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Changing Seabird Management in Hawai‘i: From Exploitation through Management to Restoration

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Abstract.—Fossil evidence indicates that diverse and abundant seabird communities were once found in the main Hawaiian Islands. However, these seabird populations have severely decreased, or even disappeared, as a result of human disturbance, habitat loss and predation from introduced mammals. Today, the vast majority of Hawai‘i’s seabirds nest on low-lying and uninhabited atolls in the Northwestern Hawaiian islands, some of which will not be able to withstand projected sea-level rises. As a result, populations of many seabird species will be further reduced unless suitable nesting habitat in the main Hawaiian Islands can be restored against predators.

The history of seabird management in the Hawaiian Islands is examined, tracing three overlapping stages. The first emphasized exploitation, the second recognized the damage done by humans and developed methods to remove the causes. The third and current stage focuses on restoration, initially of seabirds, and most recently of ecosystems. Restoration will require a scientific approach and documentation of successes and failures, improving the chances of success for future interventions. *Received 17 September 2009, accepted 23 December 2009.*

Key words.—climate change, Hawai‘i, invasive species, islands, management, Papahanaumokuakea, predation, restoration.

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The seabird populations of Hawai‘i and its northern islands are among the largest and best protected in the North Pacific, with 22 species, approximately six million breeding individuals and a total population of 15 million (Harrison 1990). In comparison, Alaska has 30 seabird species with 23 million birds (Lensink 1984) and California has 29 species with two million individuals (Carter *et al.* 1995).

The Hawaiian archipelago extends from uninhabited Kure Atoll (28°24’N; 178°20’W) at the northwestern end of the chain, to the inhabited island of Hawai‘i (19°31’N; 155°30’W) 2,500 km away at the southernmost end of the chain (Fig. 1). Seabird habitats range from coral atolls barely above sea level in the Northwestern islands to Haleakala Volcano on Maui at 3,055m in the main Hawaiian islands. While seabird numbers have greatly diminished since pre-Polynesian times (Olson and James 1982; Moniz-Nakamura 1999; Burney *et al.* 2001) and their ecological roles are reduced in terrestrial and marine systems, they are still important to the ecosystems in which they are participants (Harrison 1990).

Almost all Hawaiian seabird species and breeding locations now depend for survival on active management, such as predator control or fisheries bycatch reduction measures. Without management, there would eventually be few birds left, as has happened over large portions of the tropical Pacific (e.g. Kennedy 1982; de Korte 1984; Garnett 1984).

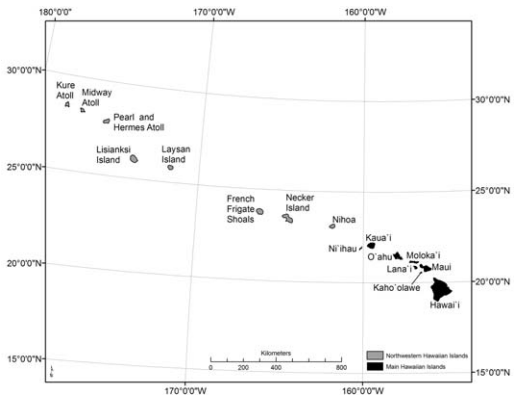


Figure 1. Hawaiian Archipelago.

The present paper explores the history of terrestrial management in the Hawaiian Islands but not management in relation to marine topics, such as oil pollution, bycatch, or food chain contaminants.

Terrestrial management of seabirds in Hawai‘i has gone through three broad, over-

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lapping phases: 1) exploitation: managing the seabird resource for consumption and ignoring damage caused by human activities; 2) remediation: dealing with threats, removing the causes, and ameliorating the symptoms of damage to the seabird resource; 3) restoration: initially of birds, and then of ecosystems. Managers of seabird resources in Hawai'i will be better prepared to respond to continuing challenges and develop responses to new ones if there is an "institutional memory" of what has occurred previously. The hope is that this review will provide the foundation for such a memory and suggest some responses.

EXPLOITATION: THE PROBLEMS ARRIVE

Hawai'i was colonized in approximately 400 AD by Polynesians who brought with them an array of plants and animals (Kirch 1982). The arrival of Europeans in 1778 brought many more plants and animals as well as sophisticated techniques for converting native ecosystems for human use (Cuddihy and Stone 1990).

Food

The bones of Hawaiian Petrels (*Pterodroma phaeopygia*) and other seabirds were present in large numbers in archeological middens left by native Hawaiians in numerous locations where seabirds no longer occur (Olson and James 1982; Athens *et al.* 1991; Moniz 1997), suggesting that Hawaiians exploited some seabirds to local or complete extirpation (e.g. Munro 1945; Olson and James 1982). In some locations, Hawaiians limited consumption of young petrels by reserving them for the ali'i or nobles (Henshaw 1902). Hawaiians elsewhere may have modified lava structures as nest sites to enhance harvests (Nakamura *et al.* 1998; Hu *et al.* 2001).

