U.S. Fish & Wildlife Service

Revised Recovery Plan for the Laysan Duck
(Anas laysanensis)

Main cover image of Laysan ducks courtesy of James Breeden, USGS.
Lower-right image of hen and ducklings walking courtesy of Michelle H. Reynolds, USGS.

Revised Recovery Plan for the Laysan Duck (*Anas laysanensis*)

(Original approved 17 December 1982)

Region 1
U.S. Fish and Wildlife Service
Portland, Oregon

Approved: Acting [signature]
Regional Director, Region 1
U.S. Fish and Wildlife Service

Date: JUL - 7 2009

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EXECUTIVE SUMMARY

Current Species Status: The Laysan duck (*Anas laysanensis*), also called the Laysan teal, is an endemic Hawaiian species and has been federally listed as endangered since 1967 (U.S. Fish and Wildlife Service [USFWS] 1967). The species is identified as Critically Endangered by the World Conservation Union (IUCN 2004). The Laysan duck currently has the most restricted range of any duck in the world, with a single naturally occurring population on Laysan Island in the Northwestern Hawaiian Islands, and a small but growing population at Midway Atoll founded by birds translocated from Laysan. Viability models for small populations of isolated species predict a high risk of extinction due to catastrophic, environmental, genetic, and demographic stochasticity. The species was extirpated from most other islands in the Hawaiian Archipelago after the arrival of humans about 1,500 years ago. To date, Laysan duck bones have been found on six islands where the species no longer occurs: Hawai`i, Maui, Moloka`i, O`ahu, Kaua`i, and Lisianski. The total estimated population size on Laysan Island has fluctuated from seven to more than 600 adult birds in the last century. The most recent (2005) population estimate of adult birds on Laysan is 611 (95% CI 538-714). The population at Midway was founded with a total of 42 wild birds translocated from Laysan in 2004 and 2005. Of this original total, an estimated 25 or 26 birds are believed to have bred. After successful breeding seasons in 2005 through 2007, the number of ducks at Midway had increased to nearly 200 individuals. Another successful breeding season at Midway in 2008 added significantly to the population, but an outbreak of botulism in August of 2008 caused the death of more than 140 ducks and a temporary set-back to this new population.

Habitat Requirements: The habitat requirements of the Laysan duck include vegetation in which to take cover, a year-round prey base of invertebrates, a source of fresh water, and protection from mammalian predators. On Laysan Island and at Midway Atoll, the ducks use all available habitats: upland vegetation, ephemeral wetlands, freshwater seeps, mudflats, the hypersaline lake, and coastal areas. The ducks feed on wetland and terrestrial invertebrates, seeds, and succulent plants. Ducklings have more restrictive requirements than adults because of their high nutritional needs for growth and initial inability to process salt water. Duckling activities therefore are concentrated near sources of fresh water with nearby cover and high prey densities. Historically, this species occurred in a diverse range of habitats on Hawaiian islands other than Laysan. Paleoecological evidence indicates the Laysan duck likely was a habitat generalist. On high elevation islands, ducks once were found both in upland forests far from standing water and in coastal wetlands. The duck’s diet probably consisted mainly of arthropods from the forest floor and wetlands.

Limiting Factors: Five factors are considered in the decisions to list, delist, or reclassify a species. These factors are:

A – The present or threatened destruction, modification, or curtailment of its habitat or range;
B – Overutilization for commercial, recreational, scientific, or educational purposes;

C – Disease or predation;
D – Inadequacy of existing regulatory mechanisms; and
E – Other natural or man-made factors affecting its continued existence.

The Laysan duck was included in the first listing of endangered species (USFWS 1967); this first listing rule was published prior to the institution of the five listing factors for threats analysis. Therefore we provide here an informal summary of how the five listing factors apply to this species rather than summarizing the threats analysis from a published listing rule. Prehistoric extirpation of the Laysan duck from the Main Hawaiian Islands most likely was caused by a combination of predation by introduced mammals, especially rats (*Rattus exulans*), hunting by humans, and habitat destruction and degradation. Alien species (*e.g.*, rabbits, mice, invasive weeds, and possibly predatory insects) alter the Laysan duck's habitat; erosion on Laysan Island dating from the island's devegetation by rabbits in the early 20th century continues today, and can be seen in the accelerated filling of Laysan's freshwater seeps and saline lake (Factor A). High duckling mortality from 1999 through 2004 suggests a lack of sufficient brood rearing habitat on Laysan (Factor A). Introduced mammalian predators would pose the most severe threat to Laysan ducks reintroduced to the Main Hawaiian Islands (Factor C). Storms, drought-related food reduction, disease, and limited carrying capacity are among the factors limiting numbers of Laysan ducks today (Factors C and E). The Laysan duck's small total population size and extremely limited distribution make the species highly vulnerable to demographic fluctuation and chance environmental occurrences such as droughts, severe storms, and epizootics (Factor E). Habitat degradation and loss in the Northwestern Hawaiian Islands may be intensified by increased storm severity and sea level rise associated with global climate change (Factor E). The actions proposed in this plan to achieve recovery are designed to address these threats to the Laysan duck and reestablish the species on additional islands.

Recovery Priority Number: The recovery priority number for the Laysan duck is 2 on a scale of 1C (highest) to 18 (lowest), reflecting a high degree of threat, high potential for recovery, and its status as a full species.

Recovery Goal: Conserve and recover the Laysan duck in order to downlist to threatened status, with the ultimate goal of removing the Laysan duck from the Federal list of endangered species (delisting).

Recovery Objective: Restore the Laysan duck to multiple self-sustaining populations in suitable habitats in the Northwestern and Main Hawaiian Islands such that the protections of the Endangered Species Act are no longer necessary.

Recovery Strategy: Recovery of the Laysan duck focuses on the following actions: (1) management to address threats to the species where it occurs now (Laysan Island and Midway Atoll) and (2) improvement of the species' distribution and total population size through (a) protection and enhancement of suitable habitat in the Northwestern and Main Hawaiian Islands and (b) sufficient reduction or elimination of threats to allow successful reestablishment of additional wild populations.

Recovery Criteria:

For the Laysan duck to be downlisted from endangered to threatened, the following criteria must be satisfied:

Criterion 1. (Factor E, small population size) The Laysan Island population is stable or increasing when monitoring data (either quantitative surveys or demographic monitoring that demonstrates an average intrinsic growth rate (λ) not less than 1.0) are averaged over a period of at least 15 consecutive years to account for population fluctuations. The average population on Laysan Island ideally should remain at roughly 500 birds over this period.

Criterion 2. (Factor C, predation; Factor E, small population size, limited distribution) A total of at least 1,800 potentially breeding ducks exist on a combination of predator-free Northwestern Hawaiian Islands (including Laysan and Midway) and at least one predator-controlled site in the Main Hawaiian Islands.

Each island or site should harbor a population of breeding adults that is stable or increasing when monitoring data (either quantitative surveys or demographic monitoring that demonstrates an average intrinsic growth rate (λ) not less than 1.0) are averaged over a period of at least 10 consecutive years to account for population fluctuations.
Each island or site should harbor a population of breeding adults that is stable or increasing when monitoring data (either quantitative surveys or demographic monitoring that demonstrates an average intrinsic growth rate (λ) not less than 1.0) are averaged over a period of at least 10 consecutive years to account for population fluctuations.

Criterion 3. (Factor A, habitat degradation; Factor C, predation and disease; Factor E, small population size and limited distribution) Island- or site-specific management plans for the Laysan duck are created and implemented. These plans will identify actions (such as monitoring to determine population establishment and collect data for modeling viability and persistence; water management; habitat improvement; removal of alien predators; and population supplementation as necessary to ensure viability) and emergency procedures sufficient to reduce threats and increase numbers to recovery levels. Alternative approaches for reducing or eliminating current threats to the Laysan duck and increasing population growth should be identified in the management plan as well.

For delisting, the following criteria must be met:

Criterion 1. (Factor E, small population size, limited distribution) A total of at least 3,000 potentially breeding adult birds exists in five or more stable or increasing populations on a combination of predator-free Northwestern Hawaiian Islands (including Laysan and Midway) and at least two predator-controlled sites in the Main Hawaiian Islands.

Each island or site should harbor a minimum of 500 potentially breeding adults, and numbers each island should be stable or increasing when monitoring data (either quantitative surveys or demographic monitoring that demonstrates an average intrinsic growth rate (λ) not less than 1.0) are averaged over a period of at least 15 consecutive years to account for population fluctuations. Ideally, these populations will be self-sustaining and require no intervention other than for ongoing management and monitoring of threats and response to new threats, epizootics, and catastrophic declines.

Criterion 2. (Factor E, small population size and limited distribution) Population viability analysis projects that under current conditions the species will persist for at least 100 years.

Criterion 3. (Factor A, habitat degradation; Factor C, predation and disease; Factor E, small population size and limited distribution) Management plans for each island or site are evaluated on a regular basis and updated to include monitoring to detect demographic or new environmental threats to Laysan ducks.

Date of Recovery: Delisting could occur by 2030 if all of the criteria have been met.

Important Recovery Actions *(for details, see the Narrative Outline and Implementation Schedule))***:**

Recovery of the Laysan duck focuses on the following actions:

1. Management and research to reduce risks and stabilize the existing populations.
2. Creation and management of additional self-sustaining populations on other islands through translocation and habitat restoration.
3. Captive propagation if necessary to provide sufficient stock for reintroductions of the Laysan duck in the Main Hawaiian Islands.
4. Public outreach to ensure that the recovery program for the species especially in the Main Hawaiian Islands is accepted and supported by local communities.

Total Estimated Cost of Recovery: The estimated cost for recovery actions over the next 5 years is $9,128,500

TOTAL ESTIMATED COST OF RECOVERY

Year	Action 1 Assess Status and Threats	Action 2 Improve Distribution and Total Population Size (Translocation and Habitat Restoration)	Action 3 Captive Propagation	Action 4 Outreach	**Total**
2010	$511,900	$1,421,000	$0	$60,000	$1,992,900
2011	$474,400	$1,277,000	$0	$60,000	$1,811,400
2012	$449,400	$1,427,000	$130,000	$35,000	$2,041,400
2013	$449,400	$1,152,000	$90,000	$35,000	$1,726,400
2014	$399,400	$1,102,000	$90,000	$35,000	$1,626,400
Total	$2,284,500	$6,379,000	$310,000	$225,000	$9,198,500

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I. INTRODUCTION AND OVERVIEW

A. STATUS OVERVIEW AND STRUCTURE OF THE RECOVERY PLAN

The Hawaiian Archipelago is the world's most isolated group of islands. This isolation has produced a high level of endemism in the flora and fauna, and many groups exhibit outstanding examples of adaptive radiation (Scott *et al*. 1986; Banko *et al.* 2001). A total of 142 endemic (*i.e.*, found only in Hawai`i) species and subspecies of birds known from collected specimens or nonmineralized fossils have been described from the Hawaiian Islands (James and Olson 1991; Olson and James 1991; Giffin 1993; Pyle 1997). Following human colonization of the Hawaiian Islands in approximately 400 A.D., endemic species declined markedly in numbers and distribution (Kirch 1982; James and Olson 1991; Olson and James 1991; Banko *et al.* 2001). Of the 142 endemic bird species and subspecies, about 95 have been extirpated since the advent of human colonization (Banko *et al*. 2001). The remaining endemic taxa are also vulnerable to extinction, with 32 taxa listed as endangered or threatened, including 30 landbirds and two seabirds. In addition to birds, Hawai`i's remaining flora and fauna also are vulnerable to extinction.  Hawai`i is home to 344 of the 1,353 animal and plant species federally listed as threatened or endangered nationwide, about 25 percent of all listed species (U.S. Fish and Wildlife Service Threatened and Endangered Species System [USFWS-TESS] 2008).

Island species in general and Hawaiian species in particular are highly vulnerable to human disturbance. In addition to the birds lost during the initial human colonization of the Hawaiian Islands, 24 more species or subspecies of Hawaiian birds have become extinct since the arrival of Captain Cook in 1778. These numbers indicate that roughly half of the Hawaiian land- and waterbirds that were present at the time of European contact have disappeared in the last two centuries (Scott *et al*. 2001).

