also been directed towards 'Io, Hawai'i 'Elepaio (*Chasiempis sandwichensis sandwichensis*), Puaiohi, Hawai'i 'Amakihi (*Hemignathus virens virens*), 'Ākohekohe (Berlin et al. *this volume,* Carothers *this volume,* VanGelder and Smith *this volume*), Maui Parrotbill, 'Ōma'o (Fancy *this volume*), 'Apapane (Carothers *this volume*), 'I'iwi, and Nihoa Millerbird (*Acrocephalus familiaris kingi*; Conant and Morin *this volume*).

How is management allocated among endemic species? Searches were recently conducted for very rare birds with the idea that management might be implemented if target species were located (Reynolds and Snetsinger *this volume*). However, this approach was abandoned because few rare species were found and the futility of restoring tiny, elusive populations was realized. When endangered species are managed, efforts are generally aimed at population monitoring, captive propagation and translocation, and controlling predators in limited areas; some efforts have also been made to attract cavity nesters to artificial nests. Most endangered species management is directed towards Dark-rumped Petrel, Nēnē, Palila, Maui Parrotbill, 'Akiapōlā'au, Hawai'i Creeper, Hawai'i 'Ākepa, 'Ākohekohe, and three critically endangered species: 'Alalā, Puaiohi, and Po'ouli. The 'Ōma'o has been the only nonendangered species receiving management, and a major justification for doing so was to develop techniques for restoring endangered thrushes.

NĒNĒ

The first attempt to recover an endemic Hawaiian bird species began with the release to the wild of captive-reared Nēnē (Kear and Berger 1980). By 1950, the wild population had declined to 30–50 individuals and there was no prospect for natural recovery. The initial phase of the recovery program involved building captive populations in Hawai'i and England and developing techniques for captive propagation and release. After much effort and persistence, breeding and releasing Nēnē became routine and 2,450 captive-reared Nēnē were released on Hawai'i, Maui, and Kaua'i over 40 years (Banko et al. 1999); however, a program of habitat management to complement the release of the captive birds was not sufficiently developed and supported. Consequently, most wild populations are not self-sustaining due to predation by introduced species of small mammals and poor food availability (Banko 1992, Black and Banko 1994, Banko et al. 1999, Scott and Banko 2000). Although extinction was prevented, the program demonstrates that species cannot be recovered without effective habitat management. Small Indian mongooses (*Herpestes auropunctatus*), feral cats (*Felis catus*), and feral dogs (*Canus familiaris*) prey on eggs, goslings, and adults in many areas; these predators are difficult and expensive to control. On Kaua'i, where mongooses are absent, predation is less of a problem and the Nēnē population is growing rapidly (Telfer 1995, 1996; Banko et al. 1999).

In addition to the difficulty of controlling predator numbers, many birds were released into areas that were not historically important for nesting (Henshaw 1902a). Over 1,000 Nēnē were released in the highlands on Hawai'i where habitat conditions were marginal (Black et al. 1997, Banko et al. 1999). Most released birds died and the survivors produced few offspring during the drought period of 1976–1983. Drought had somewhat less affect on the Nēnē population that was reintroduced to high-elevation habitat on Maui, probably because birds were able to graze on pasture grasses. Similarly, the Nēnē population reintroduced into Hawai'i Volcanoes National Park is slowly growing where nesting females and goslings have access to areas of managed grass. On Kaua'i, released birds mainly inhabit lowland pastures or other areas of managed grass where foraging opportunities are greatest (Telfer 1995, 1996).

The availability of managed grass enhances Nēnē breeding and survival (Woog and Black *this volume*); however, pastures, golf courses, lawns, roadsides, and other unnatural settings should be considered as ancillary to natural habitats. Nonetheless, it is better to have Nēnē in pastures than only in zoos. In addition, populations that utilize highly altered habitats can serve as genetic reservoirs and as safeguards when populations in wild habitats decline or disappear due to drought and other perturbations. However, maintaining at least some populations in shrub-grassland habitats dominated by native species should be a major goal. Towards this end, native plants that are nutritious and palatable to Nēnē should be encouraged to flourish in areas where predators can be controlled (Banko et al. 1999).

Conservationists around the world acclaimed the rescue of the Nēnē from extinction. Unfortunately the program was not critically evaluated until many birds had been released into habitats that could not support nesting and rearing. Substantial effort and money would have been saved if more thorough monitoring and more complete studies of limiting factors had been initiated earlier. Nonetheless, the Nēnē restoration program played an important role in attracting public attention to conserving Hawai'i's natural heritage.

