

Long-Term Persistence of Hawaii's Endangered Avifauna through Conservation-Reliant Management

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One-third of the bird species listed under the US Endangered Species Act are endemic to Hawaii. One requirement of delisting a species is the elimination or abatement of threats to that species. More than 95% of Hawaii's threatened and endangered species face multiple threats that cannot be eliminated (e.g., alien mammalian predators, invasive alien plants that alter habitat structure, disease). However, because we can manage many of the threats at scales at which the achievement of recovery goals is possible, these species could be delisted if conservation partners committed to the implementation of stewardship agreements to maintain viable populations following those populations' delisting.

Keywords: bird conservation, climate change, conservation dependent, extinction, invasive species

Endemic bird species on islands are more at risk than those with continental distributions (Trevino et al. 2007). On Pacific islands, bird species were lost rapidly after human colonization (Steadman 2006), and nowhere has there been more loss and endangerment than in Hawaii (Scott et al. 2001, Pratt TK et al. 2009a). Of the 109 known endemic Hawaiian bird species, 55 went extinct after the arrival of Polynesians and are known only as fossils, and 19 went extinct following the arrival of Europeans (Scott et al. 2001). Of the remaining 37 extant endemic species, 33 are listed under the US Endangered Species Act (ESA; http://ecos.fws.gov/tess_public/SpeciesReport.do?groups=B&listingType=L&mapstatus=1), although 9 of these have not been observed recently and may be extinct (Pratt TK 2009, Elphick et al. 2010).

The perils to the Hawaiian avifauna have been discussed extensively in the literature, particularly for the forest birds (e.g., Scott et al. 1986, Scott et al. 2001, Pratt TK et al. 2009a). Threats have included or currently include overexploitation; alien predators, competitors, and disease; habitat loss and degradation from habitat conversion; and introduced ungulates and plants (e.g., Scott et al. 1986, Pratt TK et al. 2009a). New threats are emerging with climate change and increasing human population size. Discussed less often, however, is the likelihood of recovery for any of these bird species. Typical recovery goals within the context of the ESA include sufficiently large populations and mitigation of the threats that endanger them. Implicit in this definition of *recovery* is

that once a threat is eliminated, the species would no longer need the protections afforded it under the ESA.

The realization that it might not be possible to eliminate threats to some endangered species but that threats might be controlled through continued management has led to the concepts of *conservation-reliant species* and *conservation-reliant recovery* (Scott et al. 2005, Goble 2009); up to 84% of the 1136 species listed by the ESA fall into this category (Scott et al. 2010). The concept of *conservation reliance* would allow the removal of a species from the US Fish and Wildlife Service's (USFWS) list of endangered species (*delisting*) pursuant to long-term management commitments with conservation partners (e.g., federal agencies, private landowners, nongovernmental organizations) to maintain otherwise healthy populations. These agreements would provide the regulatory assurances that threat mitigation consistent with maintaining viable populations would continue for the foreseeable future, even after a species was delisted.

Our goals in this article are to review the threatened and endangered Hawaiian avifauna and their threats and population status and to provide an assessment of the likelihood of delisting with or without those species' having conservation-reliant status.

The species and their threats

The Hawaiian bird species currently listed under the ESA, as well as their current status (distribution, population size,

population trend), are presented in tables 1 and 2; scientific names are also given. Below, we provide an overview of the listed Hawaiian birds and their threats; a summary of the threats to the species is given in figure 1 (details are shown in supplemental table S1, available online at <http://dx.doi.org/10.1525/bio.2012.62.10.8>; see also Scott et al. 1986, Pratt TK et al. 2009a).

At least 22 species of seabirds breed on the Hawaiian Islands, of which 2 are listed: Newell's shearwater (*Puffinus auricularis newelli*) and the Hawaiian petrel (*Pterodroma sandwichensis*). A third species—the band-rumped storm petrel (*Oceanodroma castro*)—has been a candidate for listing since 1989. It is somewhat of a surprise that the list includes so few seabird species, given the extraordinary pressure put on their populations by feather, egg, and meat harvesters at the turn of the last century and by current threats (see figure 1). Many of these seabirds no longer nest on the main Hawaiian Islands, primarily because of the presence of introduced predators, and are now restricted to small offshore islets and the remote Northwestern Hawaiian Islands. Many of the currently inhabited islands are small enough to allow the eradication of alien predators, which has permitted many of their bird species to recover from historic low numbers. Newell's shearwaters and Hawaiian petrels, in contrast, breed exclusively on the main Hawaiian Islands. Newell's shearwaters breed primarily on mountain slopes on Kauai, Molokai, and Hawaii (and possibly elsewhere). Hawaiian petrels were once found on all the main Hawaiian Islands, but the extant populations are restricted primarily to Haleakala Crater on Maui, the higher slopes of Lanaihale on Lanai, and remote areas of Kauai, with smaller numbers on Molokai and Hawaii.

Prior to human settlement, the Hawaiian Islands (including the Northwestern Hawaiian Islands) were home to

breeding populations of at least 11 species of waterfowl, 12 species of rail, 4 species of ibis, 2 species of heron, and 1 species of shorebird (Ziegler 2002). All but two of these species (or subspecies, for the shorebird and rail species) are or were endemic, and all but seven (77%; one species of goose, which we cover below; two species of duck; one species and one subspecies of rail; one species of night heron; and one subspecies of shorebird) are extinct. All of the remaining endemic waterbirds (six species) are listed as *endangered*. The Hawaiian stilt (*Himantopus mexicanus knudseni*) and the Hawaiian coot (*Fulica alai*) are found on all the main Hawaiian Islands except Kahoolawe and are threatened by exotic predators and habitat loss resulting from exotic plant invasion, development, and ungulates. The Hawaiian gallinule (*Gallinula galeata sandvicensis*) is subject to the same threats and once had a similar distribution but is now limited to the islands of Oahu and Kauai. The Hawaiian gallinule numbers only in the hundreds, although that number is increasing on both islands (Reed JM et al. 2011). The Laysan duck (*Anas laysanensis*) was once the most widely distributed of the Hawaiian waterbirds, but following human settlement, its range became limited to the island of Laysan, and in 1911, its population was down to 6–12 individuals (Dill and Bryan 1912). Recent translocation has established a second population on Midway Atoll, and its total population size is approaching 1000 individuals. The koloa, or Hawaiian duck (*Anas wyvilliana*), is most vulnerable to hybridization with mallards (*Anas platyrhynchos*), although historical declines also occurred from wetland loss and mammalian predators.