The Laysan duck (*Anas laysanensis*), also known as the Laysan teal, is one of six extant waterbird taxa that are endemic to Hawai`i. The Laysan duck currently has the most restricted range of any duck in the world, with a single naturally occurring population estimated at 611 (95% CI 538-714) adult birds on the small island of Laysan (Reynolds *et al.* 2006a; Figure 1), and a newly established population estimated at nearly 200 in 2007 at Midway Atoll (Reynolds *et al.* 2007a), both in the Northwestern Hawaiian Islands. In recorded history, the Laysan duck occurred on only one additional island, Lisianski, which lies northwest of Laysan (Olson and Ziegler

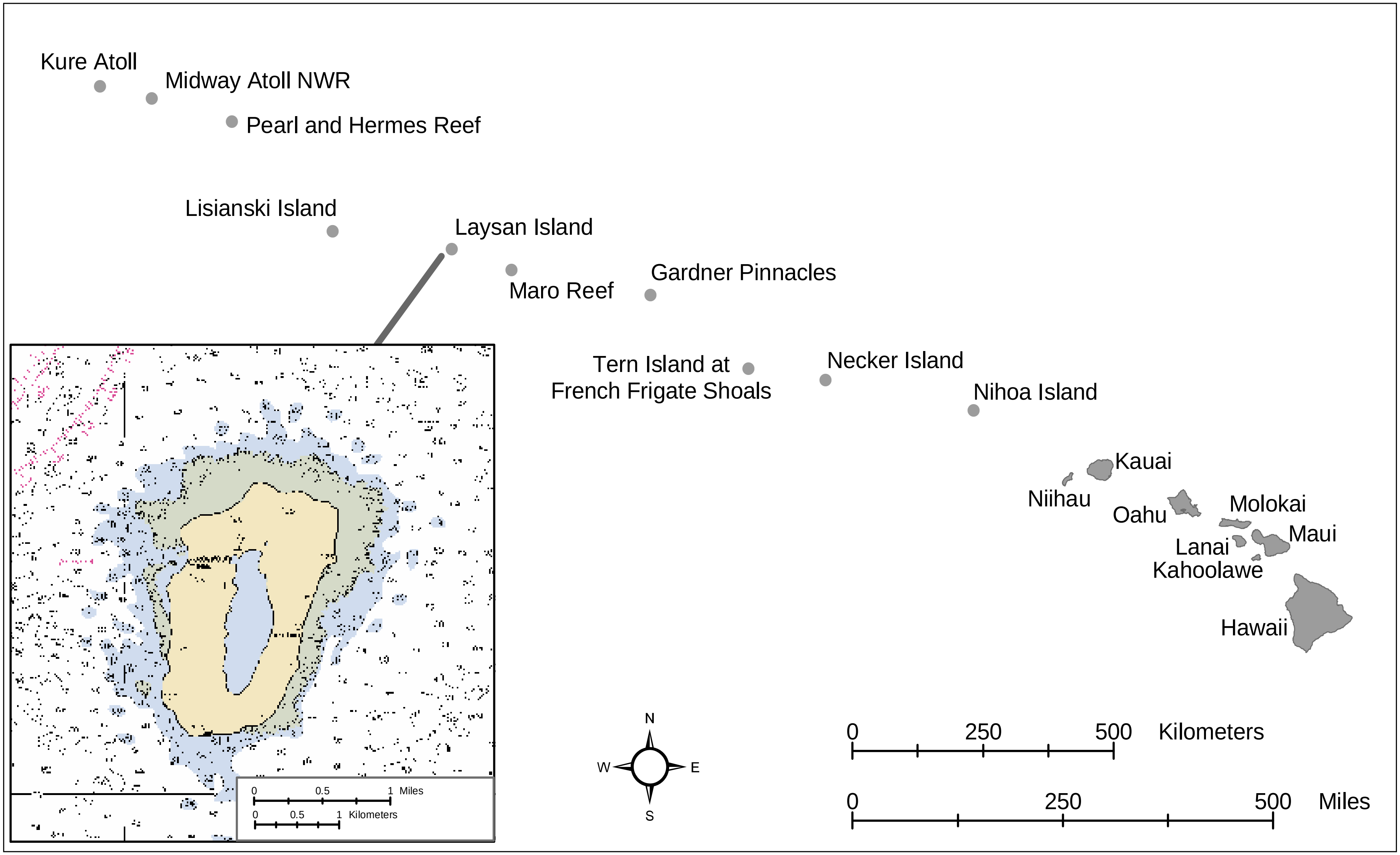

Figure 1. Map of the Hawaiian Islands, with a detail of Laysan Island.

1995). However, ducks were extirpated from Lisianski in the early 1800s, leaving the species only on Laysan Island.

We have learned through subfossil evidence that the Laysan duck likely once occurred throughout the Main Hawaiian Islands; to date, bones have been found on the islands of Hawai`i, Maui, Moloka`i, O`ahu, and Kaua`i (James and Olson 1991; Cooper *et al*. 1996). The extirpation of the Laysan duck from the Main Hawaiian Islands in prehistory likely resulted from a combination of predation by introduced mammals (*e.g.*, rats [*Rattus exulans*]), habitat loss, and predation by humans; these factors are the probable causes of the decline and extinction of many native Hawaiian birds, including several other waterfowl species (James and Olson 1982; James and Olson 1991; Olson and James 1991; Burney *et al.* 2001).

The Laysan duck was federally listed as endangered in 1967 (USFWS 1967). The International Union for the Conservation of Nature and Natural Resources lists 15 of the world's 231 species of waterfowl as endangered or critically endangered on the Red List; of these, the Laysan duck is one of the most critically endangered (IUCN 2004). The Laysan duck has a recovery priority number of 2. Recovery priority numbers are assigned to a species based on degree of threat, recovery potential, taxonomic status, and conflict with human activities. Numerical ranks range from 1 to 18, with a letter designation of "C" indicating conflict with human economic activities. The highest priority is 1; the lowest priority is 18 (USFWS 1983a, b). The Laysan duck's recovery priority number of 2 indicates that it faces a high degree of threat, has a high potential for recovery, its taxonomic rank is a full species, and it is generally not in conflict with economic activities. Critical habitat has not been designated for the Laysan duck.

The strategy to recover the Laysan duck consists of maintaining the numbers on Laysan, reducing or eliminating the current threats to the species, and reestablishing the species on several other islands in numbers capable of withstanding random catastrophes and environmental and demographic fluctuations. Populations large enough to tolerate environmental uncertainties also will be able to withstand demographic uncertainties. We estimate that the establishment of the Laysan duck on a combination of Northwestern and Main Hawaiian Islands, and management of new populations to reduce the likelihood of inbreeding, will help to promote the long-term persistence of the species.

This recovery plan is divided into four parts. Part I provides an overview of the biology of the species, the history of its decline, and current threats to its persistence. Part II summarizes past and current conservation efforts for the species and outlines the recovery strategy. Parts III and IV present the recovery criteria and actions needed to achieve recovery, including the implementation schedule, with emphasis on actions needed to achieve interim recovery goals within the next 5 years. This structure reflects the need for adaptive management in advancing the recovery of the Laysan duck; many variables remain unknown, and long-term planning without inherent flexibility is unlikely to succeed. Short-term implementation plans will be prepared every 5 years or as necessary to reflect the knowledge gained and refine the management program to maximize the success of the Laysan duck recovery program.

B. SPECIES DESCRIPTION AND TAXONOMY

The Laysan duck (American Ornithologists' Union 1998), also known as the Laysan teal, is a small (38.1 to 43.2 centimeters [15 to 17 inches] in length, weight 420 to 500 grams [14.8 to 17.6 ounces]), mostly chocolate-brown duck with contrasting bi-colored body feathers (USFWS 1982; Moulton and Marshall 1996). It has an iridescent purplish-green speculum (wing patch) and a prominent white eye ring. There is considerable individual variation in plumage. The eye ring is nearly absent on juvenile birds, and becomes more extensive and irregular in adults. Leucism, or extensive white feathering, is common on the head and neck, especially in birds older than 3 years. The plumage of both sexes is quite similar, but bill and leg coloring can be used to distinguish sexes. In males, the short and spatulate bill is olive-green with black blotches along the maxilla (upper half of the bill). Females have a slightly shorter, paler orange bill with variable black mottling. Both sexes have dull orange legs, although the male's legs typically are brighter (Moulton and Marshall 1996). Mass fluctuates significantly with season (Reynolds and Work 2005). Both males and females are lightest during the breeding season. Other morphometric characteristics (wing chord, tarsus, and bill length) are on average slightly larger for males (Moulton and Marshall 1996).

Similar to other waterfowl, Laysan ducks molt (drop) all of their flight feathers at the same time and are incapable of flight for a period of time until the new feathers grow in. On Laysan, this molt typically occurs between July and August for males and between July and September for females (Moulton and Marshall 1996). For female ducks, the molt usually occurs after brood rearing. The timing of the molt is variable, as is the timing for breeding. The occurrence of this molt should be considered in recovery efforts; although Laysan ducks are always vulnerable to predators, their vulnerability is most likely heightened during the molt, nesting, and brood rearing.

Ducklings are precocial; they hatch covered with down and with their eyes open. They are able to walk, but are led by the hen and taught how and where to forage. Similar to other island ducks, Laysan duck eggs and ducklings are large in comparison with continental species (Weller 1980). Ducklings are very large relative to adults, weighing 22 to 30 grams (0.77 to 1.05 ounces) newly hatched. They have dark brownish-yellow plumage with inconspicuous markings. The chin is somewhat lighter; the forehead, lores (area between the base of the bill and the eye), and ear patches are darker. Feathers on the cheeks, breast, belly, around the wing patches and around the eye are grayish-yellow. Most ducklings have an eye-stripe, but it is not easily distinguished from afar. The toes and lower legs are olive-brown, with bluish gray webs. Juveniles fledge after obtaining flight feathers at 55 to 65 days of age (Moulton and Marshall 1996).

The Laysan duck is unique behaviorally, genetically, and in its life history traits. It is a relatively long-lived species (12 years in the wild, 18 in captivity; Moulton and Weller 1984; Reynolds and Kozar 2000a) with a low reproductive rate in comparison with continental ducks. The clutch size averages 3.8 eggs in the Laysan duck on Laysan Island and 8 in the mallard (Weller 1980); however, average clutch size of Laysan ducks at Midway Atoll was 7 during the first two breeding seasons there (2005 and 2006; Reynolds *et al.* 2008). The Laysan duck is mostly nocturnal in its habits, feeds primarily on insects, and is very sedentary and terrestrial for a waterfowl species. Having evolved with avian predators instead of mammalian predators, the ducks are more likely to walk than fly, and when startled they tend to freeze rather than flush. These behaviors make them vulnerable to introduced mammalian predators, exploitation by humans, and may partially explain their extirpation from the Main Hawaiian Islands during the period of human colonization.

Laysan ducks exhibit several morphological adaptations to a largely terrestrial existence. They have a shorter middle toe, disproportionately long femur, and pelvic differences in comparison to continental dabbling ducks. They are also smaller, have shorter wings with fewer primaries, and moderate flight muscle reduction relative to mallards (*Anas platyrhynchos*; Livezey 1993; Moulton and Marshall 1996). The Laysan duck is not known to migrate or disperse from Laysan.

The Laysan duck is a taxonomically distinct species in the waterfowl family (Anatidae: tribe Anatini). There are 15 species of dabbling ducks endemic to islands (Weller 1980), suggesting that the ducks that colonized these islands originally were capable of long-distance flight. The Laysan duck was once thought to be closely related to the North American mallard group and the Hawaiian duck or koloa (*Anas wyvilliana*). Genetic evidence reveals that the Laysan duck's divergence from the koloa/mallard lineage is robust

(Rhymer 2001), and represents a separate colonization of Hawai`i. From a phylogenetic and biogeographic analysis, Johnson and Sorenson (1999) reconstructed the origins for the Laysan duck, and concluded that its ancestor, an ancient member of the mallard clade, was of southern hemisphere, East Asian/Pacific origin.

C. ISLAND HISTORY AND HABITAT

1. Laysan Island

Laysan lies 1,463 kilometers (909 miles) northwest of Honolulu and is accessible only by boat (Figure 1). Although feather collectors, seal and turtle hunters, and other mariners visited the island, there is no evidence that Laysan was inhabited before guano miners established a camp in 1893 (Ely and Clapp 1973). A small U.S. Fish and Wildlife Service field camp exists on Laysan Island today.

Covering 416 hectares (1,027 acres), Laysan is the largest of the Northwestern Hawaiian Islands. It is roughly rectangular in shape, approximately 3 kilometers (1.9 miles) long from north to south and 1.5 kilometers (0.9 miles) east to west. The island is made up of 184 hectares (454 acres) of vegetated habitat and 93 hectares (230 acres) of interior lake and mudflat area (USFWS data). The remaining 139 hectares (343 acres) consist of coastal dune and beach (USFWS data). The one large interior lake is characterized by high salinity, high nutrient content, and low species diversity. The lake's salinity is three to four times that of the ocean. Salt tolerant species dominate the lake's biota. The lake supports algal growth (*Dunaliella* spp.), dense populations of brine shrimp (*Artemia franciscana*) and brine flies (*Scatella sexnotata*; Caspers 1981). The lake varies in size and depth seasonally. Its maximum depth in recent decades was 6.5 meters (21 feet) (USFWS data); in the late 19th and early 20th centuries, prior to anthropogenic siltation, the lake was much deeper than it is today (Ely and Clapp 1973 and references therein).

The island's highest point is 12 meters (40 feet) above sea level (Juvik and Juvik 1998). There are coastal reef flats and tide pools around the perimeter. Fresh and brackish (up to 3.0 grams salt per 100 grams water) groundwater seeps occur in the interior of the island surrounding the lake and at several locations on the coast. In 1998, 22 seeps were identified in the interior of Laysan surrounding the lake. During drought conditions, most seeps are below ground and inaccessible to the ducks (Reynolds 2002).