'ALALĀ

The 'Alalā recovery program parallels that of the Nēnē in several ways. Recovery began when the population, range, and recovery options had become greatly reduced. The initial phase of recovery has emphasized captive propagation and release of birds to supplement the wild population. As with early Nēnē propagation, building viable breeding flocks of 'Alalā and developing avicultural techniques has been difficult and slow. Starting with three wild fledglings salvaged in 1972, only now is captive propagation becoming a viable management tool. In addition to breeding 'Alalā in captivity, wild eggs have been harvested and hatched in captivity. Young from some wild eggs have been incorporated into the captive breeding populations on Hawai'i and Maui while others have been released to the wild along with offspring of captive pairs. Since 1993, 27 captive-reared fledglings have been released in or adjacent to the new South Kona Unit of Hakalau Forest National Wildlife Refuge. Although survival of these captive-reared birds is higher than of parent-reared wild juveniles during the past 30 years (Banko and Banko 1976, National Research Council 1992), all but 6 of the 27 have died or disappeared since their release. The six surviving birds were returned to captivity until better management can be applied and habitat conditions improve. Disease and predators are proving to be a major hindrance to recovery, and the availability of suitable food needs to be investigated. Although releasing animals into habitats where limiting factors have not been managed reduces the chances of successful recovery (Griffith et al. 1989, Wolf et al. 1996), releasing 'Alalā into the wild has helped to identify some major limiting factors.

The endangered 'Io and alien small mammals are important predators of 'Alalā. Captive-reared 'Alalā and the few remaining wild individuals have frequently been chased, struck, or otherwise harassed by 'Io. Older 'Alalā are killed about as frequently as younger birds, suggesting that experience does not provide a critical benefit in avoiding predation. 'Io outnumber 'Alalā in their range in South Kona, and they will likely limit their recovery until many more 'Alalā have been released or methods are developed for reducing the threat of 'Io predation and harassment. In response to the fatalities of released birds, the eight captive-reared birds remaining in the wild were captured in 1998 and held in captivity until a plan for reducing the impact of 'Io could be developed. Subsequently, five of the eight birds were released to the wild for a second time. After one disappeared and another died, the three remaining birds were again recaptured and incorporated into the captive flock, which included the three other birds that had previously been released to the wild.

Although 'Io have killed many captive-reared 'Alalā, disease organisms, such as the protozoan *Toxoplasma gondii,* the bacteria *Erysipelas rhusiopathae,* and an unidentified fungus, have been implicated in the deaths of some birds (Work et al. 1999, 2000; unpubl. data). Feral cats are the carriers of toxoplasmosis (Wallace 1973), and birds scavenging a cow carcass may have encountered *E. rhusiopathae.* Diseased 'Alalā may be more vulnerable to 'Io predation, thus complicating the identification of mortality factors. An unexpected result of the captive-release program has been the low incidence of illness and mortality due to avian malaria and pox, which has been proposed as the most important factors preventing population recovery (Jenkins et al. 1989). Prior to their release into the wild, captive-reared birds are maintained in large, netted aviaries where they develop flight and social skills. While in this protected environment, they are exposed to mosquitoes, vectors of malaria and pox. The prevalence of *Plasmodium relictum* is uncommonly high in the South Kona mosquito population, and the aviary birds inevitably are bitten (C. T. Atkinson, pers. comm.).

Because their diet in captivity is excellent and they are treated prophylactically for malaria, 'Alalā survive with only short-term, mild symptoms of the disease, if any. Exposure to malaria while in the aviaries seems to confer immunity to the birds after their release and switch to a natural diet in the wild. Since captive-reared birds have not yet nested in the wild, it is not known whether their offspring will suffer more from avian malaria and pox without access to the high-quality diet available inside the aviaries.

The suitability of the habitat for supporting wild nestlings is poorly known, and this may be the next important challenge to managers after they have reduced predation rates. As with Nēnē, therefore, predator control and habitat management are needed to recover the species.

Palila

In contrast to recovering endangered species on the brink of extinction, a program has begun to begin recovery of the endangered Palila before it becomes critically rare or limited in distribution. The program is distinguished by the fact that years of habitat improvement and research into the Palila's life history and limiting factors have preceded the development of more intensive techniques, such as translocation and captive propagation. Palila are the last remaining finch-billed species in the main islands and rely on seeds, flowers, and caterpillars taken from māmane trees. The annual Palila population estimate fluctuates considerably, and long-term viability of the species is in doubt (Jacobi et al. 1996, Banko et al. 1998, Gray et al. 1999). Palila are not increasing in numbers or distribution despite years of increasing māmane stand density and crown size of individual trees following the reduction of ungulate populations (see van Riper and Scott *this volume*); therefore, it is time to manage the species more actively.

The Palila population is becoming increasingly concentrated on the western slope of Mauna Kea Volcano where the māmane forest is large and extends along a substantial gradient of elevation. The forest on the eastern slope is truncated along its lower margin by pastures (van Riper et al. 1978, Scott et al. 1984), and the Palila population is steadily declining (Jacobi et al. 1996, Banko et al. 1998). Management options are, therefore, limited. Similarly, opportunities to restore the diminished population on the southern slope of Mauna Kea are limited, although the forest is relatively extensive. Instead, ranching and military training inhibit population restoration. To mitigate the effects of realigning Saddle Road through Palila habitat on the southern slope, efforts are being made to reestablish Palila in recovering forest on the northern slope, where Palila have been absent for over 25 years (van Riper et al. 1978).