Guano and Feathers

Hawaiians harvested seabird feathers for ceremonial purposes (Rose *et al.* 1993), but the arrival of other peoples led to intensified slaughter of adult seabirds for their feathers. The Japanese slaughter of seabirds, especially of Laysan and Black-footed Albatrosses (*Phoebastria immutabilis* and *P. nigripes*), for the European millinery market, reached staggering levels, with minimum estimates of 250,000 birds for Midway, 554,500 for Lisianski Island, 466,050 for Laysan, and unknown numbers for Kure, French Frigate Shoals, and Pearl and Hermes (Spennemann 1998a,b). To increase profit margins, eggs and birds were also collected as fertilizer (Spennemann 1998b). Laysan Island, the only Northwestern island with significant guano deposits, was mined out in the late 19th Century (Ely and Clapp 1973; Unger 2003).

Some good did come of this. Public outrage triggered President Theodore Roosevelt's 1903 Executive Order 199-A which put Midway under Navy protection and was followed by Executive Order 1019 in 1909 which protected the remaining Northwestern islands (Shallenberger 2006).

Disturbance

The exigencies of World War II combined with contemporary attitudes to birds and ecosystems led to widespread damage in the Northwestern islands. While albatrosses earned the bemused respect of servicemen during the conflict (Ford 1942), thousands were buried alive by bulldozers or clubbed to reduce the threats to naval flight operations (Woodbury in Fisher 1949). Arata *et al.* (2009) summarized reports of 92,000 Laysan and 7,500 Black-foots killed in aircraft operations or associated control efforts. Domestic dogs (*Canis familiaris*) were allowed to run through the albatross colony and adult Sooty Terns (*Sterna fuscata*) were clubbed and their eggs crushed (King 1973). Such problems continued until biologists implemented ecological solutions (Rauzon 2001).

French Frigate Shoals were used for sporadic military exercises in the 1930s. The construction of the Tern Island runway in 1942 again created bird strike problems (Amerson 1971; Rauzon 2001). Coast Guard navigation stations were active at French

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Frigate Shoals and Kure until 1979 and 1992, respectively (Shallenberger 2006). Until 1997, Midway had a major naval air station (Shallenberger 2006). Gardner Pinnacle had its top blown flat to assist military operations in the 1960s (King 1973). Several Northwestern islands, including Necker and Pearl and Hermes, were used as practice bombing targets during the war. In the 1960s, Pearl and Hermes and Laysan hosted military visits that led to the introduction of invasive weeds (King 1973). In the main islands, Manana off O'ahu and Kaho'olawe were used as bombing targets (Green 1942), as is Kaula off Kaua'i today (Harrison 1990).

Conflicts with Laysan Albatrosses continue to the present because of their propensity for nesting on or near military runways at Marine Corps Base Hawaii, Kane'ohe, and Dillingham Field, both on O'ahu, and on the Pacific Missile Range on Kaua'i (Young *et al.* 2009; L. Young, pers. comm.).

Exfoliating lead paint from military buildings at Midway causes localized illness and death for Laysan Albatrosses on Midway (Sileo and Fefer 1987; Finklestein *et al.* 2003), with 6,745 to 10,000 young affected per year (Finklestein 2006). Ninety five buildings on Midway have lead paint, and removal of lead could cost up to $6 million (Finklestein 2006), in addition to the $100 million the Navy has already spent on Tern and Midway islands for clean up (Shallenberger 2006).

The full impact of human exploitation on Hawai'i's seabirds may never be known, but we can get some indication from the reduction in numbers of Laysan Albatrosses. Before the beginning of exploitation, the Laysan Albatross colony on Laysan Island alone may have been as large as two million birds, but by the 1920s the total population in the Hawaiian Islands had fallen to perhaps less than 20,000 pairs (Arata *et al.* 2009).

MANAGEMENT: ADDRESSING THE CHALLENGES

Recognition of damage caused by human activities and a willingness to find ways to ameliorate or remove the causes began as early as 1913 (e.g. Bartsch 1922), but efforts remain intermittent to this day, limited by law, apathy and resources.

Alien Mammals

Introduced mammals present a series of serious challenges to both seabirds and their ecosystems. Black, Polynesian and Norway Rats (*Rattus rattus*, *R. exulans* and *R. norvegicus*) and House Mice (*Mus musculus*) were inadvertently introduced to the islands as a result of human activity and shipwrecks. The Polynesian Rat arrived with the Polynesian voyaging canoes in about 400 AD (Hiroa 1964); the two other rat species arrived after European contact. In the main islands, the House Mouse was well established by 1825 (Pemberton 1925). The Black Rat did not arrive on Midway until 1943 (Fisher and Baldwin 1946).