Vegetation associations form concentric bands around the island. Scattered ground cover dominated by *Nama sandvicensis* (nama) is found closest to the coast. Moving inland, one finds vegetative associations that include coastal shrubs (*Scaevola sericea* [naupaka]), interior bunchgrasses

(*Eragrostis variabilis* [kawelu]), shrubs (*Scaevola sericea, Pluchea indica* [Indian fleabane], and *Chenopodium oahuense* [aweoweo]), vines (*Ipomoea pes-caprae* [beach morning glory] or *Sicyos maximowiczii* [anunu], *S. pachycarpus,* or *S. semitonsus*), and matted vegetation and sedges (*Sesuvium portulacastrum* [akulikuli] and *Cyperus laevigatus* [makaloa]) (Newman 1988, Morin 1992). Rainfall averaged 86 centimeters (34 inches) per year from 1992 to 2004 (range 38 to 158 centimeters [15 to 62 inches] per year; USFWS data).

Laysan Island is an important nesting colony for several million seabirds. President Theodore Roosevelt declared the island a bird reserve in 1909. Today, Laysan is protected as part of the Hawaiian Islands National Wildlife Refuge, is designated as a National Research Reserve, and is part of the Papahānaumokuākea Marine National Monument.

Although Laysan today is dominated by native plants and animals and is among the most healthy of Hawaiian ecosystems, since human contact in the late 19th century the island has undergone massive changes from which it is still recovering. Historical accounts from the end of the 1800s described the native flora and fauna in some detail (Morin and Conant 1998; Schauinsland 1899). Sandalwood trees (*Santalum ellipticum*), native palms (*Pritchardia* spp.), and grasses (*Eragrostis variabilis* and *Cenchrus agrimonioides* [kamanomano]) covered the island, but some of these are missing today. Seabirds, landbirds, seals, and turtles were much more abundant. Rabbits (*Oryctolagus cuniculus*) were introduced to Laysan around 1903, perhaps by the same people who began a guano mining operation there in the late 19th century. In the space of a decade, rabbits nearly denuded the island, ultimately causing drastic alteration of the floral and faunal composition of the island (Ely and Clapp 1973). The *Thetis* expedition sent to Laysan by the Bureau of Biological Survey to eradicate rabbits in 1912-13 was unsuccessful, despite their having killed more than 5,000 animals; the last rabbits were removed during the *Tanager* Expedition of 1923 (Ely and Clapp 1973). The seabirds recovered in the 20 years following the rabbit eradication, but three of five landbird species went extinct (the Laysan rail, *Porzana palmeri*; the Laysan millerbird, *Acrocephalus familiaris*; and the Laysan honeycreeper, *Himatione sanguinea freethii*), as did 10 species of plants and numerous invertebrates, most of which were associated with host plants that disappeared (Butler and Usinger 1963; Ely and Clapp 1973; Asquith 1994). Humans have brought many plant and invertebrate species to Laysan, notably *Cenchrus echinatus*, an invasive sandbur grass, and ants (family Formicidae). Prior to the introduction of rabbits, the island's hypersaline lake was deeper and had a coral bottom; devegetation by rabbits from 1903 to 1923 caused drifting sands to fill in the lake and some of the freshwater seeps on the island. A freshwater pond on the southwestern side of the island was completely filled with sand (Ely and Clapp 1973).

2. Lisianski Island

Lisianski Island, approximately 250 kilometers (155 miles) northwest of Laysan, is one-third Laysan's size and has a similar geology and history (Figure 1). The island is about 12 meters (40 feet) high at its highest point (Juvik and Juvik 1998). The presence of Laysan ducks on Lisianski was first noted by members of a Russian scientific expedition aboard the Moller in 1828, and the survivors of the shipwrecked Holden Borden in 1844 subsisted in large part by eating Laysan ducks (Olson and Ziegler 1995). The first visitors to the island noted an abundance of beach grasses and a few flowering shrubs, and fresh water was abundant, though sometimes brackish (Polynesian 1844 in Rauzon 2001). However, the ship sent to rescue the Holden Borden survivors in 1844 accidentally introduced mice to the island, with devastating consequences for the vegetation. Thirteen years later, a sea captain noted the near-absence of plant life on Lisianski, save for a few coarse grasses and small vines, and the Laysan ducks that had formerly been present were not seen (Polynesian 1857 in Rauzon 2001). What little vegetation the mice left behind was soon depleted by rabbits introduced to Lisianski from Laysan around the turn of the century. By 1916 the rabbits on Lisianski had died out from starvation, and the lack of forage killed off the mice as well (Elschner 1925 in Rauzon 2001). Today the flora has mostly recovered and is similar to that of Laysan, with concentric zones of viney vegetation and bunch grass. The alien sandbur *Cenchrus echinatus* has become established, however, and is spreading on Lisianski (Starr and Martz 1999; Reynolds and Kozar 2000a).

Determining the extent of change in Lisianski's invertebrate fauna since human contact is difficult, but extensive alteration is likely. A recent survey noted 59 arthropod species on Lisianski, only 15 of which were indigenous to the island. The remaining species were adventive (unintentionally introduced, but able to colonize the island; Nishida 1999). In addition, Reynolds and Kozar (2000a) found that at least one native *Agrotis* moth and its larvae were abundant on Lisianski (both are prey for the Laysan duck).

The interior of Lisianski once contained a wetland of fresh to brackish water, which sometimes was inundated with seawater during the highest tides (Polynesian 1844 in Rauzon 2001). Shifting sands destabilized by the loss of vegetation began to fill this wetland, and by 1857 nothing remained of it, though fresh water could be found by digging five feet below the surface (Polynesian 1857 in Rauzon 2001). No fresh water occurs on the surface of the island today, and a hydrologic survey of the islands suggests that the groundwater table lies at least seven feet from the surface (Meyer 2006).

3. Prehistoric Distribution and Habitat

Subfossil evidence reveals that the Laysan duck likely occurred on at least five of the major Hawaiian Islands prior to human settlement (roughly 1,500 years ago), in addition to its historical occurrence on Lisianski and Laysan (Olson and Ziegler 1995; Cooper *et al.* 1996; Figure 2). Remains of adult and flightless juvenile ducks provisionally identified as *Anas laysanensis* have been found on Hawai`i Island at elevations ranging from 1,128 to 1,792 meters (3,700 to 5,878 feet) above sea level, including sites on Mt. Hualalai, Mauna Kea, and Mauna Loa. Remains from lower elevations (61 meters [200 feet]) were found near the coast at Ka Lae (South Point). On Maui, remains were found at 825 and 1,200 meters (2,706 and 3,936 feet). On Moloka`i, subfossils were found at Mo`omomi dunes on the coast. Laysan duck bones were also found at Kalaeloa (Barbers Point) on O`ahu, and on Kaua`i at Poipu, Makawehi, and Kealia dunes.

The Laysan duck's prehistoric habitat on these high-elevation islands likely was much different from that where the species is found today. The distribution of subfossils suggests that the species was a habitat generalist, inhabiting a range of environments from high elevation forests to coastal wetlands. Additionally, apart from an artificial lake on Kaua`i (created by Polynesian salt mining), no hypersaline ecosystems exist in the Main Hawaiian Islands, indicating Laysan ducks were not historically dependent on this type of habitat.

Unfortunately, human disturbance and poor preservation conditions preclude recovery of subfossil material from some islands, and intensive paleoecological study of many of the Northwestern Hawaiian Islands is lacking. However, the wide distribution of subfossils among islands and habitats coupled with the species' distribution in recorded history suggests that Laysan ducks once were distributed throughout the Hawaiian Islands. We therefore consider the putative range of the species to encompass the entire archipelago.

D. GENERAL BIOLOGY AND ECOLOGY

1. Habitat Use

Prior to the discovery of bones in diverse habitats on other islands, the Laysan duck was believed to be endemic to and particularly specialized for Laysan Island. Many factors have contributed to this species' current isolation, as described above. The relevance of current habitat use is

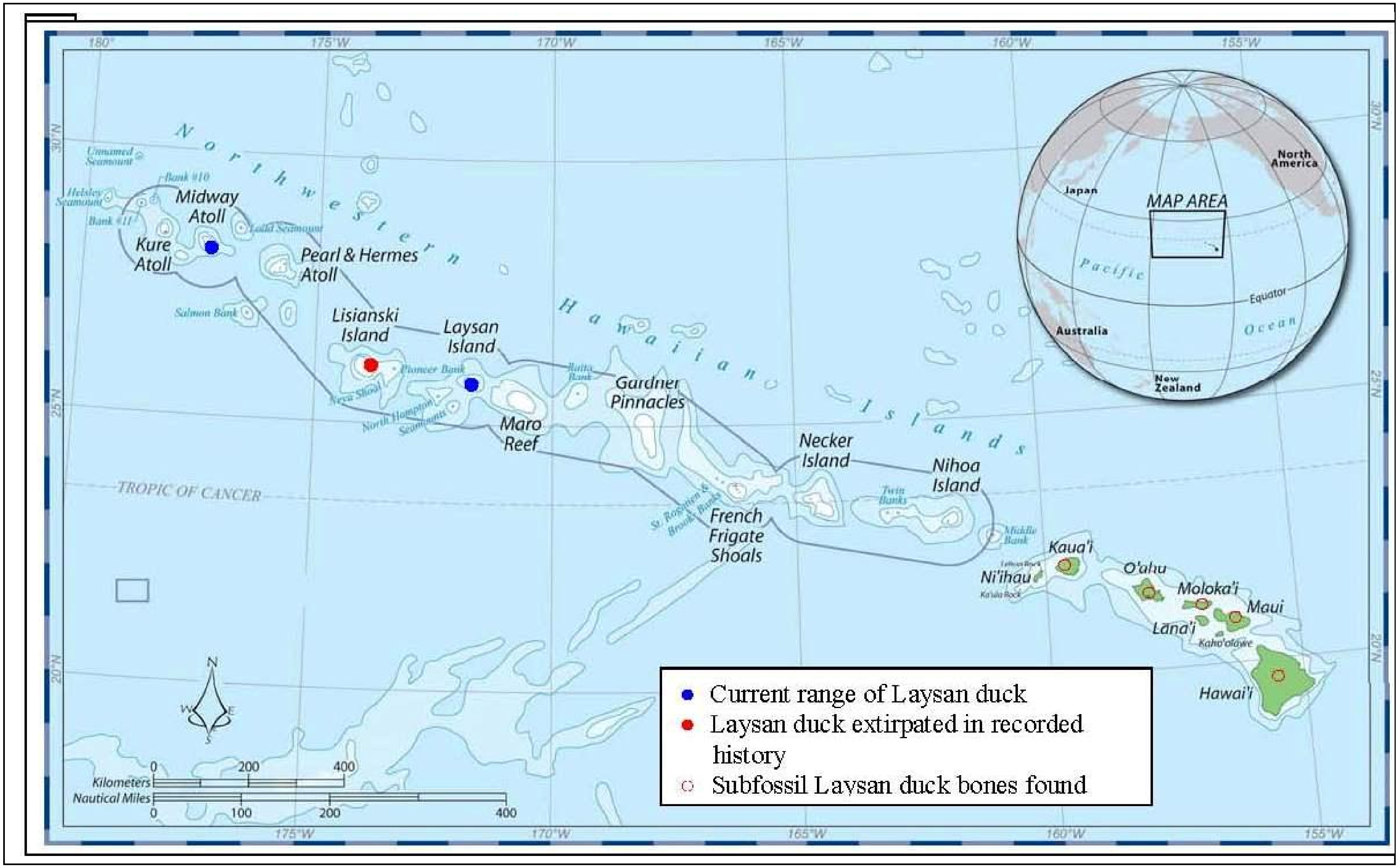

Figure 1. Map of the Hawaiian Islands indicating prehistoric and modern distribution of the Laysan duck.

difficult to interpret when a species has declined to a single remnant population (Armstrong and McLean 1995). It is important to consider the possibility that some aspects of the ecology of Laysan Island may not be ideal for this species. Substantial information about Laysan duck habitat use and behavior has been gathered at Midway (M. Reynolds, U.S. Geological Survey, pers. comm. 2008); these data have not yet been analyzed.

(a) Habitat Use and Behavior on Laysan Island.

Laysan ducks are observed on all parts of the island but are typically hidden in the vegetation and difficult to observe during the day. Before sunset, the ducks emerge from the vegetation and are more visible, especially at the lake. Moulton and Weller (1984) found that the ducks were very active at night, foraging at the lake. In contrast, Warner (1963) described lake use as insignificant during the summer months of his study. There are four distinct habitat zones on Laysan Island that we have classified as camp, coastal, lake, and terrestrial (Figure 3). The camp zone occupies less than 1 percent of the island's area, and is characterized by the presence of human structures, buckets, and tents. The camp area is significant, however, because of unique characteristics used by ducks, such as impermeable horizontal surfaces where rainwater pools (fresh water is a limited resource for Laysan ducks), surfaces such as screens and tent flies that trap insects on which ducks feed, and raised tents and tent rain-flies provide shade and cover for ducks. The coastal zone includes all habitats below the high surf line. The lake zone consists of the interior hypersaline lake, all wetlands, and mudflats. The terrestrial zone includes all "upland" vegetated habitats except those within the camp area.

Radio telemetry and behavioral observations were used in 1998 through 2000 to quantify 24-hour habitat use in these four zones and the activity budgets of adult ducks on Laysan during three breeding seasons and one winter season (Reynolds 2004). Tracking data collected from 73 radio-tagged Laysan ducks during this time period indicate that individuals spend most of their time in the terrestrial habitats (59 percent). The lake zone was used 36 percent of the total time. Considerably less time was spent in the camp (4 percent) and coastal zones (1 percent). Twenty-four-hour time budgets for activities within each habitat are shown in Figure 4 (Reynolds 2004).