In 1993, 35 adult Palila were translocated to the eastern slope to determine whether recovery could be expedited in an area where predators were controlled (Fancy et al. 1997). Although several pairs nested, about half of translocated birds returned to their original habitat on the western slope after 2 to 6 weeks. In order to further develop translocation as a management tool, 53 juveniles (> 3 months) and adults were moved to the northern slope during three trials in 1997–1998; however, most birds returned to the western slope or were killed by predators (U.S. Geological Survey, unpubl. data). Concurrently, techniques for hatching wild eggs in captivity have been developed, and a small captive population has been established with the hope of releasing birds to the wild (Kuehler et al. *this volume*).

Palila exist today primarily because foresters rehabilitated māmane forests on Mauna Kea by removing tame and feral cattle (*Bos taurus*) and reducing populations of feral sheep (*Ovis aries*) from 1921 to 1946 (Bryan 1947). However, the sheep population, consisting of about 500 animals in 1949, was allowed to increase and was maintained in the low 1,000s when sustain-yield game hunting was popularized in the 1950s (Tomich 1986). In addition, mouflon (*O. musimon*), which hybridized with feral sheep, were introduced to Mauna Kea in 1962 to enhance game hunting (Tomich 1986). Sheep and mouflon browsed māmane seedlings and foliage, severely damaging the forest (Giffin 1976, 1982).

In 1979 and 1986, district federal court ruled that feral sheep and goats (*Capra hircus*) must be eradicated to allow Palila habitat to recover (Pratt et al. 1997a). Populations of sheep and mouflon have been reduced substantially and māmane recruitment is evident (Hess et al. 1999). However, fire risks have escalated as alien grasses have increased. Understanding fire ecology in montane and subalpine dry forests and developing appropriate management schemes will be critical to recovery efforts.

Other habitat factors are also important to Palila recovery. For example, the primary insect food of nestling Palila is native caterpillars, *Cydia* spp. (Tortricidae), which eat māmane seeds (U.S. Geological Survey, unpubl. data). *Cydia* are parasitized by at least three alien and one native wasp species, possibly limiting Palila productivity where parasitism is heavy. Introduced small mammals also prey on Palila eggs, chicks, and adults. Feral cats and roof rats (*Rattus rattus*) pose the greatest threats, and may limit natural population expansion and recovery in some areas (Pratt et al. 1997a). Investigations into predator impacts and control methods continue. Unlike most other forest birds in Hawai'i, Palila are distributed above the range of mosquitoes, and avian malaria and pox seldom affect them. However, other disease organisms may impact wild Palila (U.S. Geological Survey, unpubl. data). We presume that Palila living near tree line today may not be as productive as when populations ranged much lower in elevation (Perkins 1903). Reintroducing Palila to low-elevation habitats, however, must wait until biological and political obstacles are resolved.

EXAMPLES OF HABITAT CONSERVATION

The primary goal of some programs in Hawai'i is to restore habitats or ecosystems with the expectation that many species will benefit. The National Park Service and U.S. Fish and Wildlife Service attempt to manage relatively large areas, whereas the state Natural Area Reserve System and The Nature Conservancy of Hawai'i manage habitats on a somewhat smaller scale.

Hawai'i Volcanoes and Haleakalā national parks focus primarily on landscape-scale habitat conservation. Although both parks contain many listed endangered species, the priority is removing alien animals and plants that degrade native habitats. Since the early 1970s, feral pigs, goats, and other ungulates have been removed from large, fenced areas (Anderson and Stone 1993, 1994). Vegetation recovering in these ungulate-free management units may eventually support more native birds and other species.

Similarly, habitat recovery is beginning at Hakalau Forest National Wildlife Refuge because of recent alien pest and weed management. These wet and mesic forests are vitally important for many common and endangered forest birds. In addition to removing feral animals that degrade native forests, the refuge is planting native trees and shrubs in highland areas denuded by grazing, logging, and fire. Native birds are beginning to use these emergent habitats, and they will benefit more as forest structure and composition become increasingly complex and diverse.

In an encouraging trend, adjacent landowners jointly manage portions of their land for conservation. On the island of Hawai'i, for example, Kamehameha Schools Bishop Estate, Hawai'i Volcanoes National Park, Hawaii Department of Land and Natural Resources, and Hawaii Department of Public Safety cooperate with the U.S. Fish and Wildlife Service, U.S. Geological Survey, and the U.S. Forest Service to manage the 'Ōla'a-Kīlauea Management Area. This project, encompassing over 12,000 ha of land on the upper, windward slopes of Mauna Loa Volcano, includes extremely important native koa (*Acacia koa*) and 'ōhi'a (*Metrosideros polymorpha*) forest habitat, which supports significant populations of rare and common native birds. The landowners and cooperating agencies that form the East Maui Watershed Partnership have taken a similar approach to reduce the stress of invasive plant and animal species in wet forest habitats on Maui. These joint efforts can serve as models for protecting large, continuous tracts of forest bird habitat over landscapes that have multiple ownership.