The Polynesian Rat, as the first rodent to arrive, probably had major effects on smaller seabirds, but no direct evidence exists, despite the species' devastating effects on seabird species elsewhere (Jones *et al.* 2008) and paleontological evidence of effects on other constituents of Hawaiian ecosystems (Athens 2009). The effects of the other two species have been documented (e.g. Grant *et al.* 1981; Seto and Conant 1996; Ainley *et al.* 1997). Black Rats have been removed from Midway (Murphy 1997a, b) and Mokoli'i (Chinaman's Hat), O'ahu (Smith *et al.* 2006), and Polynesian Rats from Kure (Murphy 1994). Polynesian Rats were present on the seabird islet, Popoia, off O'ahu in 1935, but were subsequently extirpated, although the agent remains unknown (Svihla 1936). Similarly, the Polynesian Rat has not been found in traps on Kolo'olawe since 1971 (KIRC 1998).

The introduction of Domestic Rabbits (*Oryctolagus cuniculus*) devastated Laysan and Lisianski before they were removed from the former by the *Tanager* Expedition in 1923 and they died off on the latter (Dill and Bryan 1912; Clapp and Wirtz 1975). Rabbits were introduced by 1916 and exterminated in 1923 at Pearl and Hermes (Amerson *et al.* 1974). Rabbits were present on Le-

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hua off Ni'ihau from at least 1930 until they were removed by 2005 (Caum 1936; C. Swenson, pers. comm.). Off O'ahu, rabbits were also reported on Molokini between 1937 and the 1950s and on Manana from the 1890s (Tomich 1969) until 1984 (Swenson 1986).

Guinea Pigs (*Cavia porcellus*) were introduced to Laysan at the same time as rabbits and may have contributed to the island's devastation before they died out by 1915 (Tomich 1969; Kramer 1971). Similarly, Donkeys *(Equus asinus*) were released on Midway but were killed off in 1912-1913 because they were trampling burrows of nesting birds (Bartsch 1922), apparently the earliest example of seabird 'predator' management in Hawai'i.

On the larger islands, including Kaho'olawe, a suite of predators became a problem for the survival of seabirds, starting with the Hawaiian introduction of dogs, Polynesian Rats, and Domestic Pigs (*Sus scrofa*), continuing with the arrival of the Europeans and Domestic Cats (*Felis catus*), and culminating with the introductions of Small Indian Mongoose (*Herpestes javanicus auropunctatus*) in 1883 (Tomich 1969) and Barn Owls (*Tyto alba*) in 1958-1963 (Ord 1964; Byrd and Telfer 1980; Berger 1981; Simons 1985; Hodges and Nagata 2001; Smith *et al.* 2002; Winter 2003; Harrison 2007).

Cats were apparently removed with live traps from small islands off Kailua, O'ahu in the 1990s. The largest program against cats and mongoose has protected Hawaiian Petrels through trapping at Haleakala National Park on Maui since the 1980s (Hodges and Nagata 2001). More recently, Wedge-tailed Shearwaters (*Puffinus pacificus*), Newell's Shearwaters (*Puffinus newelli*) and Laysan Albatross have been protected against dogs and cats at Kilauea National Wildlife Refuge, Kaua'i through fencing and trapping. Ka'ena Point, O'ahu has also been protected by trapping and rodent bait stations against cats, mongoose and rats. Feral dogs have been shot at Ka'ena Point, while attacking nestling albatrosses and shearwaters (Anon. 2007a).

Trapping and removal of predators can be problematic on the main islands because such programs may merely create a vacuum into which additional animals recruit, unless efforts are continuous, intensive and on a large enough scale (Hodges and Nagata 2001; Hays and Conant 2007; T. Tunison, pers. comm.).

Airborne dispersal of diphacinone, a rat toxicant, is now legal in Hawai'i under certain circumstances, minimizing disturbance and potentially allowing large-scale protection of colonies in even the roughest terrain (Eisemann and Swift. 2007). Also, diphacinone can be used against mongoose by air, but only legally as an indirect effect of controlling rats (Stone *et al.* 1995; Smith 1998). There is no similar way to protect colonies from cats.

Alien Vegetation

Alien plant species pose a problem on the islands. Only 49 of the 300 plant species in the Northwestern islands are native (Rauzon 2001). Beggartick *(Bidens alba)* forms dense stands on Sand Island, Midway and provides suitable habitat for avian pox-vectoring Southern House Mosquitoes (*Culex quiquefasciatus*) and flies, leading to a high prevalence of this disease in Laysan Albatross that nest nearby (Fefer *et al.* 1984). Common Sandbur (*Cenchrus echinatus*) and Hairy Horseweed (*Conyza bonariensis*) were introduced to Laysan during military operations in 1961 (King 1973) and then spread as a result of research activity (Rauzon 2001). A 60-ha infestation of *Cenchrus* on Laysan was eradicated following a ten-year program (Flint and Rehkemper 2001).

Christmasberry (*Schinus terebinthifolius*) has similarly been reduced on Mokoli'i Island (Chinaman's Hat), O'ahu to increase nesting habitat for Wedge-tailed Shearwaters (J. Eijzenga, pers. comm.). Golden Crownbeard *(Verbesnia ecelioides)* has been the subject of unsuccessful eradication efforts on Midway, Kure and Laysan, extending over almost a decade (Smith and Woodside 1998).