Habitat selection analysis indicated that a few ducks selectively used the "camp habitat" and most avoided the coastal habitat except during the post-breeding period. Most of the birds showed strong site fidelity and evidence of selective habitat use by time of day, and some showed individual variation in their use of habitat zones, as detailed in Reynolds (2004).

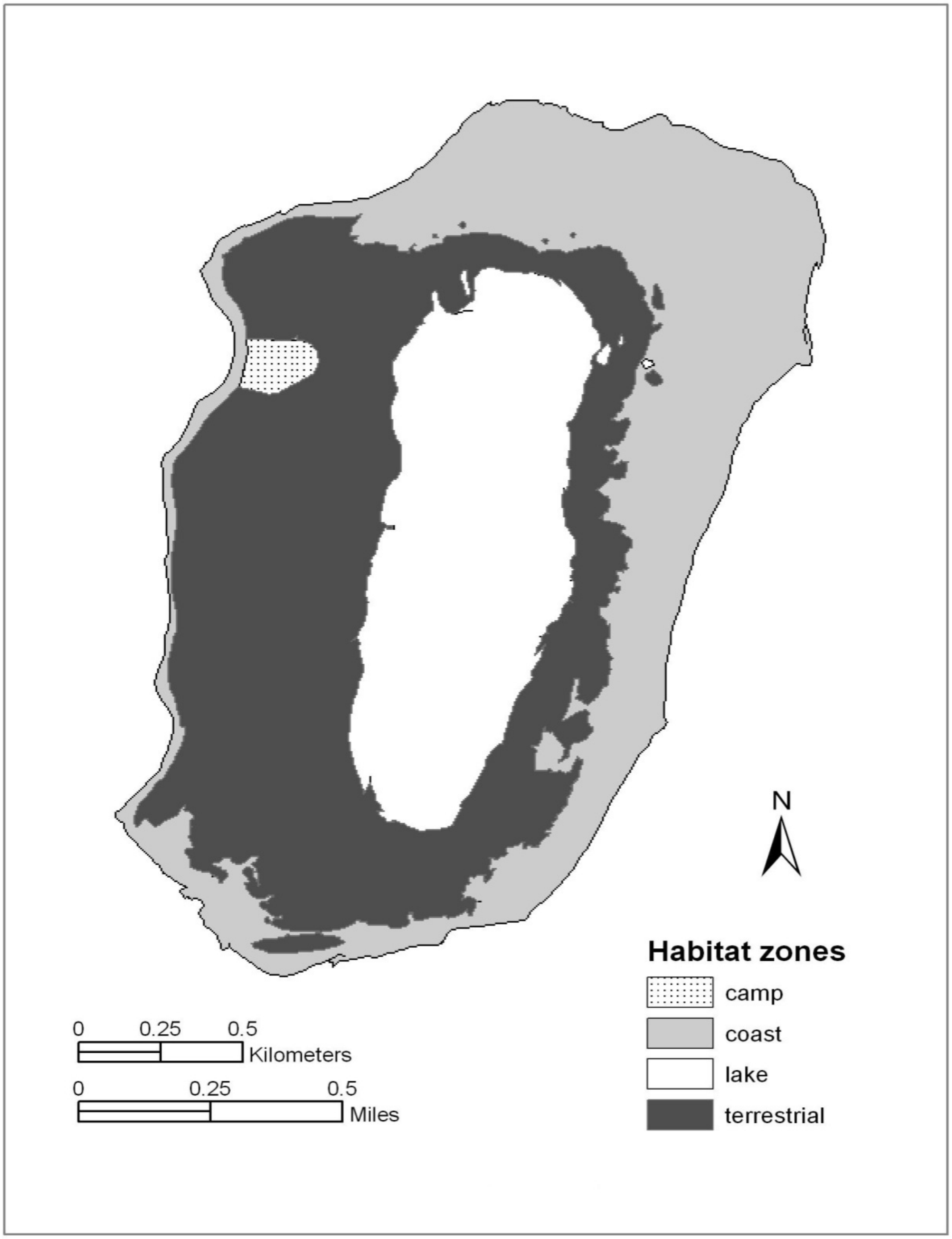

Figure 3. Map of habitat zones on Laysan Island (Reynolds 2004).

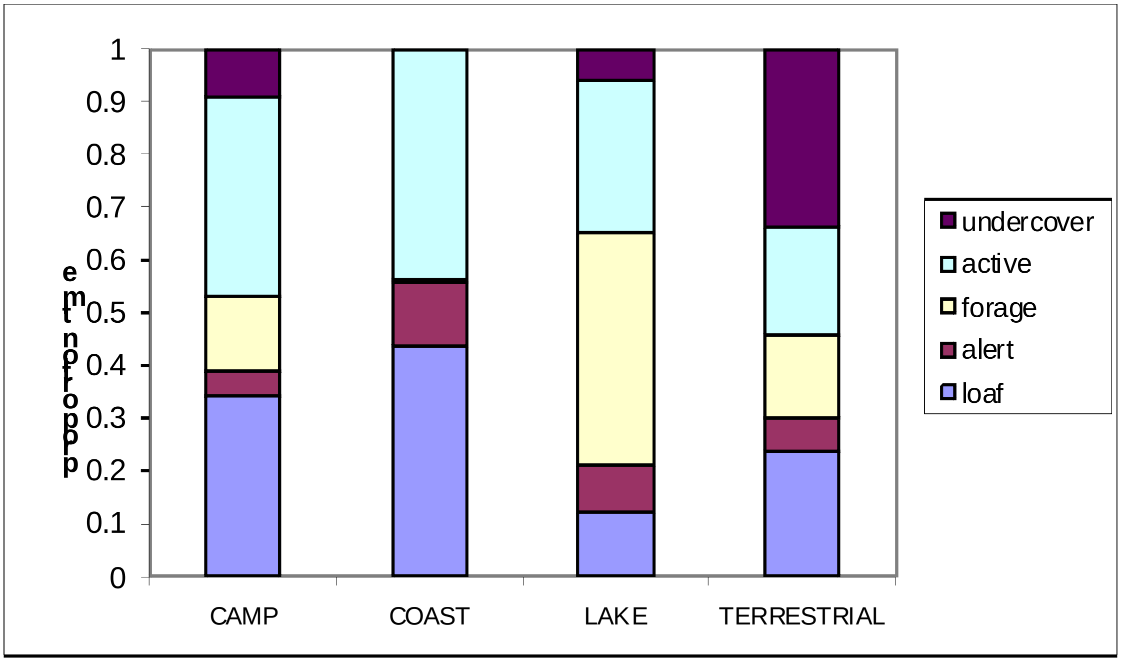

Figure 4. Twenty-four-hour time activity budget of Laysan ducks in habitat zones of Laysan Island (n = 402 observations; 8,511 minutes). Under cover = concealed in vegetation; active = locomotion, or self-maintenance or social behaviors; forage = specifically seeking/capturing food; alert = flushing, frozen, vigilant; loaf = resting, sleeping. Adapted from Reynolds (2004).

(i) Daily Habitat Use and Behavior. In the morning, ducks were active and moved between habitats. During the middle of the day, ducks took cover under bunchgrasses (*Eragrostis variabilis*) or shrubs (*Scaevola sericea* and *Tournefortia argentea* [tree heliotrope]). Most of the adult daytime activity budget was spent loafing or under cover in the terrestrial zone (76 percent). Very few adult birds (5 percent of total telemetry locations) visited the lake habitat at midday, and their primary activity was foraging (44 percent of time spent in foraging behavior). In contrast, duckling broods foraged both during the day and at night. At dusk birds moved actively between habitat zones. Some ducks visited coastal reef flats and coastal freshwater seeps in the late afternoon, and many birds visited the lake zone. The ducks rarely foraged on the coast.

During the dusk observation session, ducks loafed (31 percent of the time), were active (28 percent), foraged (22 percent), were alert (4 percent), or were under cover (10 percent) (Reynolds 2002). Night tracking sessions showed that foraging was the most important activity (46 percent of time). Approximately 50 percent of the time spent at the lake at night was dedicated to foraging, and 41 percent of time spent in the terrestrial zone at night was spent foraging. Within the terrestrial zone, Laysan ducks selected the viney vegetation over the bunchgrass habitat at night. This viney vegetation association (*Boerhavia-Ipomoea-Tribulus-Sicyos* spp. [alena-pohuehue-nohu-anunu]) was used frequently at night by foraging ducks, and had the highest invertebrate density and diversity of the terrestrial habitats. Night sessions lacked detections from the coastal zone, and few birds used the camp zone after dark (Reynolds 2004).

(ii) Seasonal Habitat Use. During the breeding seasons of 1998 to 2000 (typically April through July), the terrestrial zone was used more than the lake zone. Ducks spent less time at the lake during the 1998 breeding season compared to the 1999 and 2000 breeding seasons. Night tracking indicated more time was spent in the terrestrial zone than the lake zone during the drought conditions of the 1998 breeding season, compared with subsequent breeding seasons. This is perhaps explained by switching to terrestrial prey when prey abundance (brine flies) at the lake was reduced. Data from resighting color-banded individuals suggest that time spent in camp by some birds increased from early spring to mid-summer. Time spent in the camp zone by radio-tagged birds was correlated with an increase in moth abundance in camp (Reynolds 2004).

The coastal zone was rarely used during all months in which radio telemetry data were collected (less than 1 percent of time spent there per month). However, a seasonal increase in the time spent in the coastal zone was evident from sightings. Flocks of up to 70 Laysan ducks were recorded on the coast during the post-breeding season in September through February when radio tracking did not occur (Adams and Nevins 1994; McMahon *et al.* 1997; Reynolds 2004). The tidepools at the southern end of Laysan were a principal flocking area following molt (September through November). Loafing, preening, fighting, courtship, copulation, and bathing were observed in the flocks using the coastal areas during this period (Reynolds 2002).

(iii) Individual Variation in Habitat Use. Habitat use varied considerably among individuals. From 1998 through 2000, 9 percent of the radio-tagged birds used the camp, 18 percent used the coastal zone, 96 percent used the lake zone, and all of the birds used the terrestrial zone (n = 53 birds). Some individuals rarely used the lake zone (Reynolds 2004).

(iv) Fresh Water. The freshwater seeps surrounding the lake are drinking areas for the ducks, Laysan finches (*Telespiza cantans*), and shorebirds. Seeps and other areas of relatively low salinity support greater algal growth and the accumulation of organic matter, which attracts higher numbers of brine flies. Laysan duck hens used ephemeral wetlands and freshwater seeps as brood rearing areas. Waterfowl have suborbital glands that function for salt removal (Schmidt-Nielsen and Kim 1964) and adults drink saltwater; however, hypersaline (more than 3.3 grams salt per 100 grams water) environments can be toxic to young ducklings with undeveloped salt glands (Wobeser and Howard 1987). Although the adult Laysan duck has an efficient salt gland, fresh water is a necessary resource for the species, as evidenced by the concentration of ducks at brackish seeps, freshwater seeps, and ephemeral freshwater wetlands (Lenz and Gagne 1986; Marshall 1989; Moulton and Marshall 1996). Antagonistic interactions between ducks and other bird species are frequently observed at the freshwater seeps. This contributes to duckling mortality from trauma (see Causes of Mortality). Fresh water may be a limiting factor for ducklings, especially during drought years, or if moisture-rich terrestrial invertebrates are scarce.

Although freshwater seeps and ephemeral freshwater wetlands appear to be the primary sources of fresh water on Laysan, Laysan ducks can take water opportunistically from a variety of sources. Adult ducks drink dew and rainwater that has collected on vegetation, from pooled water on hardpan and mudflats after heavy rains, and from small excavations created around the lake to sample the water table. Around the camp, Laysan ducks readily drink water from buckets, camp structures, and watering devices. The adult ducks also obtain moisture from the ingestion of succulent plants such as *Portulaca* spp. (ihi) and terrestrial invertebrates (*e.g.*, lepidopteran [moth and butterfly] and dipteran [fly] larvae).

2. Foraging

Food availability is a primary regulator of population size and reproductive success in birds (Lack 1970). The Laysan duck's foraging ecology on Laysan, like its habitat use, probably is quite different than its prehistoric foraging ecology on the Main Hawaiian Islands. Our understanding of the foraging ecology of this species on Laysan is growing. A better understanding of the range of food resources used on Laysan will help managers more accurately predict or enhance the suitability of potential release sites on other islands.

There are many conflicting reports about the foraging ecology of the Laysan duck, possibly because of limited observations during short visits to the island and varying environmental conditions (Marshall 1989). Introductions of alien species such as the snake-eyed skink (*Cryptoblepharus poecilopleuris*), rabbits, ants, and other arthropods have had unknown impacts on the prey base and diet of the Laysan duck. We know that the native plant and arthropod communities of Laysan have been severely degraded in the last century (Conant and Rowland 1994, Morin and Conant 1998). Laysan ducks observed by Warner (1963) primarily fed terrestrially on moth larvae (*Agrotis dislocata*), and these were an important component of their diet during observations from 1998 through 2000 (Reynolds 2002). Warner considered the brine flies to be an incidental part of the diet and described the duck's brine fly chasing behavior as infrequent. More recent data indicate that brine flies are an important component of their diet, at least seasonally (Caspers 1981; Moulton and Weller 1984; Reynolds *et al.* 2006b). Warner (1963) reported a lack of fresh water during his study (conducted in the summers 1957 through 1961), so it is possible that brine fly abundance was low during Warner's study periods or that drought conditions prevailed. Native arthropods may have been more diverse and abundant in the past, prior to the introduction of alien predators such as ants, and therefore more terrestrial prey may have been available formerly for the Laysan duck. Warner (1963) hypothesized that the shift in diet to greater reliance on brine flies was influenced by the introduction of a parasitic wasp (order Hymenoptera) that feeds on moth larvae, but no research has been carried out to explore this question (Kear 1977).