CONSERVATION STRATEGIES AND OPTIONS

Goals and Priorities for Avian Conservation

Recovery plans have been written, and in a few cases revised, for all endangered Hawaiian bird species, yet there is no comprehensive strategy to conserve endemic birds generally. The goal of "no more bird extinctions in Hawai'i" is impractical, given the number of species that are critically endangered. Neither does it seem likely that many bird populations will recover naturally in response to limited habitat restoration, such as removing select alien species. Forests and other avian habitats have been so severely damaged by alien stressors that restoration of native vegetation structure and composition may take many decades. There have been few opportunities to evaluate the response of native invertebrate and bird communities to habitat changes following the removal of ungulates. In the best known example, Palila populations have been slow to respond to the increased regeneration of māmane trees resulting from the reduction of feral sheep and mouflon. Therefore, restoring many endemic birds will require species management in addition to removing or reducing factors that damage habitats.

Avian conservation in Hawai'i requires evaluating areas of essential habitat to determine which management actions will best promote the recovery of native bird communities. Lowland habitats should not be overlooked since virtually all bird species once occurred there. It also is necessary to take into account that lava flows, hurricanes, fires, cycles of forest senescence and rejuvenation, and other natural disruptions to avian habitats will occur. The scale of conservation activities must encompass large regions and cannot be limited to existing wildlife refuges, reserves, and parks. There presently is no basis for deciding what size habitats should be to sustain communities of Hawaiian birds.

Information and improved techniques also are needed to accelerate the development of avian conservation strategies in Hawai'i. Major factors limiting endemic bird populations have been identified, although additional research is needed to guide managers' efforts to overcome negative effects of these factors. Research should include investigative and manipulative approaches to provide managers with information about the underlying nature of limiting factors and the consequences, both intended and unintended, of their mitigation.

It may be useful to investigate the factors limiting alien bird populations, particularly in lowland habitats, to help restore endemic forest birds. If alien birds are relatively resistant to avian malaria and pox (van Riper et al. 1986, Atkinson et al. 1995), what factors limit their populations and potentially inhibit native species recovery? The Red-bill Leiothrix (*Leiothrix lutea*), for example, seems to be disappearing from some habitats where it once was common and increasing in some areas where it was scarce, yet there is no research into the factors responsible for this.

Birds play important roles in ecosystem function by pollinating and dispersing native and alien plants. Management strategies must account for the potential harm done to native ecosystems by birds facilitating the spread of noxious weeds and the potential benefit to bird populations that forage heavily on fruit and nectar of alien plant species. We need to determine in more detail how bird and plant interactions may affect conservation goals. Birds may also affect native and alien insect populations, as they do elsewhere (Holmes 1990), but the nature or consequences of these relationships have not been investigated in Hawai'i. Similarly, birds may affect nutrient cycling and soil development. For example, seabirds once nested in much greater numbers over a far larger area (Olson and James 1982b, 1991); their guano and burrowing may have influenced mineral availability and the dynamics of plant communities (M. Friedland and P. Vitousek, unpubl. data). Determining the function of birds in native ecosystems in greater detail will help in designing conservation strategies.

Priorities

- Identify, characterize, and prioritize habitats essential to Hawaiian birds and develop management strategies for areas where restoration of native birds and their habitats is likely to be effective. Leeward areas of Hawai'i merit special consideration. Habitats to be managed for avian recovery include dry, mesic, and wet forests and woodlands; shrub-grasslands; wetlands, including rivers, streams, estuaries, marshes, and bogs; coastlands, atolls, and islets; marine waters.
- Determine the geographical scale appropriate to recovering and maintaining viable populations of wide-ranging and sedentary species. Promote partnerships and public appreciation to manage large areas of habitat for avian and other conservation values.
- Determine additional management requirements of species that may not respond naturally or quickly to habitat management. Investigate factors that limit alien bird populations to evaluate endemic bird requirements.
- Investigate the functional role of endemic and alien birds in Hawaiian ecosystems.

Habitat Alteration and Stressors

Human activity and invasive alien plants and animals can affect the Hawaiian biota at population, community, and ecosystem levels. Gross changes in ecosystems and community structure and composition began with Polynesian colonization and continue today as native forests are converted to tree plantations and other agricultural or social uses. Few endemic Hawaiian birds have survived major, or even subtler, changes to their habitats. Passerine birds have suffered the most from habitat alteration. Remaining species generally inhabit only the uppermost extremes of their former distributions where they contend least with disease vectors, predators, and alien weeds and pests. Nevertheless, a few species actually thrive in highly altered habitats. For example, fossils of Short-eared Owl are not known from the period prior to human colonization, and populations may not have become established until humans modified habitats, introduced rodents, and perhaps reduced populations of other raptors (Olson and James 1991). The Nēnē is readily attracted to short, growing grasses found in pastures, golf courses, lawns, and roadsides (Black et al. 1994, Banko et al. 1999); however, they may have fared as well or better when the full array of native food plants were available. The 'Io, too, preys on introduced animals and occupies agricultural and other altered habitats in addition to native forest. All endemic wetland birds survive in habitats dominated by alien plants. We can only guess about their status in pristine habitats.