On Lana'i, Strawberry Guava (*Psidum guava*) is displacing uluhe ferns (*Dicranopteria linearis*) and grows so thickly that it locally excludes Hawaiian Petrels (J. Penniman,

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pers. comm.). Biocontrol now appears to be the only way to deal successfully with this species on a large scale (Smith and Wikler 2002).

Alien Invertebrates

Invertebrates have been little studied. All 47 ant species in Hawai'i on the main islands, including the 16 reported on offshore islets, were introduced (Plentovich *et al.* 2009). Their effects appear mixed. Krushelnycky *et al.* (2001) found that Argentine Ants (*Linepithema humile*) do not affect reproductive success of Hawaiian Petrels on Haleakala, Maui. Big-headed Ants (*Pheidole megacephala*), Yellow-crazy Ants (*Anoplolepis gracilis*) and Tropical Fire Ants (*Solenopsis geminata*) have been observed attacking nestling seabirds or were linked to colony losses on Kure, Kaua'i and O'ahu, respectively; but Big-headed Ants were apparently not aggressive to seabirds on islets off O'ahu (S. Plentovich, pers. comm.). Similarly, Pharaoh Ants (*Monomorium pharonis)* were reported to have only minimal impact to nesting Tristam's Storm-petrels (*Oceandroma tristami*) on Laysan Island (McClelland and Jones 2008). Only Big-headed Ants have been successfully eradicated, from Goat (Moku'auia) Islet off O'ahu (Plentovich et al. 2009).

A grasshopper (*Schistocera nitens)* reached outbreak proportions on Nihoa in 2000 and 2004, causing widespread defoliation (Latchininsky and Lockwood 2005; Latchininsky 2008). Vegetation appears to be able to sustain grasshopper population cycles (Latchininsky 2008), but over time its cumulative herbivory might kill palms and shrubs used for seabird nests. Any control effort must avoid side effects on the unique arthropods of Nihoa (Evenhuis and Eldredge 2004). The grasshopper has now been reported from French Frigate Shoals, and Necker, Laysan and Lisianski islands (Evenhuis and Eldredge 2004; Latchininsky 2008).

Finally, two species of scale (*Saissetia nigra* and *Hemiberlisia lataniae)* caused damage to Naupaka (*Scaevola sericea),* a coastal shrub, on Lisianski and Laysan, perhaps increasing nesting space for albatrosses (Beardsley, pers. comm. in Fefer *et al.* 1984; Herbst and Wagner 1992).

Seabird Diseases

Distinguishing alien versus indigenous seabird diseases is difficult for several reasons: detection of seabird disease in Hawai'i has usually been limited to mortality events, observers are few, and veterinarians are even fewer at most remote seabird colonies (Duffy 2009). Bartsch (1922) reported a major mortality of both adult and young Sooty Terns and of Black Noddies (*Anous minutus*) on Midway in 1907, suggestive of the arrival of a new disease to which birds had not been previously exposed. No other species were affected. Avian poxvirus with possible associated mortality was reported in Red-tailed Tropicbirds (*Phaethon rubricauda*) at Midway in 1963 but not in any other seabird species (Locke *et al.* 1965). Pox was later reported in Laysan Albatrosses on the island (Sileo *et al.* 1990) and then at Ka'ena Point on O'ahu, Kaua'i, and Lehua Islet, usually with little mortality (Young and VanderWerf 2008; L. Young, pers. comm.). Warner (1968) reported avian malaria in grounded Newell's Shearwaters, while Simons (1985) found none in Hawaiian Petrels.

Common Mynas (*Acridotheres tristis*), egg predators on the main islands (Byrd 1979), were rumored to be present in low numbers in the 1960s on Midway (Richardson 1992) and pox may have been introduced with them. The disease is spread primarily by mosquitoes (*C. quiquefasciatus*), and it has decreased in recent years as the refuge has made an effort to reduce mosquito resting sites by mowing bird nesting areas (Herbst and Wagner 1992) and eliminating mosquito breeding sites (E. Flint, pers. comm.). For most bird diseases, the only effective management method would be to prevent their introduction in the first place.

Tourism

Little is known of the effects of tourism on Hawaiian seabirds. When tourists are confined to paths and are unaccompanied by

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dogs, they and seabirds have continued to coexist at sites such as Kilauea and Ka'ena points, several Wedge-tailed Shearwater colonies on Maui, and on Midway (pers. obs.).

A fire during the 1885 visit of Princess Lili'uokalani to Nihoa destroyed most of the island's palms (*Pritchardia remota)* (Evenhuis and Eldredge 2004), undoubtedly affecting seabird nesting sites. Unauthorized landing by fishermen and recreational vessels have occurred in the Northwestern islands (Gagné and Conant 1983) and they are certainly a problem for the more accessible small islets around the main islands (pers. obs.). The Offshore Islet Restoration Committee (OIRC) has worked with kayak rental and tour companies on information brochures and signage for several islets around O'ahu (C. Swenson, pers. comm.).