There are only two endangered upland bird species in Hawaii: the nene, or Hawaiian goose (*Branta sandvicensis*), and the Hawaiian hawk (*Buteo solitarius*). The nene is threatened by habitat loss (from introduced ungulates,

Table 1. Hawaiian nonpasserine birds listed by the US Fish and Wildlife Service and their relevant statistics.

Common name	Scientific name	Status on the IUCN Red List ^a	Population size	Population trend ^b	Distribution
Hawaiian goose	<i>Branta sandvicensis</i>	Vulnerable	1888–1938 ^c	Increasing	H, Ma, Mo, K
Hawaiian duck	<i>Anas wyvilliana</i>	Endangered	2200 ^d (estimated)	Unknown	H, K
Laysan duck	<i>Anas laysanensis</i>	Critically endangered	773 ^e	Increasing	Lay, Mi
Hawaiian petrel	<i>Pterodroma sandwichensis</i>	Vulnerable	5520 ^f	Variable by population	H, Ma, Mo, L, K
Newell's shearwater	<i>Puffinus auricularis newelli</i>	Endangered	20,610 ^f	Declining	H, Ma, Mo, K
Hawaiian hawk	<i>Buteo solitarius</i>	Near threat	3085 ^g	Stable	H
Hawaiian gallinule	<i>Gallinula galeata sandvicensis</i>	Not listed	200–500 ^h	Increasing	O, K
Hawaiian coot	<i>Fulica alai</i>	Vulnerable	2100 ⁱ	Stable or increasing	H, Ma, Mo, L, O, K, Nii
Hawaiian stilt	<i>Himantopus mexicanus knudseni</i>	Not listed	1350 ⁱ	Stable or increasing	H, Ma, Mo, L, O, K, Nii

Note: All of these species are listed as *endangered* by the US Fish and Wildlife Service except the shearwater. Abbreviations: H, the island of Hawaii; IUCN, International Union for Conservation of Nature; K, Kauai; L, Lanai; Lay, Laysan; Ma, Maui; Mi, Midway; Mo, Molokai; Nii, Niihau; O, Oahu. ^aIUCN 2011. ^bThe population trend data come from the same citations as the population size data. ^cAnnie Marshall (Nene Recovery Action Group, US Fish and Wildlife Service, Pacific Islands Fish and Wildlife Office, personal communication, 27 March 2012). ^dEngilis et al. 2002, Fowler et al. 2009. ^eReynolds and Citta 2007, Reynolds et al. 2007. ^fPyle and Pyle 2009. ^gGorresen et al. 2009. ^hDesRochers et al. 2008, Reed JM et al. 2011. ⁱUSFWS 2012.

Table 2. Hawaiian passerine bird species listed by the US Fish and Wildlife Service as endangered and their relevant statistics.

Common name	Scientific name	Status on the IUCN Red List ^a	Population size	Population trend ^b	Distribution
Hawaiian crow	<i>Corvus hawaiiensis</i>	Extinct in the wild	60 ^c	Stable	Captivity only
Oahu elepaio	<i>Chasiempis sandwichensis ibidis</i>	Vulnerable	<2000 ^d	Declining	O
Nihoa millerbird	<i>Acrocephalus familiaris kingi</i>	Critically endangered	427 ^e	Fluctuating	Lay, Ni
Kamao	<i>Myadestes myadestinus</i> ⁱ	Extinct	Unknown ^f	Unknown	K
Olomao	<i>Myadestes lanaiensis</i> ⁱ	Critically endangered	Unknown ^f	Unknown	Mo
Puaiohi	<i>Myadestes palmeri</i>	Critically endangered	300–500 ^f	Unknown	K
Kauai oo	<i>Moho braccatus</i> ⁱ	Extinct	Unknown ^f	Unknown	K
Laysan finch	<i>Telespiza cantans</i>	Vulnerable	10,284 ^g	Fluctuating	Lay, PH
Nihoa finch	<i>Telespiza ultima</i>	Critically endangered	2807 ^e	Fluctuating	Ni
Ou	<i>Psittirostra psittacea</i> ⁱ	Critically endangered	Unknown ^f	Unknown	H, K
Palila	<i>Loxioides balleui</i>	Critically endangered	2640 ^c	Declining	H
Maui parrotbill	<i>Pseudonestor xanthrophrys</i>	Critically endangered	500 ^f	Stable	Ma
Kauai akialoa	<i>Hemignathus ellisianus stejnegeri</i> ⁱ	Extinct	Unknown ^f	Unknown	K
Nukupuu	<i>Hemignathus lucidis</i> ⁱ	Critically endangered	Unknown ^f	Unknown	Ma, K
Akiapolaa	<i>Hemignathus munroi</i>	Endangered	1900 ^c	Unknown	H
Akikiki	<i>Oreomystis bairdi</i>	Critically endangered	3568 ^c	Declining	K
Hawaii creeper	<i>Oreomystis mana</i>	Endangered	1400 ^c	Variable by population	H
Oahu alauahio	<i>Paroreomyza maculata</i> ⁱ	Critically endangered	Unknown ^f	Unknown	O
Kakawahie	<i>Paroreomyza flammea</i> ⁱ	Extinct	Unknown ^f	Unknown	Mo
Akekee	<i>Loxops caeruleirostris</i>	Critically endangered	7887 ^c	Declining	K
Hawaii akepa	<i>Loxops coccineus coccineus</i>	Endangered	14,000 ^h	Unknown	H
Maui akepa	<i>Loxops coccineus ochraceus</i>	Endangered	Unknown ^f	Unknown	Ma
Akohekohe	<i>Palmeria dolei</i>	Critically endangered	3800 ^c	Increasing	Ma
Poo-uli	<i>Melamprosops phaeosoma</i> ⁱ	Critically endangered	Unknown ^f	Unknown	Ma

Abbreviations: H, the island of Hawaii; K, Kauai; Lay, Laysan; Ma, Maui; Mo, Molokai; Ni, Nihoa; O, Oahu; PH, Pearl and Hermes.