Terrestrial habitat management in Hawai'i is meaningless without eradicating or substantially reducing populations of feral ungulates. Forest bird recovery plans and management plans for federal, state, and private natural area reserves and parks acknowledge this fact. Ungulates are the greatest threats to forest habitats (Ralph and van Riper 1985, Scott et al. 1986, Cuddihy and Stone 1990, Pratt 1994), but there has been significant progress in controlling their populations in relatively few areas. Prime examples of successful control programs include Hawai'i Volcanoes National Park, Haleakalā National Park, Waikamoi Preserve, Hanawī Natural Area Reserve, and Kamakou Preserve. In addition, ungulate control is under way in Hakalau Forest Wildlife Refuge. Sheep, goats, and mouflon are being controlled in Mauna Kea Forest Reserve, but pigs are maintained for sustained-yield hunting. The added benefit of feral pig control in moist areas is the likely reduction of mosquito populations and lower transmission rates of malaria and pox (Scott et al. 1986, van Riper et al. 1986, Atkinson et al. 1995). Feral ungulates destroy and modify Hawaiian bird habitats by eating native plants, disrupting soil processes, and increasing erosion, facilitating the spread of alien plants, and creating breeding sites for disease vectors (van Riper and Scott *this volume*). Their removal should be the highest management priority in Hawaiian bird habitats. It is important, however, to be prepared for the possible increase of some alien plants following ungulate removal.

The dominance of alien weeds in many avian habitats affects avian conservation programs in a variety of ways. Most importantly, alien plants may fundamentally change habitat structure and composition, resulting in changes in the availability of suitable foraging and nesting substrates. Some alien species affect ecosystem function by altering the availability of resources (e.g., soil chemistry, light), changing trophic relationships (e.g., seed predation and dispersal, pollination), and intensifying or speeding disturbance (e.g., facilitating invasion by other invasive species; Vitousek and Walker 1989). Therefore, it is crucial to Hawaiian bird conservation to reduce many populations of alien weeds and pests that have already invaded native ecosystems and to prevent the introduction and spread of other invasive species (Loope et al. *this volume*). Some of the most insidious species invading Hawaiian forests include *Miconia calvescens, Passiflora mollissima, Psidium cattleianum, Shinus molle, Clidemia hirta, Rubus ellipticus, Myrica faya,* and *Hedychium gardnerianum.* These and many other invasive plants crowd out native species that are sources of fruits, seeds, or invertebrates to endemic birds. Furthermore, changes in plant community structure and composition due to alien plants generally negate foraging benefits to birds. Serious threats to shrub-grasslands and woodlands include alien grasses (*Pennisetum setaceum, P. clandestinum,* and *Schizachyrium condensatum*), *Ulex europaeus, Leucaena leucocephala, Lantana camara,* and a number of other species. The introduced mangrove, *Rhizophora mangle,* and *Pluchea indica* threaten some wetland habitats (Allen 1998, Loope et al. *this volume*). Weeds are also a concern on the small islands of the northwestern chain. Habitat conditions for the Laysan Finch have improved now that *Cenchrus echinatus* has been nearly eradicated. Hawai'i Volcanoes and Haleakalā national parks have stopped the spread of some alien plants (e.g., Medeiros et al. 1997). They have shown that allocating sufficient resources and managing ungulates, fire, and other environmental stressors are important in controlling many weed species. Additional research is required to develop techniques, including biological control and chemical applications, for efficiently removing weeds. Monitoring the responses of native communities, including birds, should accompany the removal of alien species.

Forest health is critical to conserving Hawaiian forest birds, and many forests are dominated by only one or two native tree species. Pathogens or insects affecting dominant forest components would devastate native forest bird populations. Three species of endemic trees are essential to endemic passerines today: 'ōhi'a, koa, and māmane. Trees alone are not sufficient to sustain forest bird populations; understory diversity is also needed. Managers must know what agents and processes potentially threaten dominant tree species. The phenomenon of 'ōhi'a dieback is relatively well understood (Mueller-Dombois 1980, Jacobi 1993), but continued research and monitoring are warranted to avoid overlooking a pathogenic cause of tree mortality. Modeling spatial and temporal patterns of forest senescence should help guide research when large areas of forest begin to lose vigor. There is little research into the prevalence or pathogenicity of disease agents of endemic plants (but see Gardner 1997). Additional studies would help develop strategies for preventing the loss of large forest tracts to alien pathogens. Neither is there sufficient effort to prevent the establishment of insect pests that attack plants that provide important food resources to birds.