Coastal Lighting and Utility Wiring

Attraction to lights, especially during new moon periods, can result in collisions with buildings, power lines, vegetation and vehicles for Newell's Shearwater, Hawaiian Petrels and Band-rumped Storm-petrels (*Oceanodroma castro*) on Kaua'i (Reed *et al.* 1985; Telfer *et al.* 1987; Podolsky *et al.* 1998; Day *et al.* 2003), Hawaiian Petrels on Maui (C. Bailey, pers. comm.), and Wedge-tailed Shearwaters on O'ahu (K. Swindle, pers. comm.).

The *Save Our Shearwaters* (SOS) program operated through the state Department of Land and Natural Resources has rescued, rehabilitated and released nocturnal seabirds on Kaua'i since 1978 (Telfer *et al.* 1987). By 2005, the program had rescued 29,000 Newell's, 220 Hawaiian Petrels, and 15 Band-rumped Storm-petrels, according to the Proposed Operations Manual, 2005 (Save Our Shearwater Program 2005, unpublished); however, "it is estimated that as many as 50% of the downed seabirds are not found or rescued" (KSHCP 2009). While the program is successful at rehabilitating birds that are turned in, there has been no assessment of how many of the mostly fledglings that are released return to breed successfully. However, fewer than 30 of 24,000 birds released had been recovered (Ainley *et al.* 2001) and annual numbers rescued have decreased to roughly 10% of levels in the early 1990s (Fig. 2).

Management suggestions resulting from research have included shielding lights, extinguishing unnecessary lights during the fledging period or removing them permanently, maintaining the Save Our Shearwater Program, burying or rerouting powerlines and lowering powerlines to tree-top height (e.g. Hailman 1986; Ainley *et al.* 1995).

A Habitat Conservation Plan proposed by the Kaua'i Island Utility Cooperative (KIUC) will allow island utilities and other companies to "avoid, minimize and mitigate incidental take of listed seabird species associated with its facilities and operations" (Federal Register 2007; KSHCP 2009), but the list of actions proposed fails to include many of the actions suggested by Ainley *et al.* (1995).

Even in broad daylight, wires and antennae can be a problem. Fisher (1966) reported that antennae killed 3,000 Laysan Albatrosses in six months on Midway, as well as several thousand Sooty Terns. The refuge at Midway has subsequently greatly reduced superfluous wiring, along with other structures. On the main islands, the impact of communication towers in Hawaii remains unknown. There are 261 registered towers

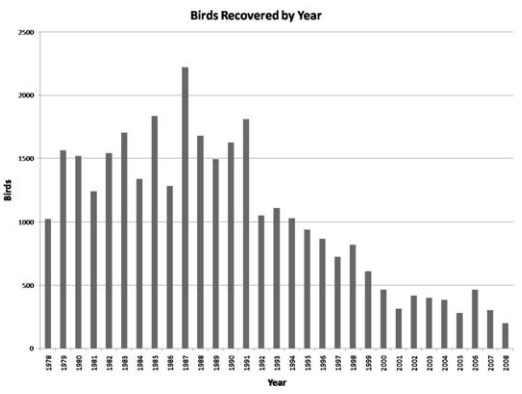


Figure 2. Number of Newell's Shearwaters recovered on Kaua'i by the Save Our Shearwaters Program from 1978 to 2008 (Ainley *et al.* 2001; additional data from the Department of Land and Natural Resources, Kaua'i).

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on the Hawaiian Islands and 52 of these are over 200 feet (Forest Conservation Council 2004). Do these have any effect on seabirds, especially nocturnal procellariids? The Federal Communications Commission was the subject of an unsuccessful challenge to force it to consult with the Secretary of Interior before allowing seven towers on Hawai'i and Kaua'i that allegedly threaten Hawaiian Petrels and Newell's Shearwaters (American Bird Conservancy v Federal Communications Commission, 545 F.3d (9th Circ. 2008).

Recent work suggests that flashing lights on the U.S. mainland cause much less mortality than do steady lights (Gehring *et al.* 2009). A change to flashing lights in Hawai'i would be inexpensive and might help to solve problems before they arise.

Wind Turbines

There are five wind farms for electric generation in Hawai'i, with a total of 96 turbine units (American Wind Energy Association 2009). The State and U.S. Fish and Wildlife Service have agreed to a 20-year Habitat Conservation Plan for the 20-unit farm above Ma'alaea, Maui (Kaheawa Wind Power 2006). The plan allows limited "take" or accidental mortality of Hawaiian Petrels in return for a monitoring program for downed birds, surveys for nesting colonies, protection of colonies or other options, so that "the ratio of birds protected to the adjusted take remains greater than one throughout the life of the project". The other wind farms apparently have no such plans, nor are they monitoring for petrel mortality.