(a) Diet Composition.

The Laysan duck is primarily insectivorous, but feeds opportunistically on seeds, leaves, and algae (Reynolds *et al.* 2006b). Behavioral observations indicate that adult and larval lepidopterans, adult and larval terrestrial dipterans, blatteria (cockroaches), grass seeds, sedge achenes, and succulent leaves are taken while foraging in terrestrial habitats (Reynolds *et al.* 2006b). Fecal samples were collected opportunistically from adult ducks in the summer of 1985 and in 1998 through 2000. Analysis of fecal samples is a non-intrusive method for determining diet composition, but the method is biased towards finding the indigestible hard parts of insects, which pass intact through the digestive system. Fecal samples contained items in 16 prey categories. Dipteran adults were the most common prey type identified and the most abundant prey item counted. Dipteran larvae, seeds, brine shrimp, lepidopteran larvae, beetles, and amphipods (sandhoppers) were also abundant in the samples, as were ants (Reynolds *et al.* 2006b; Table 1). Based on the birds' behavior, and because so many specimens passed through the digestive system completely undigested,

Table 1. Frequency of occurrence of taxa identified in Laysan duck fecal samples (proportions of samples with prey types) collected on Laysan Island at the lake in 1985 (Lenz and Gagne 1986) and 1998-2000 at both the lake and terrestrial habitats (Reynolds *et al.* 2006b).

Year	N	Prey type	(Common name)	Frequency of occurrence (%)
1998-2000	118	Dipteran adult	(adult flies)	47
		Dipteran larvae/pupae	(fly larvae or pupae)	39
		Formicidae	(ants)	36
		Seeds		31
		Lepidopteran larvae	(butterfly or moth larvae)	25
		Coleoptera	(beetles)	23
		Plant fibers		17
		Artemia spp.	(brine shrimp)	15
		Acari	(mites and ticks)	11
		Amphipoda	(sandhoppers)	8
		Unknown arthropod		7
		Dictyoptera	(cockroaches and mantids)	3
		Diptera terrestrial	(terrestrial flies)	3
		Lepidopteran adult	(adult moth or butterfly)	3
		Araneida	(spiders)	2
1985	28	Dipteran adult (*Neoscatella sexnotata*)	(brine fly)	39
		Artemia	(brine shrimp)	32
		Lepidopteran larvae	(moth or butterfly larvae)	32
		Dictyoptera	(cockroaches and mantids)	21
		Dipteran larvae (*N. sexnotata*)	(brine fly)	21
		Amphipoda	(sandhoppers)	14
		Dipteran terrestrial	(terrestrial flies)	11
		Acari	(mites or ticks)	7
		Araneida	(spiders)	7
		Formicidae	(ants)	4
		Dermaptera	(earwigs)	4
		Coleoptera	(beetles)	0
		Lepidopteran adult	(moth or butterfly adults)	0
		Plant fibers/Seeds		0

ant consumption is likely incidental to the consumption of other prey.

(b) Foraging Behavior.

Laysan ducks use a variety of foraging behaviors and substrates. Foraging behaviors in the lake include some tactics typical of dabbling ducks in aquatic environments: dabbling, up-ending, and head-dipping. Other more unusual foraging tactics included, brine fly chasing, dry sand filter-feeding, and dive-bomb fly-catching. Unique foraging behaviors included tunneling through lake foam to feed on invertebrates suspended in the froth generated during high winds around the lake (M. Reynolds, pers. comm. 2002). At the lake zone, the ducks spent 6 percent of their total activity budget feeding on adult brine flies (Reynolds 2002). Brine fly foraging tactics included chasing after adult brine flies at a run, and snapping at flies while walking, standing, or swimming. Laysan ducks also took advantage of the carcasses of seabirds (a rich source of flies, larvae, and beetles), and the tents in camp, which trap moths (Warner 1963; Moulton and Weller 1984; Moulton and Marshall 1996; Reynolds 2002). Historical records note that one duck used to forage for moths near the house of the guano mining company's director (Fisher 1903).

Many duck species show notable shifts in diet during breeding. Generally, female dabbling ducks increase their consumption of protein-rich foods (animal matter) for egg production (Baldassarre and Bolen 1994). The Laysan duck exhibited strong seasonal differences in foraging behavior. Between July and November 1998, no foraging on brine flies was observed, whereas from March to May 1999 (early in the breeding season) the ducks spent greater than 50 percent of their foraging effort at the lake on brine flies, suggesting a preference for brine flies only when they are very abundant (Reynolds 2002).

(c) Invertebrate Abundance.

The role of food availability in the population dynamics of dabbling ducks is not well understood (Owen and Black 1990). The quantity of invertebrates in wetlands used for brood rearing was a good predictor of mallard duckling growth and brood survival in other ecosystems (Cox *et al.* 1998). We suspect invertebrate abundance affects the female's body condition and her ability to lay and incubate as well as duckling growth and survival on Laysan. Dramatic increases in brine fly densities can occur on Laysan, especially during wet La Niña years, and the ducks appeared to initiate successful breeding after these brine fly peaks in years when data were collected (U.S. Geological Survey [USGS] data 1998, 1999; USFWS data 2000, 2003). In contrast, there is evidence to suggest that during poor food years, such as the El Niño Southern Oscillation drought years, reproductive failure on Laysan is likely, perhaps owing to the low abundance of invertebrates in both the wetland and terrestrial habitats.

Drought and reproductive failure occurred during El Niño Southern Oscillation events of 1987, 1993, and 1998; low prey abundance was recorded in 1987 and 1998 (Marshall 1989; Reynolds 2004).

(i) Lake Zone. A large number of insect species regularly inhabit areas adjacent to bodies of water and provide an important prey base for waterfowl. Most aquatic flies develop as aquatic larvae and pupae, emerging as adults that occupy the wetlands and margins of aquatic habitats. Changes in flooding regimes and lake depth are known to influence the abundance of aquatic dipterans. In particular, wetland flooding triggers the emergence of dipterans, and prolonged dry periods reduce fly emergence (McCafferty 1998).

Salt-tolerant aquatic organisms such as brine flies and brine shrimp can reach very high densities in hypersaline environments such as the lake on Laysan Island. Brine fly numbers and lake level were measured between 1998 and 2000 to explore the relationship between water depth and fly emergence in this hypersaline ecosystem (Fig. 5). Many factors ultimately are responsible for producing optimal

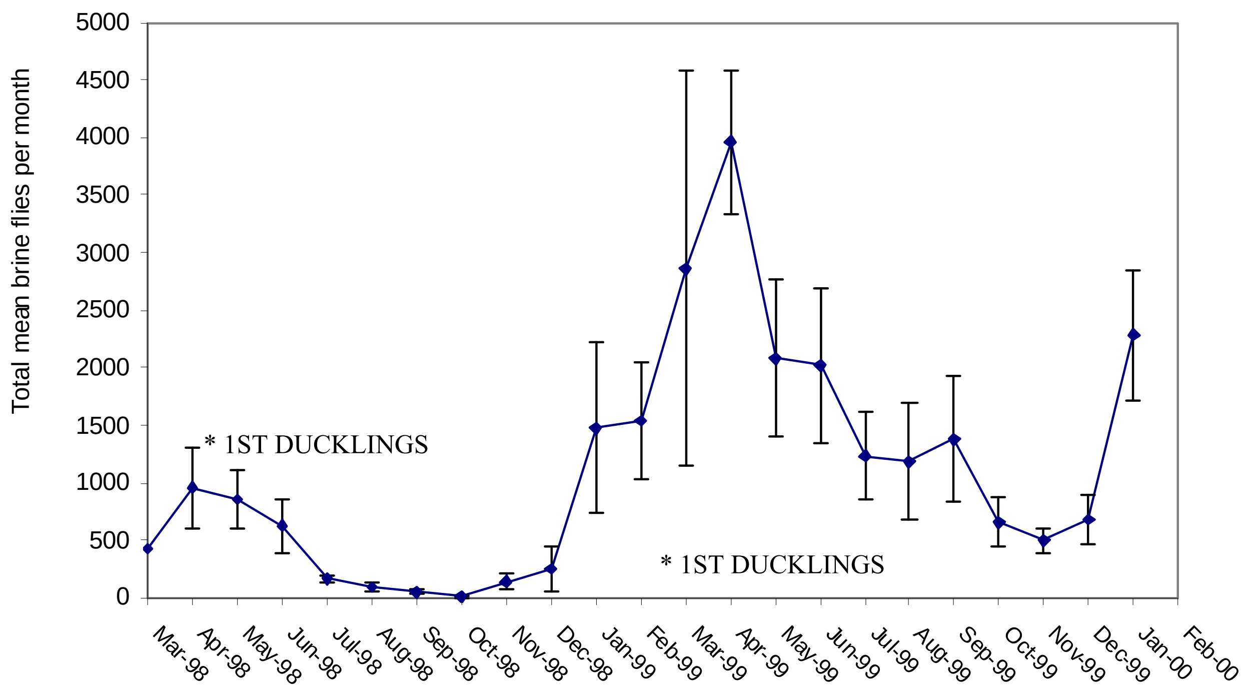

Figure 5. Seasonal brine fly (*Neoscatella sexnotata*) abundance on Laysan Island reported as monthly mean with standard error, and first brood sightings of Laysan ducks 1998 to 1999 (Reynolds 2002).

conditions for the brine flies. Primary production, temperature, and nutrient loads are important ecological variables that influence the life cycle and abundance of wetland flies. Lake level was a positive predictor of fly abundance because greater lake depths (as a result of increased rain and flooding) reduce salinity, which triggers fly emergence. There is, however, a time lag between flooding and fly emergence. Lake gauge measurements do not reflect the direct effect of water levels and salinity on mudflats, thus lake level and fly abundance are not synchronized (Fig. 5; Reynolds and Kozar 2000a).

Artemia, or brine shrimp, are zooplankton that inhabit high salinity ponds and lakes from which fish and most other crustaceans are excluded. On Laysan, the origin of the resident brine shrimp *Artemia franciscana* has not been determined, but they are suspected to be an endemic race of the species (Lenz and Dana 1987). *Artemia* are abundant year-round and their distribution is influenced by prevailing winds (Reynolds and Kozar 2000a). *Artemia* are more salt tolerant than brine flies and have a greater relative abundance at higher salinity. The primary predators on *Artemia* are waterbirds, but few waterbirds can subsist on *Artemia* alone. Red-necked phalaropes (*Phalaropus lobatus*) at Mono Lake in California, for example, exhibit a preference for brine flies and are unable to maintain their body weight when fed only *Artemia* (Rubega and Inouye 1994). *Artemia* contain fewer calories and lipids (fats) than brine flies (Herbst 1986 in Rubega and Inouye 1994), which may explain why Laysan ducks prefer brine flies, a more nutritionally profitable prey when available at high densities.

(ii) Terrestrial Zone. Comparison of arthropod abundance in terrestrial vegetation types indicates that significantly more prey (dipterans, coleopterans [beetles], and adult and larval lepidopterans) occur in the viney and mixed vegetation complex compared with bunchgrass associations (see Habitat, above). One year of terrestrial arthropod sampling showed that arthropod abundance peaked in both vegetation types after the spring rainy period; however, longer term sampling is needed to determine seasonal trends or environmental conditions that influence “pulses” in terrestrial arthropod abundance (Reynolds 2002). Droughts are also likely to negatively impact terrestrial arthropod abundances.

(iii) Camp Zone. Adult lepidopterans were the only arthropods sampled in the camp zone. There was a strong seasonal abundance pattern of moths in the years 1999 through 2000, with abundance peaking during the summer months. There was a significant correlation (Pearson correlation coefficient = 0.84, p = 0.013) between the Laysan duck's use of this habitat zone, prey abundance, and duckling production in 1999 (Reynolds 2002).

3. Reproductive Biology

(a) Courtship Behavior

Courtship behaviors occur most of the year on Laysan, and most adult pair bonds are established by September and October. Monogamous pairing and female-only parental care characterize the mating system of the Laysan duck. Pair bonds typically dissolve during brood rearing and molt (typically in summer), but if a brood fails early in the breeding season, females usually reunite with their original mates. Mate fidelity within a breeding year based on sightings data was 83 percent for 35 known pairs. Over 2 years of observations on Laysan, 69 percent of mated pairs (n = 26 marked pairs) reunited once molt and brood rearing were complete (Reynolds 2002).