^aIUCN 2011. ^bThe population trend and population size data in each row are from the same source. ^cGorresen et al. 2009. ^dVanderWerf et al. 2001. ^eRowland et al. 2007. ^fUSFWS 2006. ^gMorin and Conant 2002. ^hScott et al. 1986. ⁱThis species is likely to be extinct (Gorresen et al. 2009, Elphick et al. 2010).

exotic plants, and development), disease, and exotic predators (figure 1). The nene was once found on all the main islands but was extirpated from all of them except Hawaii. Its range recently expanded again to include Maui, Kauai, and Molokai as a result of successful captive breeding and reintroduction, although only the population on Kauai is self-sustaining. The Hawaiian hawk is endemic to the island of Hawaii, although it once lived on other islands (Banko PC et al. 2001). In table S1, we list what were once considered threats to the species, but it is not clear that there are significant current threats beyond its being limited to a single island (see below). This species' current range on the island of Hawaii still includes much of its historic range, apparently because of its ability to use altered habitat and introduced prey (Klavitter 2009); it is being considered for delisting (USFWS 2008a).

There are currently three endangered passerines on the Northwestern Hawaiian Islands: the Nihoa finch (*Telespiza ultima*), the Nihoa millerbird (*Acrocephalus familiaris kingi*), and the Laysan finch (*Telespiza cantans*). Unlike the rest of the species discussed so far, these species are threatened by the intrinsic nature of their restricted distributions and low abundance rather than by external threats introduced by human activities. All three species have small population sizes, and the two Nihoa Island passerines were limited to that single island, although the millerbird was recently introduced to Laysan, and the Laysan finch breeds on two islands.

The endangered Hawaiian forest birds are passerines, mostly honeycreepers, on the larger islands. According to the historic record, there were 49 Hawaiian forest bird species, 28 of which are now extinct; if forest passerines

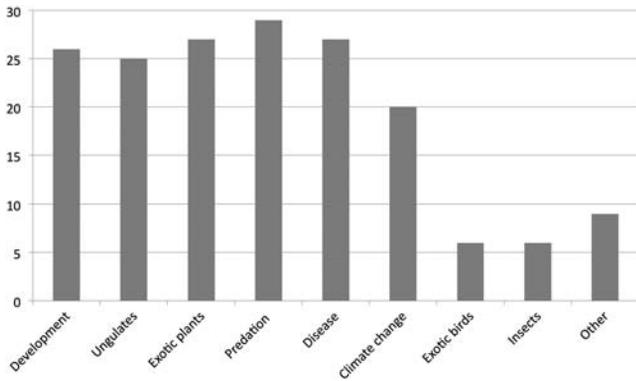


Figure 1. Threats to listed Hawaiian bird species or subspecies ($n = 33$). The “Predation” category refers specifically to predation by introduced predators. The “Other” category includes a variety of threats, such as nutrient deficiency, inbreeding, light pollution, and power-line collision. Detailed descriptions of the threats and supporting citations are found in supplemental table S1, available online at <http://dx.doi.org/10.1525/bio.2012.62.10.8>.

found in the subfossil record are also included, the number of extinct species increases significantly (Pratt TK 2009). Of the extant forest passerines, many are listed as *endangered* or *threatened*, and at least one—the alala, or the Hawaiian crow (*Corvus hawaiiensis*)—is extinct in the wild. Some of the forest birds listed under the ESA have not been reported reliably in years, and nine are suspected to be extinct (table 2; Pratt TK 2009, Elphick et al. 2010), although high confidence is difficult because of the Hawaiian terrain where these forest birds live (Scott et al. 2008). Well-documented threats to the Hawaiian forest birds include exotic predators; habitat loss and degradation from introduced ungulates, exotic plants, and development; and disease, particularly avian malaria and avian pox (figure 1). Disease is the biggest problem in reducing habitat availability, because it limits the range of most forest birds to elevations above 1500 meters, where mosquitoes are absent because of cool temperatures (Scott et al. 1986, LaPointe et al. 2009). Less well established and controversial is evidence for negative impacts from competition from exotic birds, particularly from the Japanese white-eye (*Zosterops japonicus*) and the Japanese bush warbler (*Cettia diphone*). Insects, particularly the western yellow-jacket (*Vespula pensylvanica*), parasitoid wasps, and the Argentine ant (*Linepithema humile*) are thought to compete with the palila (*Loxioides balleui*) through predation for the same invertebrate prey. Other proposed potential insect competitors include parasitic wasps and flies (Banko PC and Banko 2009).

Potential for the elimination or control of threats

Eliminating many of the threats to Hawaiian birds will not be easy. Here, we discuss the threats more generally, as well

as their potential for elimination or control on the Hawaiian Islands. The first step in securing the future for endemic Hawaiian birds is to ensure that there is secure habitat across a range that is sufficient to warrant the species’ delisting. The second is to ensure that these habitats are managed in order to control the factors threatening forest birds at conservation-relevant scales. Hawaii’s Comprehensive Wildlife Conservation Strategy (CWCS) and species recovery plans provide a blueprint for conservation action in the islands, although an institutional framework is missing.

Native habitat in Hawaii has been lost to conversion most extensively for development and agriculture. Housing and tourism development has been a particular problem for coastal habitats, such as wetlands, because of their concentration in areas favored by waterbirds on the main islands (Griffin et al. 1989). Agriculture has also been concentrated on low coastal lands through midlevel elevations. With the recent collapse of the sugar industry in Hawaii, extensive areas once used for sugarcane are awaiting their next uses. If sugarcane fields become housing, the increase in human population size and its associated pressures will affect all avian habitats. With increasing human population size, the importance of linking the implementation of recovery plans and the CWCS to statewide integrated development planning will also increase.

Ungulates (pigs [*Sus scrofa*], goats [*Capra aegagrus*], sheep [*Ovis aries*], deer [*Axis axis* and *Odocoileus hemionus*]), European rabbits (*Oryctolagus cuniculus cuniculus*), and black (*Rattus rattus*) and Pacific (*Rattus exulans*) rats have or have had tremendous impacts on habitat loss and degradation. They eliminate native plant species and prevent plant regrowth, and their actions encourage exotic plant invasion (e.g., Pratt LW and Jacobi 2009). Ungulate eradication has been achieved on increasingly larger islands in the Pacific (Kessler 2002). Eliminating ungulates from larger islands such as Maui or Hawaii would be biologically difficult and very expensive, although it could probably be done (e.g., Cruz et al. 2005). Instead, large fences have been erected to exclude mammals (figure 2), and the increased use of fences could provide sufficient habitat for bird species to recover (e.g., USFWS 2008a). Installing and maintaining fencing is expensive and difficult, but in some areas, it has been quite effective and has allowed native plants to regrow (e.g., Cabin et al. 2000). Even this level of management, however, has been difficult to implement in parts of Hawaii, particularly on state-owned forests and in wildlife management areas, because of social pressures to maintain recreationally viable populations of ungulates. The problem of social or political issues in Hawaiian conservation was addressed by Leonard (2009) and Goble and colleagues (2012 [in this issue]).