There are plans to put wind farms on Kaua'i and Lana'i (Department of Business, Economic Development and Tourism 2009) which have the potential for much greater mortality of Newell's Shearwaters and Hawaiian Petrels. While the National Academy of Sciences (2007) has found little effect of wind farms on birds elsewhere, it cautioned that effects may be indirect and cumulative through construction and maintenance, erosion, vegetation clearing and noise. Also, the study did not address procellariids which, as night-flying birds in conditions of poor visibility in high wind situations, appear vulnerable; hence, an assessment of potential cumulative impact on Newell's Shearwaters and Hawaiian Petrels is needed before wind farms proliferate.

Management

Even conservation efforts can harm seabirds. There are anecdotal accounts of the tracks made by managers being used by mammals to reach burrows in dense vegetation. Ungulate exclusion fences are widely used in Hawai'i, and Hawaiian Petrels have been reported to collide with such fences (C. Bailey in Swift 2004). Swift (2004) found that weaving white flagging into fencing increases their visibility and reduces petrel collisions. This fencing is now used on several islands (D. Burney, D. Hu and J. Penniman, pers. comm.). Researchers visiting offshore and Northwestern islands are now expected to take measures to prevent the introduction of invertebrates and seeds, such as using only sterile clothing and footwear, either bought new or frozen overnight (B. Flint, pers. comm.), because of past spread of weeds by researchers (Rauzon 2001).

RESTORATION

Ecological restoration has been operationally defined as "the process of intentionally altering a site to establish a defined, indigenous historic ecosystem" (Society for Ecological Restoration in Morin and Conant 1998). In Hawai'i, the desired end state for restoration is rarely stated explicitly, but it usually appears to be the state before the arrival of humans and terrestrial predators.

Managers in Hawai'i are generally limited by an incomplete knowledge of the original biota and ecosystem functions, by subsequent climate change, and the arrival and extinction of many species, so ecosystems can never be truly restored. We can claim success if the restored ecosystems function as reasonable approximations to 'similar' systems (Simberloff 1990; Jackson and Hobbs 2009; Norton 2009).

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Seabird Restoration

Managers have a limited repertoire of single-species techniques to restore seabird species in Hawai'i. These include artificial nesting sites, habitat alteration, sound attractants, decoys, translocation, and, above all, protection from terrestrial predators (e.g. Rauzon 2007). Artificial nest sites were used at Kilauea National Wildlife Refuge, Kaua'i for Newell's and Wedge-tailed Shearwaters (Byrd *et al.* 1984), for Red-footed Boobies *(Sula sula)* at Kane'ohe, O'ahu (Rauzon and Drigot 1999), and for Wedge-tailed Shearwater colonies on Maui (F. Duvall, pers. comm.). Removal of underbrush created suitable habitat that led to the establishment of the Laysan Albatross colony at Kilauea Point, Kaua'i (Harrison 1997) and increased nesting sites for Wedge-tailed Shearwaters on Mokoli'i Island, O'ahu (Smith *et al.* 2006). Sound attractants and decoys helped increase landings of Laysans at Kilauea Point before the colony became established (Podolsky 1990), but were unsuccessful for Laysans off O'ahu (Podolsky and Kress 1996) and have so far been unsuccessful for Short-tailed Albatrosses, Bulwer's Petrels *(Bulweria bulwerii)* and Tristam's Storm Petrels on Midway (J. Klavitter, pers. comm.). Translocations using eggs cross-fostered under Wedge-tailed Shearwaters have been used successfully to establish a Newell's Shearwater colony at Kilauea Point, Kaua'i (Byrd *et al.* 1984; Telfer 1986) and Laysan Albatross eggs have been transplanted to reduce the need to cull eggs from Barking Sands, Kaua'i (B. Zaun, pers. comm.).

On the main Hawaiian Islands, creating islands of habitat protected from predators has been a major restoration technique. Techniques have ranged from fencing to exclude ungulates and dogs, boulder piles to exclude off-road vehicles, signs and guides to reduce human disturbance, and trapping or shooting predators (cf. Harrison 1997; Rauzon 2007, Young *et al.* 2009). Managed Wedge-tailed Shearwater colonies include Hawea Point, Maui, Mo'omomi, Moloka'i, and Ka'ena, Zombie and Black points, O'ahu (DLNR 2007; Harrison 2007; Pala 2008, D. Drigot, pers. comm.). Multi-species efforts include Ka'ena Point, O'ahu with Laysan Albatross and Wedge-tailed Shearwaters and Kilauea Point, Kilauea National Wildlife Refuge, Kaua'i, with Laysan Albatrosses, Red-footed Boobies, and Wedge-tailed and Newell's shearwaters (Byrd *et al.* 1984; Young *et al.* 2009; B. Zaun, pers. comm.).