(b) Nesting

Many ecological variables affect waterfowl breeding, including climate, hydrologic patterns, and temporal availability of suitable food (Baldassarre and Bolen 1994); the Laysan duck's productivity therefore is highly variable from year to year. The nesting season for the duck on Laysan generally runs from April through July, but timing of reproduction is flexible in response to habitat conditions (Moulton and Marshall 1996; Reynolds *et al.* 2007b). Early broods (December to February) were produced on Laysan in 1996, 1999, 2000, and 2006 (Bernard *et al.* 1996; Depkin and Lund 2001; Reynolds *et al.* 2007b); abundant rainfall and/or brine flies occurred during those years, (Reynolds 2002; Reynolds *et al.* 2007b).

Laysan ducks have a reduced clutch size on Laysan (average 3.8 eggs) compared to other dabbling ducks, but average clutch size reported from Midway in 2005 and 2006 was greater (7 eggs, n = 45 nests; Reynolds *et al.* 2008). The species also produced large eggs for its body size (Ripley 1960). Large eggs could be advantageous at hatching if bigger ducklings are better able to survive under less predictable feeding conditions typical of island ecosystems (Lack 1970).

Prior to their translocation to Midway, Laysan ducks were seldom observed to breed before their second year, and thought unlikely to breed successfully until after that (Reynolds *et al.* 2006a). Renesting when the first clutch or brood was lost was considered uncommon (Moulton and Marshall 1996). The first two breeding seasons at Midway demonstrated extensive plasticity in these aspects of breeding biology, with early second-year birds breeding seven months after their arrival from Laysan, and significant occurrence of renesting and multiple broods from individual hens yielding fledglings (Reynolds *et al.* 2006a).

Laysan ducks should be considered “upland nesters,” because they typically choose nest sites far from the lake (mean distance 347.6 meters [1,140 feet) from lake and wetlands; range 15 to 850 meters [49 to 2,789 feet]; n = 17 nests). Females tend to nest in their daytime home ranges (Moulton and Weller 1984, Reynolds 2002). Nests made from dead grass, rootlets, and down are well concealed under native bunchgrass and often hidden in grass clumps covered with vines (*Sicyos* spp.). Of 32 nest sites described, the majority (78 percent) occurred in the native *Eragrostis variablis* (Moulton and Weller 1984; Reynolds *et al.* 2007b).

Incubation lasts 28 to 29 days (Marshall 1992a). Apparent nest success (nests fledging at least one young) in 1999 and 2000 averaged 44 percent (Reynolds 2002), but previous studies reported much lower nest success (11 percent) due to egg predation by Laysan finches (Moulton and Weller 1984). Egg predation rates recorded in some studies may have been elevated by disturbance of nests by researchers (Moulton and Weller 1984). The most recent studies, using methods modified to prevent nest disturbance by researchers, recorded hatching success of 48 percent, based on 61 eggs from 17 nests (Reynolds 2002). Our understanding of the nesting biology of the Laysan duck will benefit greatly from additional study on Laysan and at Midway.

(c) Brood Care

Ducklings are precocial (hatched with down, open eyes, and the ability to forage) and leave the nest on the day of hatching (Marshall 1989). Ducklings follow the hen very closely for the first four days. During this period, hens lead ducklings from upland nesting sites to wetland areas used for brood rearing. These areas are characterized by high densities of invertebrates, fresh water, and nearby vegetative cover (*Cyperus laevigatus* [makaloa] or *Ipomoea* spp.; M. Reynolds, unpublished data).

In years with high nesting success, the formation of creches (combined broods from two or more hens) is common. In 2000, 47 percent of hens with broods cared for ducklings that were not their own, and 32 percent of these hens appeared to raise broods cooperatively with other hens (n = 112 broods). Parental care such as guarding, brooding, leading, and following was combined or shared among two to four hens with ducklings of different age classes. At least 4 percent of hens observed had their ducklings taken by a more aggressive hen (Reynolds 2002).

This level of brood mixing is unusual in dabbling ducks. The high rate of mixing might be explained by kin selection, female body condition, or improved foraging efficiency of larger broods (Eadie *et al.* 1988). Brooding females are often in poor nutritional condition by the time their young hatch. Female Laysan ducks with broods are the lightest of all adult birds, implying that maintaining normal weight during incubation is difficult (Moulton and Weller 1984). The energetic cost of brood rearing could reduce a hen's chances of survival. If a hen relinquishes care of ducklings to a closely related female in good condition, both females might benefit: the mother increases her chances of survival, and the adoptive mother cares for closely related offspring that carry her genes. A form of reciprocal altruism could also account for the duck's creching behavior, in that individuals caring for the young of others will likely be receive that benefit themselves in the future (Eadie *et al.* 1988).

On Laysan, conditions might lend themselves to such a system: there is a high probability of meeting the same individual, there is strong site fidelity, birds are long-lived, and individual recognition probably is widespread. Furthermore, it is possible that larger broods forage more efficiently, and accepting the ducklings of another hen increases the fitness of a hen's own ducklings. It is typical for eight to 20 ducklings of different age classes to form a foraging flock and run through swarms of brine flies (Reynolds 2002). As clouds of flies rise up from the disturbance, the ducklings snap at them while running with their necks outstretched (Moulton and Marshall 1996). Alternatively, brood amalgamation may merely be a result of crowded brood rearing habitat and is not a benefit to young or adults (Williams 1974 and Bedard and Munro 1977, cited in Afton and Paulus 1992; Kehoe 1989). None of these possible hypotheses has been tested on Laysan. Not all hens adopt ducklings; creching behavior remains an enigma.

Based on daily sightings of marked hens with new ducklings at the lake (n = 112 broods), 41 percent experienced complete brood loss during the downy duckling stage, and 23 percent of these ducklings died during their first week after hatching (Reynolds 2002). Seven percent of marked hens in 2000 produced a second brood after losing the first one. Less than 25 percent of females reared broods to independence during the years 1977 to 1978 and 1986 to 1987 (Moulton and Marshall 1996). In 1998 only 1 percent of color-banded hens raised broods to independence, in comparison to 33 percent in 2000 (Reynolds 2002). Complete reproductive failure occurred in 1987 and 1993 (Marshall 1989, Moulton and Marshall 1996), and reproduction was very low in 2002 (Agness and Payne 2002) and 2006 (Bechaver *et al.* 2006). Laysan ducks use various habitats on Laysan Island for different purposes, exhibit seasonal variation in habitat use, and display individual variability in their habitat use. Furthermore, some foraging behaviors and prey species are unique to Laysan. Therefore, prey choice flexibility and the seasonal relationships between prey abundance and duck reproduction are of great interest.

The density of ducks and timing and amount of rainfall may exert significant influence on food abundance and availability, which in turn influence observed differences in annual reproduction (Reynolds *et al.* 2007b). In addition, the phenology of nest initiation and brood emergence affects duckling survival rates because of seasonal variables other than food availability, such as changes in rainfall and crowding at freshwater seeps, albatross density, and the abundance of non-breeding ducks – all of which can affect duckling mortality resulting from trauma and exposure (see Reynolds and Work 2005).

High density of nesting birds may reduce nest site availability for Laysan ducks. On Laysan Island, Laysan ducks avoid nesting in tern colonies, and did not share nest sites with Laysan finches in *Eragrostis variabilis*. Future studies are needed to determine whether nest success is limited by competition with Laysan finches or for nest sites, avian egg predation, or poor female body condition.

4. Demography

(a) Population Size

The single naturally occurring population of Laysan ducks has undergone severe fluctuations in the past century, with estimates ranging from as few as seven adults in the early 1900s to perhaps as many as 688 adult birds in 1961 (USFWS 1982) (Marshall 1992b). In the past decade alone, duck estimates have varied from fewer than 100 to approximately 600 individuals (Reynolds 2002; Reynolds *et al.* 2006a).

Sincock and Kridler (1977) described the Laysan duck as the most difficult to survey of the four endangered birds of the Northwestern Hawaiian Islands. Previous research has determined that direct count and line transect methods are inadequate for determining population size in the Laysan duck (Sincock and Kridler 1977; Marshall 1992b). Mark-recapture and mark-resight methods yield the best results for this species (Moulton and Weller 1984; Marshall 1992b). Since 1961, population estimates have been made opportunistically, using the Lincoln-Peterson index (Lancia *et al.* 2005), and field studies initiated in 1998 emphasize methods to estimate annual population size more precisely. Estimates indicate that the population on Laysan Island has increased from roughly 300 to 600 adult birds between 1998 and 2005 (Table 2; Reynolds 2002; Reynolds *et al.* 2006a). This increase represents a rebound since the precipitous decline during the 1993 die-off. Because of environmental variability and limited carrying capacity on Laysan, the duck population there is not likely to grow much beyond this level. For a more detailed discussion of current monitoring methods, see *Laysan Duck Population Monitoring*, below.

Table 2. Estimates of Laysan duck population size on the island of Laysan using line-transect and mark-resight methods**.** Estimates for 1998-2001 were made from the highest count chosen from multiple surveys conducted each year.

Year	Estimated number of adults	95 % confidence interval	Method used	Notes	Number of birds marked	Source
1958	594	None published	Line transect		N/A	Warner 1963
1961	688	None published	Line transect		N/A	Warner 1963
1961	544	404 - 831	Lincoln-Petersen Index	Estimates recalculated in 2001	149	R. Walker, unpublished field notes
1979	489	432 - 540	Lincoln-Petersen Index	April estimate	269-296	Moulton and Weller 1984
1980	510	None published	Lincoln-Petersen Index		502	Moulton and Weller 1984
1986	423	± 128 SE	Lincoln-Petersen Index	Mean estimate Jun-Aug	200	Marshall 1992b
1987	538	± 73 SE	Lincoln-Petersen Index	Mean estimate April-June	270	Marshall 1992b
1998	288	232 -321	Lincoln-Petersen Index	Adult estimate	100	Reynolds and Citta 2007
1999	292	263 - 321	Lincoln-Petersen Index	Adult estimate	158	Reynolds and Citta 2007
2000	322	290 - 354	Lincoln-Petersen Index	Adult estimate	220	Reynolds and Citta 2007
2001	459	391 - 537	Lincoln-Petersen Index	Adult estimate	260	Reynolds and Citta 2007
2002	500	440 - 560	Lincoln-Petersen Index	Adult estimate	---	Reynolds and Citta 2007
2003	523	442 - 604	Lincoln-Petersen Index	Adult estimate	---	Reynolds and Citta 2007
2004	581	503 - 682	Lincoln-Petersen Index	Adult estimate	---	Reynolds and Citta 2007
2005	611	538 - 714	Lincoln-Petersen Index	Adult estimate	---	Reynolds *et al.* 2006a

At Midway Atoll, Laysan duck numbers grew rapidly after birds were moved there from Laysan in 2004 and 2005. Reynolds and coworkers (2007a) estimated maximum numbers to be 51 in 2005 (following the first year of breeding), 104 in 2006, and 192 in 2007 (the latter figure including the number of fledged juveniles banded in October 2007). This rate of growth was initially projected to yield a population roughly the size of Laysan's by 2009 (Reynolds et al. 2008), but the botulism mortalities in late 2008 have set back this progress The absolute carrying capacity of Midway for Laysan ducks will change with additional habitat restoration.

(b) Sex Ratio

The sex ratio of Laysan ducks on Laysan Island often is skewed toward males. Male to female ratios in 1979 and 1980 were reported as 56:44 by Moulton and Weller (1984), who noted female mortality from attacks by unpaired males. Harassment and forced copulation of females by unmated males occur occasionally, but may increase in frequency with the number of extra males in the population. Recent sex ratios were less skewed. The estimated sex ratio was even in 1998, 53:47 in 1999, 52:48 in 2000, and even in 2001 (Reynolds 2002). No adult female mortality resulting from trauma was observed from 1998 through 2001, when the ratio of males to females was lower.

(c) Mortality and Survival

From 1998 through 2000, the annual survival rate for adult males was estimated at 98.1 percent, and the estimate for adult females was 97.8 percent. Duckling survival varied from approximately 10 to 30 percent during this same time period (Reynolds 2002). This level of duckling survival is considered poor for a waterfowl population lacking mammalian predators. On Laysan the great frigatebird (*Fregata minor*), vagrant raptors that occasionally stay on the island for weeks or months, and Laysan finches (which prey on eggs) are the only potential predators on the ducks. Frigatebirds have been observed to take the chicks of terns and other seabirds (A. Marshall, U.S. Fish and Wildlife Service, pers. comm. 2008), but the total impact of great frigatebird predation on ducklings is presumed to be minimal. The ducks are alert to frigatebirds and ducklings have been observed diving underwater when frigatebirds descend or swoop down near them. Duckling survival is an important variable controlling population growth on Laysan (Warner 1963, Reynolds 2002).

(i) Causes of Mortality.

Laysan duck carcasses are rarely found, and few causes of adult or duckling mortality have been identified, with the exception of the 1993 die-off caused by starvation and echinuriasis (Work *et al.* 2004). Data from Laysan duck carcasses incidentally collected on Laysan in 1993 and 1998 through 2006 revealed that factors contributing to mortality were quite different for adults and nestlings (Work *et al.*

2004; Reynolds and Work 2005; USGS National Wildlife Health Center [NWHC] Honolulu Field Station unpublished data, 2007). Of 21 adult carcasses found during this period for which the cause of death could be determined, 13 mortalities were caused by emaciation and infestation by the nematode *Echinurea uncinata* (echinuriasis) (Work *et al.* 2004; Reynolds and Work 2005; USGS NWHC unpublished data, 2007). Other causes of adult mortality included bacterial infection, botulism, and an unpassed egg (Reynolds and Work 2005). In addition, evidence of echinuriasis was found in three of nine carcasses of immature birds and birds of unknown age that were suitable for exam; the other six were found to be emaciated (NWHC unpublished data, 2007), Work *et al.* 2004; Reynolds and Work 2005). Moulton and Weller (1984) reported adult mortality by intraspecific attack and seabird collision during studies in 1978 and 1979, but no adult carcasses from 1993 or 1998 through 2001 exhibited any signs of trauma. In the summer of 2003, the first case of (adult) mortality due to avian botulism was documented (Reynolds and Work 2005).