The problems posed by exotic, invasive plants are extensive and expanding. It is difficult to know how many species of plant have been introduced to the Hawaiian Islands, but it is believed to be in the thousands and might exceed 10,000 (Ziegler 2002). Many of these species have become invasive (e.g., Sakai et al. 2001). Because of the continued

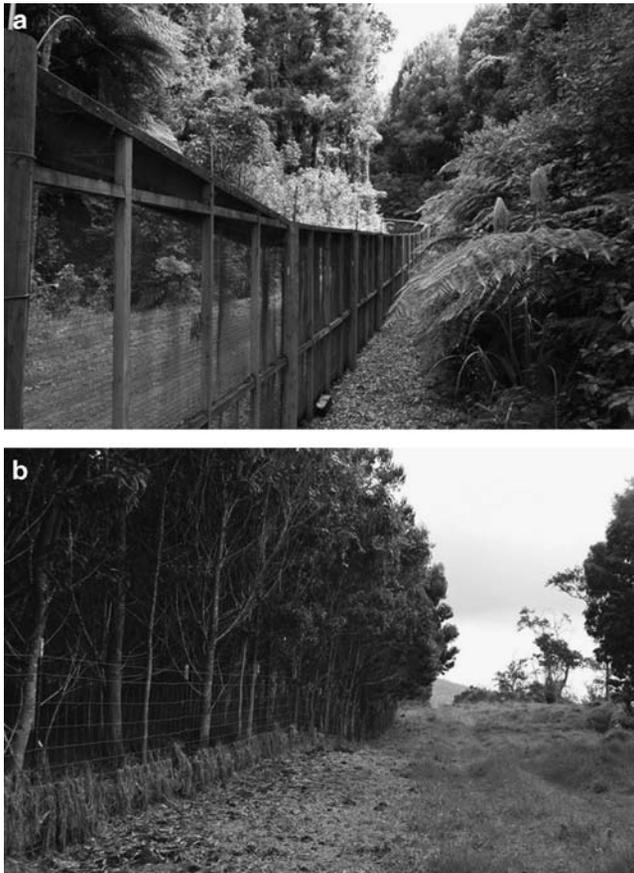


Figure 2. (a) Predatorproof fence at Mangatautari Reserve, New Zealand. (b) Ungulate fence at the Puu Waawaa Experimental Forest on the island of Hawaii, which shows the difference in vegetation cover and structure inside and outside of a fence. Photographs: Eric A. VanderWerf.

accidental introduction of exotic plants and the time lag commonly observed before established introduced species become invasive, we can expect the problems from this threat to increase over time. There is ample evidence that invasive nonnative plants pose a threat to Hawaiian birds. For example, the Oahu elepaio (*Chasiempis sandwichensis ibidis*) prefers riparian forest habitat along streams, and these areas are dominated by nonnative plants. Although elepaios can forage and nest in nonnative forest, they suffer from a high rate of nest depredation, because many of the dominant trees bear fruit or nuts that provide food that may support dense rat populations and may attract rats into the forest canopy, where they encounter and prey on elepaio nests (VanderWerf 2009). For the more specialized forest birds—particularly, the Maui parrotbill (*Pseudonestor xanthophrys*), the akohekohe (*Palmeria dolei*), the akikiki (*Oreomystis bairdi*), and the akekee (*Loxops caeruleirostris*)—gradual conversion of native forest to nonnative forest by invasive plants, such as the strawberry guava (*Psidium cattleianum*), the velvet tree (*Miconia calvescens*), ginger

(*Zingiber officinale*), and many other species, will result in the loss of suitable habitat and a reduction in range for many species. Each invasive plant species might require its own method of eradication, which means that extensive experimental work will be required in order to develop eradication or control techniques for them. Some species can probably be eradicated or at least controlled (such as the red mangrove [*Rhizophora mangle*] and, hopefully, *Miconia* spp.), but others (e.g., guava [*Myrica* spp., *Schinus* spp.]) are so well established that complete eradication is no longer possible. Whether this causes any bird species to be conservation reliant depends on the level of plant suppression achievable and the level of tolerance that native species have to mixed native–alien plant composition and structure. Wetland birds are likely to be conservation reliant because of exotic plants; some types of wetland plants, such as mangrove, can be effectively—but not permanently—removed (Rauzon and Drigot 2002).

Rodents (rats and mice [*Mus musculus*]) pose threats to species primarily through nest depredation. In Hawaii, rodents are found from sea level to mountaintops, from beach to forest, on all of the main Hawaiian Islands and on many of the smaller islands. Rats have been eradicated successfully from many islands around the world through the extensive use of poisoned baits (Howald et al. 2007), with larger and larger islands being made predator free. In the Hawaiian Islands chain, rodents have been removed from some small islands (Smith et al. 2006). Eradication from larger islands, such as Oahu or Kauai, however, does not appear to be possible with current technology, but it is being investigated. This leaves the possibility of rodent control, rather than eradication. Intensive rodent trapping can afford some relief to forest birds (e.g., VanderWerf 2009). Predatorproof fences that exclude all predators, including rats and mice, have been used in New Zealand and Australia to create predator-free “mainland islands” (Saunders and Norton 2001), but they are expensive to build and require maintenance to ensure their continued performance. Consequently, except on very small islands, rodent-threatened species, such as Oahu elepaio, puaiohi (*Myadestes palmeri*), and the waterbirds, will be conservation reliant in perpetuity. Kahoolawe Island is small enough that the elimination of rats, cats, house mice, and mongooses (*Herpestes javanicus*) is possible. If this island can be made predator free, its isolation would make it attractive for the introduction of threatened and endangered species at risk from sea level rise (see below) due to climate change.

The mongoose poses problems with limited solutions similar to those of rodents. They are absent from the smaller islands and from Kauai. The benefit of their absence is demonstrated by nene, which are probably conservation reliant on all islands except Kauai, where there are no mongooses. On Kauai, nene are increasing in number, but on Maui and Hawaii, the populations have remained stable despite continued releases of captive-bred birds.