A variety of efforts have begun to restore the plant life of the seabird islands and breeding colonies. Native and non-natives were planted to revegetate Laysan Island in 1923 and 1930 after the departure of the rabbits (Lamoureux 1963a). Clearing of alien plants and outplanting of native vegetation also occurred on Midway, French Frigate Shoals, offshore islands and Ka'ena and Black points, O'ahu, at various colonies on Maui, and at Mo'omomi Bay on Moloka'i (G. P. Wilder in Munro 1944: 37; Anon. 2007b; Pala 2008; F. Duvall, W. Garnett, and J. Eijzenga, pers. comm.).

Ecosystem Restoration

An ecosystem approach to conservation of seabird nesting areas might be said to have begun with George Munro's efforts from 1911 to 1934 to maintain the watershed on Lana'i (Lamoureux 1963b). The outplantings probably inadvertently helped ensure the survival of the Hawaiian Petrel population on the island (cf. Hirai 1978).

The first comprehensive restoration plan for restoration of an ecosystem including seabirds in Hawai'i involved Midway Island, 485 ha (U.S. Fish and Wildlife Service 1991). While the plan had an ecosystem focus, actions had to be justified in terms of current federal laws, regulations and programs, rather than a larger framework. In addition, the Navy was still active at Midway so the plan had to balance the needs of the Navy and the Fish and Wildlife Service.

The plan called for rat control and an integrated vegetation management program restoring native vegetation and controlling two weeds *Casuarina equisetifolia* and *Verbesina encelioides*. Eastern and Spit islands were to be restored as nesting habitat by removal of

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alien species and human debris such as antennae. Almost two decades later, the plan is still being followed (J. Klavitter, pers. comm.). Eastern Island has been cleared of most trees and human debris. Rats have been removed (see above), the refuge is removing mosquito breeding areas (E. Flint, pers. comm.) and it has created an artificial wetland that has allowed the introduction of Laysan Duck (*Anas laysanensis*; Reynolds *et al.* 2004).

The Laysan Island Ecosystem Restoration Plan (Morin and Conant 1998) marked a sea change in management of seabirds in Hawai'i because of its explicit goal to "allow the re-creation of a functioning ecosystem that is as similar as possible to that which was present on Laysan Island when humans first wrote of their visits to the island". The 1899 visit of Schauinsland (1996) and sediment data (Athens *et al.* 2007) provided some idea of the ecology of Laysan, 370 ha, before its later destruction through guano mining and the introduction of rabbits.

The plan goes beyond the planting of native plants to include native arthropods and their host plants, and the reintroduction of ecological equivalents for extinct or extirpated species. The plan was to stretch over 20 years and much of it remains incomplete, primarily because of funding issues. Efforts continue, including reintroducing or enhancing eight plant species known to have been lost during the island's tumultuous history (Rehkemper *et al.* 2006).

At Lehua Island, a 110 ha important seabird breeding island off Ni'ihau, a similar ecosystem effort has begun with a broad focus on entomology, botany and removal of alien species (U.S.F.W.S. and D.L.N.R. 2007). Native plants have been reintroduced and there are long-term plans to introduce native pollinators and land birds from the Northwestern islands (VanderWerf *et al.* 2007; Wood 2008).

On Kaua'i, the 162 ha Upper Limahuli Valley, at 500-1000 m elevation, may offer the most challenging restoration site, because it is on one of the main islands and, while isolated by 250 m cliffs, it is vulnerable to a continued influx of rats, cats, pigs and invasive plants. The area holds breeding populations of Hawaiian Petrels and Newell's Shearwaters as well as endangered plant species. The entire watershed will be enclosed with ungulate-proof fences and the alien species removed (D. Burney, pers. comm.). Plans call for active management of both native flora and fauna (National Tropical Botanical Gardens 2007). This prototype should serve for such efforts on the main islands.

Kaho'olawe, 11,520 ha off Maui, has ongoing efforts focused at restoring vegetation and ending the massive erosion caused by damage from ungulates, use as a military firing range and lowland forest clearing (Hommon 1980; KIRC 1998). The effort is the only one in Hawai'i that "places traditional practices and cultural protocols at the forefront of ecological recovery efforts" (KIRC 1998). Although the island has minimal seabird resources at present, except on several offshore sea stacks (Gon and Chun 1992), future plans call for removal of the cats which should allow the restoration of Hawaiian Petrels (KIRC 1998). In the next several centuries, Kaho'olawe could provide a rich opportunity for the restoration of lowland ecosystems and seabird colonies, based in part of paleobotanical information (Athens *et al.* 1992; KIRC 1998). Unfortunately, the existing plan, with only ten lines devoted to seabirds, out of 117 pages, is unclear as to how seabirds will be incorporated.

At Ka'ena Point on O'ahu, populations of both seabirds and rare native plant species have recovered following exclusion of vehicles (DLNR 2007). The future construction of a multi-species exclusion fence (e.g. Day and MacGibbon 2007; Speedy *et al.* 2007) will offer a barrier behind which to implement a more elaborate ecosystem approach on 13 ha.