Fourteen of 19 ducklings, in contrast, died of traumatic injuries, while four died of emaciation and one of bacterial infection (Reynolds and Work 2005). Aggression has been observed toward ducklings by non-reproductive adult ducks, and rarely, by hens with broods toward a duckling from another brood. Stray ducklings are often bitten or charged if they approach a non-parent (M. Reynolds, pers. obs.). One such attack was suspected to cause duckling mortality (Boswell and Keitt 1995). Attacks on ducklings by adult ducks have been reported in other species in crowded habitats where food may be limited (Pienkowski and Evans 1982). Ducklings also are susceptible to trauma from aggression by albatrosses and other large seabirds, which are abundant on Laysan and at Midway. In 1992 Refuge field staff found 10 ducklings with crushed skulls. Great frigatebird attacks were suspected as the cause of death (Newton and Chapelle 1992). One duck in the first cohort translocated to Midway died of trauma probably inflicted by an albatross (Reynolds *et al.* 2006a).

Duckling mortality also has been ascribed to exposure of ducklings separated from the brood, especially during rainstorms (Moulton and Marshall 1996). Few ducklings died of echinuriasis, pneumonia, or starvation. Some downy-stage duckling carcasses examined contained yolk sac remains, indicating these birds did not die of starvation; exposure was suspected (NWHC unpublished data, 2007).

(ii) Mortality Trends. Brood monitoring data and the age structure of carcasses found incidentally between 1998 and 2000 (n = 86) reveal that downy-stage ducklings are the most vulnerable, especially during the first six days after hatching (Reynolds and Work 2005). Most carcasses (76 percent) found were ducklings in the downy plumage stages less than 18 days old. Duckling carcasses from 1998 through 2001 were found mostly in the spring and summer after the peak of hatching (Reynolds 2002). Of carcasses recovered in 1998 through 2003, adults comprised 17 percent of the specimens, 81 percent of which were females (Reynolds and Work 2005). Most adult carcasses from those years were found in mid- to late summer after the peak of breeding. Adult carcasses during the 1993 die-off were found from August 1993 to January 1994 (Darnall and White 1993; Bauer and Gauger 1994).

5. Population and Species Viability

Elimination or reduction of threats and restoration of a viable population is the recovery goal for the Laysan duck. A viable species is one that will persist over a long period of time (by convention, more than 100 years) and that exhibits resilience to chance disturbances. Viability may be attained by maintaining independent viable populations or by having multiple interconnected populations. In the latter case, none of these populations is necessarily viable by itself, but the constituent populations function collectively as a larger interdependent "metapopulation" (Levins 1968). In an analysis of Hawai`i's historic avian extinctions, the pattern is that species having large, well-distributed populations are most likely to persist over time in the face of multiple anthropogenic threats (Hu 1998). A population that becomes sufficiently reduced in size becomes vulnerable to stochastic forces, a circumstance which often leads to its extinction (Meffe and Carroll 1997).

In recent times, the natural distribution of the Laysan duck was limited to a single island with limited carrying capacity, and the risks to that population are considerable. In addition to protection of the species on Laysan Island, an appropriate management strategy to attain long-term viability for the Laysan duck includes restoration and management of habitat, removal and control of introduced predators in suitable habitats in the Main Hawaiian Islands, and the establishment of additional wild populations that are managed to minimize the risk of inbreeding depression. The growing population at Midway Atoll is the first step toward reducing the risk of extinction to the Laysan duck (see B. Translocation, under Recovery Strategy, below). Ideally, restored habitats would support wild populations without the need for intensive management; however, intensive management will be required in some areas. In these cases, Laysan ducks could be established and managed at one or more suitable sites on other islands while habitat restoration proceeds.

Long-term monitoring from Laysan and data from a well-monitored translocation flock will improve demographic and carrying capacity estimates needed to develop informative models of population dynamics and persistence. Molecular analysis of tissue samples from Laysan and Midway will yield estimates of heterozygosity (a measure of genetic variability). Such heterozygosity values and their correlation with potential indicators of fitness could be included usefully in future genetic models, but it should be noted that such correlations, while informative, may not be definitive (*e.g.*, Balloux *et al.* 2004; Brouwer *et al.* 2007).

(a) Threats to Population Viability.

Extinction can be considered a two-phase process. Primary factors can cause initial population reductions at broad spatial scales (Hu 1998). After populations have declined, secondary threats are likely to affect the species because of its reduced abundance and possibly restricted distribution. Island species are especially vulnerable to anthropogenic extinction because of their particular adaptations, such as reduced reproductive rates, ecological naïvete (*i.e.*, unfamiliarity with mammalian predators), and low resistance to new diseases (Temple 1985).

(i) Primary Threats. The broad causes for bird extinctions have been classified into four main categories: (1) harmful species introductions, (2) human exploitation, (3) habitat loss, and (4) trophic cascades (secondary extinctions; *i.e.*, extinctions resulting from other extinctions) (Diamond 1984 in Hu 1998). The extirpation of Laysan ducks from the Main Hawaiian Islands is estimated to have occurred about 1,500 years ago. Introduction of predatory or competing species, human exploitation, and habitat loss are suspected as the primary factors responsible for the duck's decline. Although we can only speculate about prehistoric human exploitation in the extirpation of the Laysan duck, the devastating effect of introduced rats on ground-nesting Hawaiian birds is well documented (Berger 1981). In a subfossil chronology from Kaua`i, the last stratum containing the bones of Laysan ducks is the first containing bones of rats and other introduced mammals (Burney *et al.* 2001). These subfossil records suggest that the initial dispersal of Polynesian rats (*Rattus exulans*) was more rapid than that of early human settlers (Burney *et al.* 2001), a condition which in turn implies that rats may have been preying on Laysan ducks and other native biota prior to widespread habitat alteration and hunting by a large human population. It is important to note, however, that paleoecological records from the Main Hawaiian Islands yield insufficient detail to ascribe the extirpation of the Laysan duck to any one factor (H. James, Smithsonian Institution, pers. comm. 2006). Predators remain a threat on all of the Main Hawaiian Islands, and additional predators have been introduced since Western colonization, including black rats (*R. rattus*), Norway rats (*R. norvegicus*), house cats (*Felis cattus*), and Indian mongooses (*Herpestes auropunctatus*; Scott *et al.* 1986).

(ii) Secondary Threats. A population that is sufficiently reduced or isolated becomes increasingly vulnerable to secondary threats, and these must be adequately addressed to ensure species viability. These are primarily stochastic threats (the result of chance events), and when they act on a small, localized population, such threats can lead to extirpation or even extinction. Laysan ducks are highly vulnerable to catastrophes, demographic and environmental stochasticity, and may be vulnerable to inbreeding depression (Shaffer 1981; see Genetic Considerations, below). Demographic stochasticity is the effect of random events on the reproduction and survival of individuals, and is usually considered to be a threat only to small populations (Meffe and Carroll 1997). In the case of the Laysan duck, such a chance event might include an uneven sex ratio that leads to increased female mortality from harassment by excess males. Environmental stochasticity refers to random variation in climate or other parameters that affect vital rates of an entire population (as opposed to individuals), such as drought during the breeding season that affects food supply, or heavy rain that floods nests during incubation. The effects of environmental stochasticity are similar whether the population is large or small (Caughley 1994).

Extremes of environmental stochasticity, such as severe storms, droughts, and tsunamis, and of anthropogenic disturbance, such as an introduction of rats to Laysan or sea-level rise resulting from global climate change, may be catastrophic for the Laysan duck under current circumstances. Disease and other anthropogenic threats also pose serious risks (see Current Threats, below). The impact of these threats can be reduced by: (1) creating many populations that are widely distributed to decrease the chance of a catastrophe simultaneously affecting all of them; (2) reestablishing birds on large, high islands, for example, Kaua`i and Kaho`olawe, that provide more protection from storms and sea-level changes; and (3) developing post-disaster contingency plans to restore populations affected by catastrophes.

(iii) Genetic Considerations. The viability of isolated populations may be threatened by genetic stochasticity, especially if numbers are low. Decreasing population size eventually leads to inbreeding, and possibly to inbreeding depression. The risk of inbreeding depression in populations established by translocation is an important topic in conservation biology and merits some discussion here. The effects of genetic drift (changes in allele frequencies through chance fluctuations rather than selection [an allele is an alternative form of a gene that arises by mutation]) is also amplified in small populations. Random mutation can produce deleterious alleles in any population, but such changes may spread rapidly through a small population (Caughley 1994). These genetic effects may increase the vulnerability of a species to extinction by impeding population growth and reducing the genetic variability required to adapt in response to new selective pressures. Genetic variation is the basis for evolutionary potential, and the ability of a species to persist over the long term is closely tied to the reservoir of genetic diversity upon which it may draw to respond successfully to environmental change (Fisher 1930; Allendorf and Leary 1986).

Susceptibility of island species to the negative effects of inbreeding is uncertain. Concerns about the effects of low genetic diversity in Laysan ducks in the source population include diversity further reduced in new populations founded by relatively few individuals, low disease resistance, reduced evolutionary capacity to respond to environmental change, and on an ecological timescale, failure of new populations owing to rapid transmission of existing deleterious alleles or new ones arising from mutation in small founding populations. Preliminary results from studies of individual genetic variation and disease resistance in Hawaiian honeycreepers suggest that birds with greater genetic variation demonstrate higher resistance to an introduced disease, avian malaria (Jarvi *et al.* 2004).

Currently we lack the information necessary to determine the role of genetic management in ensuring the persistence of Laysan duck populations established through translocation. Laysan duck genetics have not been studied, and we currently have no information about past or present genetic diversity in the species. Therefore we do not know how genetically representative new populations are of the source population on Laysan Island, nor what adverse founder effects may have long-term impacts on these new populations. However, we can make some inferences based on the species' prehistoric and modern distribution and on our knowledge of population fluctuation and persistence in recorded history. The Laysan duck likely suffered an initial genetic bottleneck after the species first became isolated on Laysan following human settlement of the Hawaiian Islands, and likely suffered another when numbers fell to only 12 individuals (seven adults and five juveniles) in 1912 during the rabbit infestation of the island (Dill and Bryan 1912). As a result, the species is likely to have a low level of genetic variability overall. Inbreeding depression is often expressed as low reproductive success, reduced hatchability, and decreased disease resistance (Friend and Thomas 1990; Hale and Briskie 2007). We have no indication that Laysan ducks exhibit these signs; moreover, at Midway the Laysan duck has exhibited remarkable plasticity and increase in some vital rates (Reynolds *et al.* 2006a, 2007a, 2008) and numbers there have increased rapidly. However, a comprehensive study of the species' breeding biology has never been conducted, and nothing is known of its disease resistance.

It is likely that many or most deleterious alleles have already been purged as the Laysan duck has traversed successive bottlenecks, and reduced genetic variation may not manifest as inbreeding depression in new populations established on other islands. Indeed, the species' persistence and rebound on Laysan in the wake of successive bottlenecks, and the rapid increase from a small number of founders at Midway suggests that the incidence of deleterious recessive alleles in the species' genome remains low, and retention of the diversity present in the founders of the Midway population is high. A recent study of genetic variation in new populations of another historically "bottlenecked" island species, New Zealand's South Island saddleback (*Philesturnus carunculatus carunculatus*), found that the low genetic variation found in the subspecies was retained through even second- and third-order translocations (Taylor and Jamieson 2008). These translocations gave rise to rapidly growing and self-sustaining populations on islands with sufficient carrying capacity. Pending the results of molecular studies, the Laysan duck appears to have a similar potential for population growth despite its probable low genetic variability;

however, its evolutionary potential to adapt to environmental change or exposure to new pathogens is uncertain.

Genetic samples were collected from approximately 200 wild individuals on Laysan in the years 1998 through 2000, from the 42 ducks translocated to Midway, and from another 25 individuals on Laysan in 2008. Analysis of these and additional samples from Laysan is needed to assess the overall genetic variability in the species and inform management to maintain that variability. Bloodlines representing the highest levels of the genetic variability that exists in the species, if they can be identified, would be desirable to target for founders for new populations or for breeding stock if a captive flock is established.

E. REASONS FOR DECLINE AND CURRENT THREATS

The Laysan duck was included in the original Endangered Species List of 1967 because of its small population size, limited distribution, and dependence on a fragile island ecosystem (USFWS 1967). The threats to the species and its habitat today are the same as in 1967, when the Laysan duck was listed, and in 1982 when the original recovery plan was published (USFWS 1982). Until 1995 the species was believed to be endemic to Laysan Island, but we now have information on the wider historical and prehistoric distribution of the species throughout the Hawaiian archipelago. Discoveries of Laysan duck subfossils on other islands provide justification for reestablishment of the species in portions of its former range as a critical component of recovery (Cooper *et al.* 1996).