Feral cats are widely recognized as significant threats to bird populations, particularly on islands and in urban

settings (e.g., Nogales et al. 2004, Sims et al. 2008). Because of the small size of the Hawaiian Islands relative to their extensive urban and exurban development, cats are found widely throughout the major islands and significantly affect bird populations (Loope et al. 1988, Banko WE and Banko 2009, Lindsey et al. 2009). Cats in Hawaii are serious predators on forest birds, such as palila (Banko PC et al. 2009), as well as seabirds and waterbirds (figure 3). Controlling cats is politically problematic in Hawaii, as it is in other places, because a large sector of the public objects to feral cat control (Zasloff and Hart 1998). However, the continued existence of cats in native bird habitat conflicts with the recovery objectives for native birds.

Cattle egrets (*Bubulcus ibis*) were introduced to Hawaii to eat invertebrates in agricultural areas (Paton et al. 1986), and black-crowned night herons (*Nycticorax nycticorax*)

reached the islands on their own. These species are a threat to endangered waterbirds and to seabirds in some areas, particularly when these predators' roosts get large, because they are effective predators of chicks. We do not know whether all of these predators could be killed in a practical fashion; it would have to be a statewide eradication, because the birds can fly between islands, so recolonization could quickly occur. Because the night heron is a native species, advocating its control might be problematic for wildlife managers. However, native predators are routinely controlled on the mainland to maintain recreationally viable populations of game species, and takes of night herons in Hawaii are allowed at commercial prawn aquaculture sites where night herons eat prawn stock, so there is precedent for local control if problems occur. Within the realm of threats to Hawaiian birds, however, these predators seem to be a less serious threat (except near large roosts), and we think that it is unlikely that any endangered species would remain conservation reliant because of the effects of these predators alone.

The primary avian diseases of concern in Hawaii are avian malaria and avian pox, which have devastated forest birds and greatly limited their distributions (Foster et al. 2007, LaPointe et al. 2009). There is also potential for the introduction of new diseases, particularly avian influenza and West Nile virus. One vector for all of these diseases is the mosquito (*Culex quinquefasciatus*), so the potential for threat elimination relies on the ability to control mosquitoes. Although mosquito control is practiced worldwide—primarily to reduce disease risk to humans—there is no evidence that eradication of this disease vector through current methods is possible, even on islands. Even effective control on a small scale can be difficult (e.g., Knight et al. 2003), although some interesting work is being done on the potential for the biological control of mosquitoes (LaPointe et al. 2009). Consequently, the recovery of most Hawaiian forest birds will be severely hampered by mosquitoes and disease, so these species will remain conservation reliant. Controlling mosquitoes on even a local scale will be difficult (LaPointe et al. 2009), but not all methods of control have been fully investigated. There is one long-term possibility for some reprieve in that some forest bird species are exhibiting resistance to avian malaria (Foster et al. 2007). It is also possible that the evolution of disease resistance may be accelerated through increased numbers of birds at lower elevations through a reduction of nondisease threats (e.g., rodent control; Kilpatrick 2006). The evolution of disease resistance should not, however, be relied on for threat removal, particularly because it is unlikely to outpace the problem of mosquito range expansion projected from climate change (Benning et al. 2002, Atkinson and LaPointe 2009). Forest restoration or creation at high elevation would help ameliorate this problem, but only on Maui and Hawaii.

It might be possible to reduce numbers of exotic invasive birds such as the Japanese white-eye and the Japanese bush warbler, but complete eradication is probably impossible.

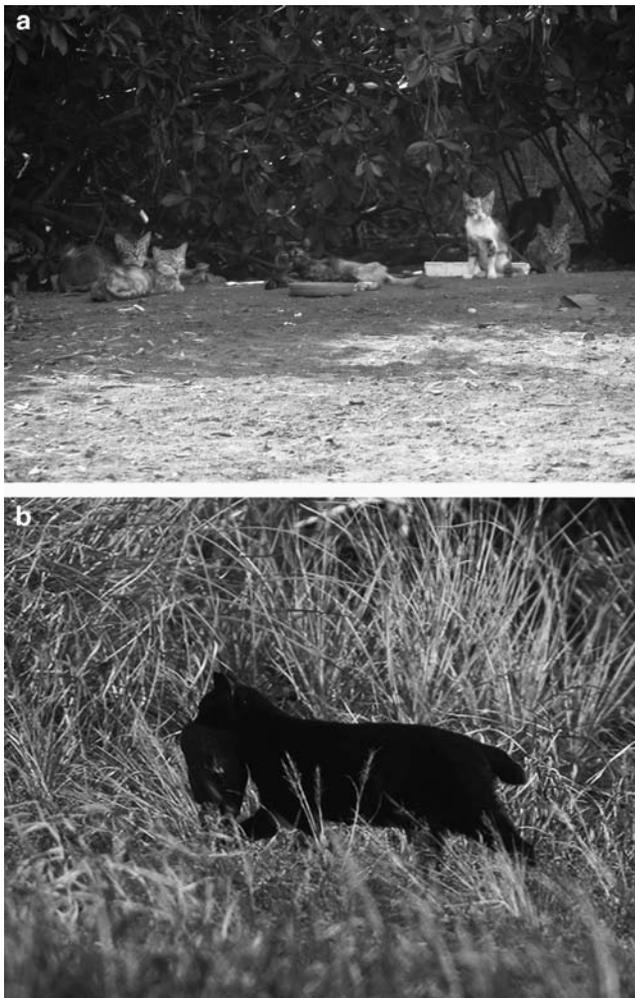


Figure 3. (a) Feral cats at a feeding station adjacent to the Honouliuli Unit of Pearl Harbor National Wildlife Refuge on Oahu, Hawaii. Photograph: Aaron Nadig, US Fish and Wildlife Service. (b) Feral cat at the same refuge carrying an endangered Hawaiian coot. Photograph: Michael Walther, Oahu Nature Tours.

As was discussed earlier, the evidence for competition of threatened and endangered species with exotic birds and its impacts on native species is controversial, and until that evidence is decisive, it would be difficult to say whether the presence of those exotic birds would cause any species to be conservation reliant. Exotic insects and fish present a similar story to that of the exotic birds. There is some evidence that they are competing with native birds by taking the prey base—insects competing with forest birds (see the discussion on forest birds above) and tilapia (*Oreochromis niloticus*) possibly competing with Hawaiian stilts and coots—but it is not clear that the effects ever limit the populations of native birds. Other incipient problem species include the invading coqui (*Eleutherodactylus coqui*) and Jackson's chameleon (*Chamaeleo jacksonii*), both of which feed on arthropods. If any of these competitive interactions is found to limit populations, local control might be more likely than elimination of the threat.