The Offshore Islets Restoration Committee (OIRC) was set up in 2002 to undertake the "first coordinated, multi-agency approach to planning state-wide biological surveys, restoration, and education activities focused on offshore islets" (Swenson 2008). OIRC was instrumental in initiating the Lehua Island restoration and has perhaps most importantly established a multi-island plan

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for long-term restoration that looks beyond agencies, jurisdictions and funding cycles to establish conservation priorities (Swenson 2008). Over time, this planning effort should stimulate the restoration of dozens of small offshore islets in Hawaii.

FUTURE CHALLENGES

The future of our seabirds rests on two main groups: 1) the mountain-nesting procellariids, Hawaiian Petrels, Newell's Shearwaters and Band-rumped Storm-petrels, threatened or endangered because of predation and invasive alien plant species on their nesting grounds on the main islands, and 2) the lowland nesting species that are now confined to a few protected areas, offshore islands and inaccessible cliffs of the main islands, or are safe on the Northwestern islands of The Papahanaumokuakea Marine National Monument.

Mountain Procellariids

The nesting sites of the Band-rumped Storm-petrel remain unknown (Harrison *et al.* 1990; Slotterback 2002), so there is little that can be done for its conservation, aside from continuing efforts to locate colonies and document basic life history parameters. However, we do know many of the nesting sites of Newell's Shearwater and Hawaiian Petrel and, unless we could somehow establish sustainable populations of both on small, predator-free islands, there will never be a safe future for these species without continuing management efforts (cf. Scott and Goble 2006). For the colonies on the main islands, we need new techniques and a quantum leap in resources and thinking, or both species will eventually become extinct or, at best, a few surviving birds heard occasionally in the mountain mists.

The highest priority is to find any large remaining colonies of the mountain petrels. The recent rediscovery of a major colony of Hawaiian Petrels on Lana'i has allowed the beginning of a management program (J. Penniman and F. Duval, pers. comm.), but other colonies remain "undiscovered" on Maui (Cooper and Day 2003; Wood and Bily 2008). Techniques exist or are being developed to protect or augment such colonies (Rauzon 2007), but they need to be applied at appropriate scales to be effective. We also need to develop "stand-off" management techniques to protect colonies while minimizing disturbance, such as counting birds by radar or acoustically, switching to aerial bait drops for predator control, and using remote sensing to detect new colonies through changes in local vegetation because of increased guano input.

Most critical is preventing the mongoose from becoming established on Lana'i and Kaua'i, the islands with the major remaining breeding populations of Newell's Shearwaters and Hawaiian Petrels. Mongoose have been reported several times from Kaua'i but we do not know if a population has become established.

Lowland Seabirds

The Northwestern islands today represent the "last best hope" for many lowland-nesting Hawaiian seabirds and their ecosystems; however, the Northwestern island seabirds face major challenges associated with climate change, including rising sea level (Baker *et al.* 2006) and perhaps also changes in prey distribution associated with changes in ocean temperature and circulation.

We may have at most a century before rising sea levels become a problem, but it could take that long to implement solutions such as armoring islands against erosion, or raising them, or establishing colonies on protected peninsulas or fenced areas on the main islands. We may have to make a choice between the wilderness experience of tropical atolls or having nesting sites for Black-browed Albatrosses in 2100 AD, as breeding on several islands will be increasingly vulnerable to submergence or over-wash from winter storms. We need to know the preferred habitats of different species so we can design new nesting areas. Islands may become arks, requiring artifice, not accident. Managers will need answers and options, even though they may not like them.

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The Papahanaumokuakea Marine National Monument Draft Management Plan (2008: pages 169-173 out of 350) contains an extremely limited agenda for habitat restoration and monitoring of the Northwestern islands, including Midway. This agenda should be elaborated upon to address not just the present, but also the pressing future, all the while being mindful that the Monument owes its existence to its seabirds, starting in 1909 with President Theodore Roosevelt's Executive Order 1019 (Shallenberger 2006).

Conclusion

For restoration, due to a paucity of information from the past, we usually are doing little more than treating the most serious symptoms. In all but the simplest systems that may not be good enough. There is evidence from various seabird ecosystems that removing cats or rats will increase mice (Courchamp *et al.* 1999) and that removing rats and mice increases ants, and that removing ants may increase ticks (Duffy 1991). Similarly, removing one invasive ant species on an islet close to the main islands may simply lead to replacement by another (S. Plentovich, pers. comm.). All these outcomes have the potential to leave island ecosystems, if not the seabirds, worse off than when we started.

Above all, restoration needs to be planned; *ad hoc* management will get us only so far. For planning to occur, we need a scientific approach and documentation in the refereed literature of our successes and failures (Duffy and Kraus 2008). As should be evident from reading this paper, especially the management and restoration sections, too much of our best work is documented only in unpublished reports, so we tend to reinvent the wheel. Experiments and modeling can also help us shorten our learning curves, so we gain from our past efforts, making future interventions more efficient and likely to be successful.

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