A pressing management concern in dry Hawaiian forests and woodlands is fire. Alien annual grasses greatly facilitate fire through the accumulation of dead leaves and stems, which burn rapidly. As previously discussed, fire seriously threatens the Palila population on the dry, western slope of Mauna Kea. Fire also disrupts shrubland and woodland communities in the lower elevations of Hawai'i Volcanoes National Park (Hughes et al. 1991), although Nēnē may opportunistically use areas that are recovering from burns (Banko et al. 1999). Hawai'i Volcanoes National Park actively manages fire threats, a policy that is needed at Pōhakuloa

Training Area, Mauna Kea Forest Reserve, and other areas where alien grass cover is high.

Hawaiian forest bird populations have declined in part because alien predators and parasites have depleted invertebrate food resources (Banko and Banko 1976; U.S. Geological Survey, unpubl. data). The loss of native invertebrates may hinder the recovery of some bird species. Techniques for controlling invertebrate pests, however, are largely undeveloped and managers have few tools and little expertise at their disposal. Efforts generally consist of reducing yellow jacket (*Vespula pensylvanica*) populations in a few localities. Controlling yellow jackets and other invertebrate predators and parasites over large areas may prove to be very difficult (Cole et al. 1992). Therefore, efforts should focus on preventing the introduction and spread of the most damaging alien species, while developing techniques for control at the landscape level (Loope et al. *this volume*).

Priorities

- Permanently remove feral ungulates from essential avian habitats.
- Control the spread of alien weeds and remove them from important avian habitats.
- Develop and implement plans for managing fire threats.
- Restore native plant communities following ungulate and weed removal.
- Determine the distribution of alien invertebrate pests that deplete avian food resources and develop and implement management techniques.
- Identify threats to habitats posed by plant pathogens and herbivorous invertebrates and develop strategies and techniques for their prevention or control.

Population Monitoring

Monitoring bird species is important because managers need information on population trends to plan and develop recovery efforts. Surveys of species distributions, densities, and habitat associations were conducted throughout the state in forested areas during 1976–1983 (Scott et al. 1986). However, plans to survey each major island every five years since the baseline was established have not been carried out. Although there may be little practicality in learning that rare species are becoming rarer, trends of more common species are important to determine.

At Hakalau Forest National Wildlife Refuge, where there is a comprehensive monitoring program, counts are conducted annually, sometimes seasonally, and there is a relatively long history of monitoring. Trends suggest that there has not been sufficient management or time to determine changes in bird populations. The avian community is dominated by common nectarivorous or omnivorous species, although the refuge was established primarily for three endangered insectivorous species, ʻAkiapōlāʻau, Hawaiʻi ʻĀkepa, and Hawaiʻi Creeper. Annual monitoring of forest bird populations has recently been implemented in ʻŌlaʻa-Kīlauea, Keauhou, and Haleakalā. Mauna Kea Forest Reserve has the longest record of continuous population monitoring (20 years in the year 2000) and is the largest tract of forest that is surveyed annually. Until recently, counts on Mauna Kea have focused mainly on endangered species.

Select species are monitored regularly in some areas; for example, Nēnē and Dark-rumped Petrels at Hawaiʻi Volcanoes National Park. In addition, forest birds in Kīpahulu Valley are now being monitored annually in Haleakalā National Park. Many seabird species are monitored annually on Laysan, Tern, and Midway in the Hawaiian/Pacific Islands National Wildlife Refuge Complex. The Laysan Duck (*Anas laysanesis*) and Laysan Finch are surveyed frequently, if not annually, whenever trained observers are available. All bird species are surveyed on Nihoa at about 2–3 year intervals. Annual counts of waterbirds are conducted throughout the state. The Bishop Museum maintains a database of unusual bird observations (R. L. Pyle, pers. comm.). There is no comprehensive, systematic, or long-term monitoring of migratory bird populations in Hawaiʻi, except perhaps for Kōlea (*Pluvialis fulva*; Johnson and Johnson 1993).

Priorities

- Monitor population trends of common and endangered birds to evaluate conservation priorities, strategies, and tactics.
- Monitor endangered passerines whose populations occur in the low 100s or 1,000s and that have some prospect for recovery, including Nihoa Millerbird, Puaiohi, Laysan Finch, Nihoa Finch (*Telespiza ultima*), Palila, Maui Parrotbill, ʻAkiapōlāʻau, Hawaiʻi Creeper, Kauaʻi ʻĀkepa or ʻAkekeʻe (*Loxops caeruleirostris*), Hawaiʻi ʻĀkepa, and ʻĀkohekohe.
- Evaluate responses of avian populations to changes in plant and invertebrate communities generated by the removal of alien species and other management.
- Determine the abundance and distribution of nesting Dark-rumped Petrels and Newell's Shearwaters and develop conservation strategies.