Mallards were first introduced to Hawaii in the late 1800s, primarily as an ornamental species and later to stock hunting areas. Biologically, it should be possible to eradicate mallards and, hopefully, to prevent their reintroduction, but in practice, this has proven difficult. The prime threat that mallards pose is hybridization with koloa. Koloa are noticeably smaller than mallards, and hybrids are intermediate in size, although one might need to have them in hand to distinguish some individuals; hybrids can also be identified genetically (Fowler et al. 2009). The requirement for capturing individuals to unambiguously identify them might make control difficult, particularly because genetic evidence suggests that getting rid of only green-headed ducks (male mallards) would not be sufficient for control (inferred from data from Fowler and colleagues [2009]). Action needs to be taken while apparently pure populations still exist on Kauai, but if all ambiguous ducks must be caught before their removal or release (pending purity assessment), it will be costly. In addition, ensuring public support might be difficult.

Inbreeding is a factor for only a few species. For nene, there is evidence of inbreeding depression in the form of reduced reproductive success. The captive flock in Paxinos and colleagues' (2002) study was probably genetically depauperate, but the contribution of captive-released birds is not clear. There is little that can be done about this unless one wants to introduce genetic material through crossbreeding with a related species. For the alala, inbreeding depression is becoming a serious problem, but again, little can be done unless genetic material is introduced through crossbreeding with closely related species.

Newell's shearwater is attracted to lights, which results in direct mortality from collisions and indirect mortality of grounded birds from predation by exotic predators. There are ways to correct this problem, such as shielding lights and placing power lines underground (Reed JR et al. 1985, Telfer et al. 1987). The conservation program Save Our Shearwaters reduces mortality from predators and other

causes by collecting, rehabilitating, and releasing grounded shearwaters. In response to the problems caused by light attraction and seabird collisions, the County of Kauai has temporarily changed its football stadium's use during the seabird breeding season to mostly daylight hours (www.hawaiiinewsnow.com/global/story.asp?s=12843587), and recent lawsuits (e.g., www.ens-newswire.com/ens/may2011/2011-05-16-092.html) are improving the landscape for protecting light-attraction-prone species, which has resulted in new habitat conservation plans (e.g., www.fws.gov/policy/library/2011/2011-17452.html).

Although climate change is now widely recognized as having the potential to affect species distribution, interspecific interactions, and phenology, we are still in the very early stages of predicting the effects on Hawaiian birds. The potential for negative impacts, however, is extensive, and these problems could defeat some conservation efforts already in place or currently being planned. The most obvious problems to be faced by Hawaiian endemics include the expansion to higher elevation of disease vectors for forest birds, the loss of coastal wetlands and saltwater incursion for waterbirds, the loss of low-lying breeding colonies for seabirds, and changes in rainfall patterns and the drying of many areas that would affect virtually all plants and arthropods. Islands in general are particularly vulnerable to climate change, and although there has been some work on predicting the effects of climate change in Hawaii (e.g., Loope and Giambelluca 1998, Benning et al. 2002), we are still far from understanding the extent and details of the problems and what might be done about them (Pratt TK et al. 2009b).

Assessment of likely conservation reliance status of Hawaiian birds

A species is conservation reliant if it requires human intervention to avoid extinction or the threat of extinction. It will not be easy to manage threats to an extent that will allow "recovery" of many listed species, but it is possible for some, although it will take substantially more resources than are currently allocated for these efforts. For these species, we think that long-term persistence will depend on active management after delisting (figure 4). Of the currently listed Hawaiian birds, five (the leeward species) appear to have no or minimal conservation reliance, and only the Hawaiian hawk is near the desired degree of recovery on the basis of listing criteria. All of the other listed species will require some sort of conservation management agreement that provides assurances that the control of nonnative species will continue at scales that are conservationally relevant (figure 4).

The threats to Hawaiian petrel or Newell's shearwater are habitat loss due to conversion and ungulates, predation by exotic predators, and light pollution, all of which can be managed on but not eliminated from the main Hawaiian Islands. The petrel might also be affected by mosquito-borne disease, and we cannot yet eliminate mosquitoes. A first step toward achieving the recovery goals for these

Degree of conservation reliance	Possibly too late	Kamao, Olomao, Kauai oo, Ou, Kauai akialoa, Nukupuu, Oahu alauahio, Kakawahie, Poouli				
	Extreme	Akikiki, Akekee	Hawaiian crow, Oahu elepaio, Puaiohi			
	Heavy, over large area		Maui parrotbill, Hawaii akepa, Maui akepa	Hawaiian goose, Akiapolaau, Akohekohe, Hawaii creeper	Palila	
	Heavy, over restricted area		Hawaiian petrel, Newell's shearwater	Hawaiian duck, Hawaiian gallinule	Hawaiian coot, Hawaiian stilt	
	Modest, often intermittent		Nihoa finch, Laysan finch, Nihoa millerbird, Laysan duck			
	None				Hawaiian hawk	
		0	1	2	3	4
		Degree of recovery achieved				

Figure 4. Listed Hawaiian bird species relative to their degree of conservation reliance and the degree of species recovery achieved (as of 2006, the last year for which these data are available). The degree of recovery is indicated on a scale of 0 to 4 (0, not evaluated; 1, 0%–25% of the recovery objectives have been achieved; 2, 26%–50% achieved; 3, 51%–75% achieved; 4, 76%–100% achieved; USFWS 2008b).

species would be creating predator-free zones on breeding colonies using predatorproof fences and translocating the species to predator-free areas at lower elevations with direct access to the sea, where the threats of light pollution are greatly reduced. These solutions would require long-term management.

If the Laysan duck were established on a few more islands and if threat removal were achieved, the species might be considered *recovered*, but the long-term effects of sea level rise may require the use of main-island sites for introductions. We think that the only endangered waterbird that might be recovered through threat removal is the Laysan duck; the rest will be conservation reliant. Recovery of Hawaiian stilts, Hawaiian coots, and Hawaiian gallinule would require the control of alien predators—particularly rats, cats, bullfrogs (*Rana catesbeiana*), and mongoose—and of invasive wetland plants—particularly mangrove, California grass (*Urochloa mutica*), pickleweed (*Batis maritima*), and water lettuce (*Pistia stratiotes*) (Rauzon and Drigot 2002). Waterbird persistence also requires water management to maintain seasonally flooded wetlands, which are critical for food and cover production. Sea level locations of many of the existing waterbird refuges make these species particularly vulnerable to sea level rise. Therefore, an extension of existing refuges inland and upward in elevation, where that intervention is possible, could ameliorate climate change effects; this could be completed before the species' delisting. Combining this with an overall increase in protected areas, including an addition of upper-elevation sites,

continued predator control, and the erection of predator-free fencing, could move these species beyond their recovery goals. The populations of two of these species, the Hawaiian stilt and the Hawaiian coot, are near their recovery goals and are stable or increasing in numbers (USFWS 2006, Reed JM et al. 2011), and 75% or more of their recovery actions have been achieved. Increased intensity and scale of ongoing management activities, including strategic growth of the protected areas system, could result in delisting.

The koloa has the same habitat issues, as do the other waterbirds, but it is also threatened by hybridization with mallards. If mallard eradication is rapid and successful and is followed by a breeding and reintroduction program from true stock, the recovery of this species may be possible. The Laysan duck may recover if it can be established on a few more of the Northwestern Hawaiian Islands; with sufficient predator control, other islands, such as Molokai, may also be appropriate. The long-term effects of sea level rise, however, might require the use of main-island sites by this species (since it once lived on all of the islands, however, this would represent a reintroduction rather than an introduction).

The Hawaiian hawk was originally listed because of its limited range and its perceived small population size and threats from habitat loss. More recent information, however, suggests that even though its range is limited, its populations are larger than was previously thought, its population has been fairly stable for the last 20 years and breeds well in exotic habitats, and it is not threatened by disease (Klavitter 2009). This species has been proposed for delisting (USFWS 2008a) and is not a conservation-reliant species.

The nene on Maui and Hawaii has much the same problems as do the seabirds, being threatened by exotic predators, habitat loss (to ungulates, exotic plants, and development), and disease (figure 1, table S1). As with seabirds, we see nene on these islands as being conservation reliant. In contrast, the nene on Kauai appear to be doing well and might be delisted without postrecovery management agreements.

The Northwestern Hawaiian Island passerines present a hopeful contrast to the other endangered Hawaiian birds, because they might be recoverable under traditional delisting criteria. For example, the establishment of the Nihoa millerbird on several more islands would likely be sufficient to consider it *recovered*. The recovery plan for this species (USFWS 1984) suggests translocating this species, and 24 birds were recently introduced to Laysan Island (www.fws.gov/pacific/news/2011/Nihoa_Millerbird_Translocation_FAQs_091611.pdf). The Laysan finch is already established

on two islands, although the population on Pearl and Hermes is still quite small because of habitat limitation and will probably not become viable, so the establishment of additional populations might secure its future. The Nihoa finch's recovery will possibly be more difficult, because the species is known only from a single high island, and there are few other similar islands to which it could be translocated. For all of the Northwestern Hawaiian Island populations, there are two caveats: There would have to be long-term vigilance to ensure that exotic plants and predators do not gain access to these islands, and some of the translocations may need to be onto the main islands because of the anticipated sea level rise associated with climate change. If one removed predators from Kahoolawe and Lehua islands, this would provide additional management opportunities. Recovery for the Laysan and Nihoa finches is a bit more difficult. One would want to establish multiple populations on other islands, but evidence suggests that they have poor immunity to diseases, so main-island sites might not be feasible (Morin and Conant 2002).

The palila, which is limited to a single island and is mostly in a single declining population, exemplifies the myriad and interacting problems facing endangered forest birds in Hawaii. Mammalian predators, avian malaria, and overgrazing by sheep are the most important factors limiting their range and population size. The subalpine forest habitat of this species is severely overbrowsed by feral and domestic ungulates (sheep), although effective fencing could solve this problem. In addition, introduced grass cover is high, which suppresses mamane (*Sophora chrysophylla*) regeneration and might increase fire threat, and food shortages may account for high losses of eggs and chicks at the end of the breeding season; the food shortages might be caused by exotic insects preying on and parasitizing native insects (especially native caterpillars), particularly at low elevations. It is unlikely that any of these threats can be eliminated, and they can probably be controlled only by permanent and ongoing management measures. All of the native endangered forest birds face the same problems as those listed for the palila, making all of the birds conservation reliant. In addition, if it turns out that competition from exotic birds and insects is affecting forest bird populations (table S1), these threats also fall into the category of control through long-term efforts rather than being threats that can be eliminated. Developing threats from climate change, new exotic species invasions, and our inability to eliminate existing threats reinforce the need for continuing stewardship to protect these endemic species.

We can use the akiapolaau (*Hemignathus munroi*) as an example of how delisting as *conservation reliant* might be achieved. The recovery goal for this species is at least two stable or increasing populations for 30 years at numbers that ensure viable populations. Hakalau Forest National Wildlife Refuge has 8500 hectares (ha) of akiapolaau habitat above an elevation of 1350 meters that could support 425 pairs of birds. Assuming two additional managed conservation areas, each with 8500 ha within the recovery area identified

by the species' recovery plan (USFWS 2006), that would be a breeding population of 1275 pairs in areas where ungulates had been removed and excluded with fencing, where habitat had been restored or created at higher elevations, and where invasive plants and predators were managed. Development of conservation management agreements with ranchers of the Bishop Estate, the State of Hawaii, or The Nature Conservancy would provide the regulatory assurances needed for the akiapolaau to be delisted. Nearly 200,000 additional hectares of recovery habitat are available on Hawaii, with increased opportunities for habitat restoration at higher elevations. Assuming a home range of 20 ha for a breeding population of 2500 pairs, about 50,000 ha would have to be managed. A population of several thousand breeding pairs is consistent with current viability targets (Traill et al. 2010). The endangered forest bird species on Kauai, Molokai, and Oahu have lower prospects for recovery because of insufficient habitat for forest birds above the putative disease belt to maintain viable populations (LaPointe et al. 2009). The only hope for saving these species if they are unable to adapt to or to evolve resistance to malaria and pox might be to hold them in captivity—an extreme case of conservation reliance.