REINTRODUCTION, TRANSLOCATION, AND CAPTIVE PROPAGATION

Many endemic species must be reintroduced to portions of their historic or prehistoric range, because their reproductive potential and dispersal capabilities are limited. Recovering the Laysan Duck, for example, must include reintroducing populations to other islands and atolls in the northwestern chain; it may also involve reintroduction to some of the major islands where it once occurred (Olson and Ziegler 1995, Cooper et al. 1996, Moulton and Marshall 1996; J. G. Giffin, pers. comm.). Reintroduction and translocation may also be necessary to restore other species, such as 'Akiapōlā'au and Hawai'i Creeper, in habitats recovering from ungulate damage, for example in Hawai'i Volcanoes National Park and Mauna Kea Forest Reserve. Experimental reintroductions of Palila and 'Ōma'o, however, suggest that results may vary according to species and habitat (Fancy et al. *this volume*).

Where a species or subspecies has been extirpated, it may be possible to introduce a close relative. For example, it may be possible to introduce the Nihoa Millerbird to Laysan Island, where the Laysan Millerbird (*A. f. familiaris*) became extinct after introduced rabbits denuded the island. This may reduce the threat of extinction on one island while helping to restore the terrestrial community on the other (Morin et al. 1997).

In addition to expanding their distribution, reintroducing and translocating Nēnē to former range may help establish adaptive traditions of seasonal movement to more suitable habitats. For example, Nēnē families translocated from one island or habitat to another might return to their original breeding grounds after the goslings fledge. When mature, some females might return with their mates to nest in the new area, thereby promoting adaptive patterns of movement and possibly survival and productivity. When Nēnē are reintroduced to Moloka'i (C. Terry, pers. comm.), there will be opportunities to experiment with establishing interisland movement to Maui.

Releasing captive-reared birds to reintroduce or bolster populations is an alternative or supplement to translocating wild individuals and has been used with Nēnē, 'Alalā, 'Ōma'o, and Puaiohi. In addition, common species, such as the Hawai'i 'Amakihi, have been experimentally reared and released (Kuehler et al. 1996).

Nests of 'Alalā and Nēnē have been managed in the wild to enhance productivity, and other species may be similarly manipulated to facilitate their restoration. 'Alalā eggs were removed from the wild and hatched in captivity to provide new stock for release to the wild and for captive breeding (Kuehler et al. 1995). Manipulated pairs renested within 2 weeks of egg removal, but no chicks fledged. Palila eggs were removed from the wild for the same purpose, but all stock was retained for captive breeding. Manipulated pairs renested within 2 weeks and some fledged chicks (U.S. Geological Survey, unpubl. data). Wild Puaiohi also renested readily when their eggs were removed to establish a captive breeding flock (Snetsinger et al. 1999). Nēnē eggs have been salvaged from abandoned nests and the goslings were raised in captivity for later release, thereby increasing wild recruitment (Baker and Baker 1996).

In contrast to terrestrial bird reintroduction, reestablishing seabirds and waterbirds in former range may involve only controlling predators and attracting birds with calls and artificial nest sites. This technique might be especially effective for reestablishing breeding colonies of Dark-rumped Petrels and Newell's Shearwaters.

Priorities

- Develop strategies and priorities for reintroducing species into habitats that are recovering from ungulates and other stressors and for supplementing populations that have reached critically low levels.
- Develop techniques for hatching, rearing, and releasing species that may be difficult to recover by other methods.

PREDATOR CONTROL

Alien predators threaten Hawaiian birds in all habitats found on the major islands. Conserving endemic birds, therefore, requires reducing or eliminating predatory threats posed by introduced small mammals, particularly rats, feral cats, and mongooses. Preventing the establishment of ground predators on the islands and atolls of the Hawaiian/Pacific Islands National Wildlife Refuge Complex is crucial to conserving resident seabirds and endemic passerines.

Rats have been controlled in Hawai'i primarily in an experimental context to demonstrate their effects on bird survival and productivity. Although rats prey on birds, they may also compete for fruits, seeds, insects, snails and other food items and they may modify habitats by lowering plant productivity, recruitment, and survival. As in New Zealand, rat control may be on the verge of becoming a viable management tool in at least a few areas in Hawai'i. For example, rats have been eradicated from Kure Atoll (D. Smith, pers. comm.) and Midway Atoll (R. J. Shallenberger, pers. comm.). Rats and other predators are being reduced in portions of

Hanawī Natural Area Reserve (M. S. Collins, pers. comm.), Keauhou forest (T. L. C. Casey, pers. comm.), Hakalau Forest National Wildlife Refuge (J. T. Nelson, U.S. Geological Survey, unpubl. data), and Mauna Kea Forest Reserve (P. C. Banko, U.S. Geological Survey, unpubl. data).

The mongoose limits the abundance and distribution of many ground-nesting birds. On Kaua'i, where mongooses are absent, Newell's Shearwaters and Nēnē are relatively abundant. Although controlling mongooses is possible on a local scale, it requires great effort and expense over large areas (Stone et al. 1995). Controlling feral cats is also necessary to protect populations of ground-nesters, such as Dark-rumped Petrels (Hu et al. *this volume*). In addition, cat control is important to maintaining passerine populations, including Palila and 'Alalā. Because disposing of cats elicits strong emotional responses from some people, control programs must include public education. Controlling rats and mongooses, on the other hand, seems to create comparatively little concern among the public.

Priorities

- Prevent mongooses from becoming established on Kaua'i, Lāna'i, and Kaho'olawe.
- Test, register, and implement more economical and effective methods for distributing mongoose poisons.
- Convince legislators and the public of the necessity to eradicate feral cat populations and develop, register, and implement methods for their control.
- Accelerate research for developing efficient techniques for landscape-scale rodent control.

Disease

Avian malaria and pox are potent factors limiting populations of many Hawaiian birds (Warner 1968, Scott et al. 1986, van Riper et al. 1986, Jarvi et al. *this volume,* Shehata et al. *this volume,* van Riper et al. *this volume,* VanderWerf et al. *this volume*). Recent research has confirmed the pathogenicity of malaria in 'I'iwi, a once widespread, common species that is declining in most portions of its range (Atkinson et al. 1995). The ecology of the most important vector of avian diseases in Hawai'i, the mosquito (*Culex quinquefasciatus*), is being investigated to guide management (D. LaPointe, pers. comm.). Feral pigs create breeding sites for mosquitoes, but pig removal and mechanical reduction of breeding sites does not reduce mosquito populations in areas apparently smaller than the dispersal range of mosquitoes (C. T. Atkinson and D. LaPointe, pers. comm.). This reinforces the importance of conducting management over large areas of habitat to conserve birds.

Immunogenetics and resistance to avian malaria are being investigated in Hawaiian honeycreepers with a view towards developing methods for maintaining population stability through maintaining genetic diversity at loci important in immunological responsiveness to pathogens (Jarvi et al. *this volume*). Evidence that some species are co-evolving with malaria may be suggested by the persistence and reappearance of 'Ōma'o, O'ahu 'Amakihi, O'ahu 'Elepaio, and Hawai'i 'Amakihi in some low-elevation localities where mosquitoes are abundant. Research into the genetic, physiological, and ecological bases for the persistence of lowland endemic bird populations will help guide conservation strategies. Similar research is needed to understand the persistence of some endemic species in South Kona, Hawai'i, where the abundance of mosquitoes and prevalence of malaria are high. Investigating the role of diet in the survival of young birds infected by mosquitoes may partially explain malaria resistance, as observed in wild-released 'Alalā.

Hawaiian wetlands also require management to reduce avian disease. Avian botulism outbreaks have occurred at Aimakapā Pond, Hawai'i, as recently as 1996 and killed most Hawaiian Coots, some Black-necked Stilts, and many other waterbirds (Morin 1996).

Priorities

- Prevent the establishment of species or strains of mosquitoes adapted for high elevations ($>$1,500 m).
- Evaluate the effects of landscape-scale removal of feral pigs on mosquito populations and develop other methods for reducing mosquitoes.
- Remove breeding sites of mosquitoes on Midway Atoll to prevent avian pox outbreaks.
- Investigate immunogenetics and resistance to malaria of low-elevation bird populations and develop strategies for genetic management.
- Determine the possible synergistic relationship between nutrition and resistance to malaria and pox.
- Manage wetlands to prevent outbreaks of avian botulism.
- Determine the role of other infectious diseases in lowering the hatchability and survival of forest birds.

CONCLUSIONS

Large-scale habitat management is essential but not sufficient in itself to recover many endemic Hawaiian species. Preserving biodiversity over large areas is difficult, expensive, and often controversial where other human activities conflict. Strategies for avian conservation, therefore, must be effective, efficient, and justifiable to the public. Techniques for landscape-scale predator control are not yet available but are being developed. Ungulate control, on the other hand, is applicable over large areas and may reduce the incidence of avian disease vectors and reduce the spread of weeds. However, public attitudes towards killing vertebrate species, whether alien or not, often hamper control programs. Efforts to educate and counter negative perceptions must be launched on a broad scale. Alien weeds and invertebrates also negatively impact native ecosystems and are very difficult to control. More effective control efforts are needed and new invasive species must not become established.

Opportunities are limited for managing areas not already designated for conservation. Therefore, it is essential to manage areas adjacent to protected lands in partnership with other landowners, as seen in the ʻŌlaʻa-Kīlauea and East Maui Watershed partnerships.

Reintroduction, translocation, captive breeding, and other techniques are necessary tools for recovering and conserving uncommon species. There is now expertise, facilities, and stable funding to support such specialized management actions. However, at least 11 taxa on four islands are probably not recoverable because they are so rare. We regret the loss of these species but must act swiftly to combine habitat and species management approaches to save species for which there is more hope.

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