Endangered species management: Knowing and doing

Although it is obvious that there is still a lot to learn in the protection of endangered Hawaiian birds, particularly with regard to the effects and amelioration of climate change, we already know enough to control predators and to conserve and restore habitat—actions that we know can lead to significant progress in species recovery. In fact, significant knowledge of the required actions for species recovery was presented in early recovery plans for these species, and many of the management recommendations highlighted more than 25 years ago by the USFWS (1983) and by Scott and colleagues (1986) to help recovery Hawaii's endangered birds have changed little to this day. For example, the USFWS (1983) called for the removal and management of ungulates in the Alakai Wilderness Preserve on Kauai. Today, for the first time, a fence is being built; in the interim between recommendation and the start of its implementation, three native bird species have (probably) gone extinct, and another species (the akikiki) has been listed. Other examples of a failure to act on known species management needs include the failure to remove feral sheep and goats from critical habitat for the palila 29 years after the US Court of Appeals, Ninth Circuit, and 24 years after the Hawaii District Court rulings (both are *Palila v. Hawaii Department of Land and Natural Resources*). We fail to act on the knowledge available to us for species recovery for a variety of reasons (e.g., insufficient funds, other priorities, social or political obstacles; Banko PC et al. 2001, Leonard 2009, Goble et al. 2012 [in this issue]). The conflicts between hunting interests and feral pig and ungulate control in endangered forest bird habitat and the

unresolved conflicts between taro farming and waterbird management are testimony to the challenges presented for conservation when there are conflicting societal goals. These situations provide an opportunity for *structured decisionmaking*. This approach is normally used to assess risks associated with managing these resources under different management scenarios (e.g., Ralls and Starfield 1995). However, for many of Hawaii's endangered birds, the problem is not understanding the threats or how to eliminate them; rather, it is finding the political will to do so. Only time will tell if structured decisionmaking will be more effective in Hawaii than previous decisionmaking tools have been.

Pining for what might be if things had been done differently in the past will not help save what remains of Hawaii's endemic avifauna. Learning from these failures, however, might keep us from repeating them. What we need to do now is to decrease the severity of the tragedy of Hawaiian bird extinctions. It is important to recognize that Hawaii is not all bad news; there have been noteworthy local successes.

On the big island of Hawaii, landscape-scale conservation actions by the Three Mountain Alliance, a watershed partnership, to conserve native habitat and species has reduced the abundance of invasive exotic plants and animals over large areas of the million-acre area managed by the Alliance. Eradication of black rats (*R. rattus*) from Midway Island resulted in increased numbers and reproductive success of Bonin Island petrels (*Pterodroma hypoleuca*; Rauzon 2007). The cessation of stilt hunting in the 1940s and the creation of protected wetlands managed for waterbirds starting in the 1970s led to significant increases in the numbers of Hawaiian stilts, coots, and gallinule (Reed JM et al. 2011). Captive breeding, release, and translocation of nene have resulted in significant increases in the species' range and population size and an apparently secure population on Kauai (Banko PC et al. 1999). Translocation of Laysan ducks to Midway Atoll doubled the number of populations and more than doubled their numbers (Reynolds et al. 2008). Elepaio numbers increased on Oahu in areas with predator control (VanderWerf 2009). The successful placement of ungulate fencing followed by ungulate removal from within the fenced areas at Hakalau Forest National Wildlife Refuge and the replanting of koa led to the restoration of koa forests and to akiapolau population increases in the restored stands (Price et al. 2009).

In the face of the identified need for continuing species-specific intervention for most of Hawaii's endangered birds, is Hawaii a hopeless case? Some have suggested that investing resources to save very rare species is a lost cause and that triage is necessary. However, it is not clear that we have yet reached that stage (Pratt TK et al. 2009b); for example, few would have expected the Laysan duck to have persisted from its low of 6–12 birds nearly a century ago. In addition, we have many effective management tools for these species (e.g., Pratt TK 2009).

Hawaii's threatened and endangered birds provide us with a window to the future of bird conservation. The challenges of postrecovery management for conservation-reliant species are many, but perhaps the biggest is implementing the needed management actions at scales that are conservationally relevant. Recovery plans for these species provide the needed conservation blueprint. Other recommendations can be found in the published literature (e.g., Scott et al. 2001, Pratt TK et al. 2009a). P. C. Banko and colleagues (2001) provided an excellent list of management and research priorities for Hawaiian bird conservation, and they made a strong case for developing a comprehensive management plan for the state. As part of a long-term plan, we suggest delisting within the context of conservation reliance, which would mandate that a management plan is in place that requires continued management interventions consistent with those implemented to get the species to recovery status. This might be a politically favorable solution in some regions, because it would reduce the federal imprint on local species management and would increase the opportunities, impact, and responsibility of local groups in conservation programs. We need to investigate the best ways to enact long-term stewardship if conservation reliance is to become a standard for downlisting a species' legal protection status. Kraus and Duffy (2009), for example, presented an approach for exotic species eradication prior to invasion that relies on nongovernmental organizations (see also Bocetti et al. 2012 [in this issue]).

Saving Hawaii's remaining endemic bird species will require a broader coalition of public and private conservation partners willing to commit to the long-term management necessary to sustain Hawaii's endemic avifauna in a changing world. Although the islands are too large and complex for threats to be eliminated, the distributions of the birds are small enough that needed management actions can be sustained at conservation-relevant scales and intensities. In some ways, one might view Hawaii as a biological and political microcosm of the problems faced by endangered species worldwide. The key to increasing the chances of Hawaii's endangered forest birds' surviving until the 200th anniversary of the National Wildlife Refuge system in 2103 lie in habitat restoration, the reduction of known threat factors, and the creation of recovery habitat at higher elevations over tens of thousands of acres. Ultimately, our greatest hope lies in the birds' abilities to adapt and evolve and in our willingness to implement well-documented recovery actions at scales that will make a difference to conservation.

Acknowledgments

We thank Aaron Nadig of the US Fish and Wildlife Service for providing literature on animal control; Aaron Nadig and Michael Walther (Oahu Nature Tours) for providing unpublished photographs; Rick Camp of the US Geological Survey and Lenni Freed of University of Hawaii for providing copies of in-press publications; Michelle Reynolds and

Marcos Gorresen of the US Geological Survey and Nick Holmes of the Kauai Endangered Seabird Recovery Project for providing direction for several species' assessments; the Nene Recovery Action Group for providing unpublished population size data; and Sheila Conant, Tim Male, and three anonymous reviewers for commenting on an earlier draft of the manuscript.

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