1. History of Decline: Range Contraction and Reduced Numbers

Waterfowl were conspicuous casualties of human settlement of the Hawaiian Islands (Williams 1996). The many extinctions documented in the subfossil record include at least eight species of endemic Hawaiian waterfowl, the largest unique assemblage of waterfowl known. Extinct Hawaiian waterfowl include the moa-nalo – large, flightless, and herbivorous duck species – and a large flightless goose (Olson and James 1991). Only three species of endemic waterfowl remain in the islands: the nēnē (*Branta sandvicensis*), the koloa, and the Laysan duck (USFWS 1967). All three species have been listed as endangered since the first list of endangered species was published in 1967.

As described above in the "Prehistoric Distribution and Habitat" section, subfossil remains of Laysan ducks have been recovered on five of the eight major Hawaiian Islands (Cooper *et al*. 1996; see Figure 2). The distribution of these subfossils strongly suggests that Laysan ducks once occurred throughout the archipelago and occupied a wide range of habitats before they were extirpated (in prehistory) from the Main Hawaiian Islands. Paleoecological studies in the Main Hawaiian Islands are ongoing (H. James, pers. comm. 2006) and may uncover additional material that will refine our knowledge of Laysan duck distribution, habitats, and prehistoric decline.

The range of the Laysan duck known from recorded history has been limited to the islands of Lisianski and Laysan. Shipwrecked castaways on Lisianski and visitors to Laysan Island ate Laysan ducks. Reports describe the naïve birds as “tame,” which certainly facilitated their exploitation (Polynesian 1844 in Rauzon 2001; Olson and Ziegler 1995). The Laysan ducks on Lisianski likely disappeared after successive shipwrecks between 1844 and 1846. Introduced mice probably accelerated their decline by competing for food and destroying vegetative cover (Olson and Ziegler 1995).

Since their restriction to Laysan Island, the ducks probably have never been very numerous. In 1891 a visitor to the island described the bird as “not very plentiful” (Rothschild 1893-1900), and 11 years later Walter Fisher wrote “the Laysan duck is, of all the birds on the island, the one most likely to be exterminated when the present favorable regime comes to an end. There are probably less than a hundred of this species now living” (Fisher 1903).

Indeed, the Laysan duck came to the brink of global extinction in 1911 during a period of commercial guano mining by the Northern Pacific Phosphate and Fertilizer Company (Ely and Clapp 1973). Rabbits were introduced to Laysan and Lisianski Islands around 1903. The rabbits overran and devegetated both islands. The Laysan duck nearly disappeared during this period: only seven adults and five juveniles were observed in 1912 (Dill and Bryan 1912). Through a combination of starvation and deliberate eradication, rabbits were eliminated by 1923, and shortly thereafter both the vegetation and the duck population began to recover. By 1957 numbers had climbed to around 500 birds, which seems to approach the present carrying capacity of the island (Moulton and Weller 1984; Moulton and Marshall 1996).

2. Current Threats

The small total number of Laysan ducks and the species’ distribution in two isolated locations with limited carrying capacity are the greatest ultimate threats to this species. The Laysan Island duck population experiences periodic declines in response to chance events, and given the small populations on Laysan and at Midway, such events pose a significant threat to the species’ existence. The most recent major population declines were in 1993, when Laysan Island suffered a severe drought and the ducks experienced an epizootic of echinuriasis (Work *et al.* 2004), and in 2008 when more than 150 ducks succumbed to botulism at Midway (Klavitter and Laniawe 2008). The Northwestern Hawaiian Islands are vulnerable to severe storms, and global climate change could increase the frequency and intensity of storms. Alien plant and insect species continue to invade the islands, and given the frequent vessel traffic in the Northwestern Hawaiian Islands, the likelihood of additional introductions is high, as is the chance of oil spills or other contaminants washing ashore. Parasite outbreaks have occurred on Laysan, and diseases are a potential problem that remains unassessed. Any of the threats described below has the potential to cause the extinction of the Laysan duck (see Population and Species Viability, above; Mangel and Tier 1994; Townsend *et al.* 2000).

The threats to the Laysan duck are classified according to the five factors identified under section 4(a)(1) of the Endangered Species Act in consideration for listing, delisting, and reclassification decisions. These five factors are as follows:

A – Present or threatened destruction, modification, or curtailment of habitat or range;
B – Overutilization for commercial, recreational, scientific, or educational purposes;
C – Disease or predation;
D – Inadequacy of existing regulatory mechanisms; and
E – Other natural or man-made factors affecting the continued existence of a species.

Currently, no threats under Factors B or D affect the Laysan duck; threats under Factors A, C, and E are described below.

Factor A

(i) Alien Species. Nonnative plants, invertebrates, and vertebrates all pose indirect threats to the Laysan duck (Factor A). Introduced plants displace native vegetation, destroying preferred nesting habitat and cover for birds, and may reduce foraging habitat for native arthropods. At least 150 nonnative invertebrates have found their way to Laysan (Morin and Conant 1998; Nishida 1999). Alien invertebrates can directly alter habitat by feeding on native plants that are not adapted to herbivory.

Future accidental introductions also pose a serious risk. Other Northwestern Hawaiian islands have experienced recent invasions of exotic plants, ants, grasshoppers, mosquitoes, spiders, reptiles, mice, and rats, any of which could have severe impacts on the native flora and fauna of Laysan (Conant and Rowland 1994; Morin and Conant 1998). Quarantine measures are in place, but even if strictly enforced, uncontrollable events could result in the introduction of new species to the island. In 1970, for example, a Japanese fishing vessel ran aground on Laysan's southern shore. An investigation of the ship found evidence of rats aboard, though none were ever discovered on the island (USFWS 1982). In the past 20 years, at least 11 vessels have wrecked in the Northwestern Hawaiian Islands; the risk of accidental introductions of alien species is real and unpredictable. In 2000, 10 new species of introduced arthropods (14.3 percent of total species collected) were identified on Laysan from prey samples collected during Laysan duck prey monitoring from 1998 through 2000 (Nishida 2000; Reynolds 2002).

(ii) Filling of Lake and Seeps. Laysan's interior lake and surrounding freshwater seeps have undergone sedimentation exacerbated by the rabbit-caused devegetation and shifting shorelines (Bailey 1919; Wetmore 1925 *in* Ely and Clapp 1973). A similar process took place on Lisianski, as described earlier. Open, devegetated spaces, called "blow-outs," persist on the island today. Small sand storms develop during windy weather, sometimes forming short dunes that drift into seeps and ponds (Morin and Conant 1998). Drifting sands have caused the lake to shrink since the beginning of the 20th century. Maximum lake depth was reported as 9.1 meters in 1859, when the lake had a coral bottom. By 1923 the lake depth was 4.6 meters with a sand bottom, though the depth tends to vary seasonally and with rainfall: in 1986 the maximum depth was 6.5 meters (Ely and Clapp 1973, Lenz and Gagne 1986). Reports described a permanent freshwater pond on the southwestern interior of Laysan until 1923, when it was completely filled by sand. Early visitors to the island noted ducks concentrating in and around the pond (Ely and Clapp 1973). Recent observations show that ducks spend a lot of time foraging at the lake in areas with lower salinity or at freshwater seeps, which have the highest prey densities and are an important source of fresh water for ducklings (see Habitat Use, above). Lower salinity favors the growth and emergence of brine flies, an important prey source for the ducks.

Factor C

(i) Alien Predators. Although introduced mammalian predators are not currently present on Laysan Island or at Midway, these predators contributed to the extirpation of the Laysan duck throughout most of its former range, and they still pose a major direct threat to the recovery of the species. Recovery of the Laysan duck will require reestablishment of the species on at least two of the Main Hawaiian Islands, nearly all of which are inhabited by numerous alien predators, including cats, dogs (*Canis lupus familiaris*), pigs (*Sus scrofa*), mongooses, and several species of rats. Such alien predators have devastating effects on ground-nesting birds (Berger 1981, Scott *et al*. 1986, Burney *et al*. 2001), and adult ducks are vulnerable to predation as well. Laysan ducks are incapable of flight during their annual molt, and having evolved in the absence of terrestrial mammalian predators, they tend to run or freeze in place rather than fly as an escape response.

Ants, which are not native to Hawaiian ecosystems, are extremely destructive to native species and may pose a threat to Laysan ducks, especially to eggs and newly hatched ducklings. Researchers believe big-headed ants (*Pheidole megacephala*) may have caused mortality of nestling Laysan finches (Conant and Rowland 1994).

(ii) Disease. Viruses, bacteria, and invertebrate and fungal parasites can negatively affect bird populations. Depending on its severity, a disease outbreak can become a catastrophe. Waterfowl populations in particular are susceptible to epizootics, in part because these birds are often gregarious or concentrated in a few refuges, thereby facilitating disease transmission (Baldassarre and Bolen 1994). Laysan ducks are known to experience mortality from infection by a parasitic nematode and population-level effects from epizootics involving this parasite (see below), but the threat of other diseases has not been evaluated. Most diseases require a certain proportion of susceptible individuals in order to spread throughout a host population (Townsend *et al.* 2000). Laysan periodically harbors high duck densities, which could provide a threshold for transmission of density-dependent diseases. A severe epizootic could diminish the population to the point at which demographic stochasticity could cause extinction (Mangel and Tier 1994).

Laysan lies in the Pacific flyway and is often visited by continental migratory birds. Migratory waterfowl passing through the island could introduce diseases to which Laysan ducks may have low resistance. Avian malaria, a disease devastating to Hawaiian passerines (songbirds), may have been introduced to the Hawaiian Islands by migratory waterfowl (Warner 1968). Hawaiian birds evolved in the absence of many diseases that are common elsewhere and may have lower resistance compared to their mainland counterparts (van Riper and van Riper 1985; Jarvi *et al*. 2001; Jarvi *et al.* 2004). A new disease introduced to Laysan could cause an epizootic in the duck population. The Laysan duck's susceptibility to duck plague, avian cholera, and other infections that damage waterfowl populations elsewhere is unknown. The accidental introduction of new disease vectors and hosts could be very damaging. Avian botulism, another significant risk to the Laysan duck, is a typically fatal paralytic disease caused by a neurotoxin produced under warm, protein-rich conditions by the bacterium *Clostridium botulinum*, which is commonly found in soils. Waterfowl and other birds ingest the bacteria, and the toxin, incidentally while foraging. The first documented case of avian botulism in the Laysan duck was discovered in the carcass of an adult duck from Laysan in 2003 (Reynolds and Work 2005). A major outbreak of botulism at Midway in August of 2008 resulted in the death of more than 150 ducks (Klavitter and Laniawe 2008). This outbreak necessitated a review of water management at Midway to facilitate efficient response and minimize the risk of such high mortality in a future event. Such epizootics potentially could devastate a Laysan duck population, and selection of future translocation sites must include evaluation of how this threat may be managed or mitigated.

Echinuria uncinata, a nematode (roundworm) that infests the proventriculus (gizzard), can be extremely pathogenic to waterfowl, although susceptibility varies among species. This parasite causes tumor-like nodules on the proventriculus, resulting in blockage and compaction of the digestive tract (Cornwell 1963). Laysan ducks are susceptible to *E. uncinata* infestations. In other ecosystems, various crustaceans may serve as intermediate hosts for this parasite, including amphipods (*Gammarus* spp.), isopods (*Asellus aquaticus*), cladocerans (*Daphnia* spp.), and conchostracans (*Lynceus brachyurus*) (Austin and Welch 1972; Anderson 1992), but the intermediate host on Laysan is unknown. Some of these aquatic invertebrates occur at Midway and throughout Hawai`i, but in the archipelago *E. uncinata* is known only from Laysan (T. Work, pers. comm. 2005). In Europe and North America, *E. uncinata* infestations occur in stagnant freshwater pools with high waterfowl densities (Cornwell 1963; Austin and Welch 1972). Laboratory studies of infected mallard ducklings demonstrated that birds stressed by crowding had larger parasites and higher parasite loads (Ould and Welch 1980). On Laysan, an outbreak of echinuriasis in 1993 that coincided with drought and high density of ducks resulted in a die-off of 75 percent of the population (Work *et al.* 2004). It is likely that only one or two stagnant freshwater seeps were available to the birds; crowding around these resources may have increased disease transmission (Friend and Franson 1999). During the epizootic, which lasted from August 1993 to January 1994, the carcasses of 48 adult ducks were found around the lake. Starvation and echinuriasis were identified as the causes for mortality in nine of 13 specimens examined (Work *et al.* 2004). It is estimated that the Laysan duck population dropped from more than 600 to fewer than 100 adult birds during this time period (David and Hunter 1994; Reynolds 2002).

The prevalence of parasitic nematodes in the population is unknown, but such nematodes have been associated with adult or duckling mortality in 1993, 1998, and 1999 (NWHRC 1993, 1998, 1999, 2000). Fresh fecal samples (n = 26) collected from 20 live birds in the years 1998 through 2000 were screened for parasites. Preliminary analysis showed that four of these birds (27 percent of samples) were infected with *Echinuira uncinata*. Tapeworm (class: Cestoda) eggs were found in 18 birds (81 percent of samples) (USGS, unpublished data). Eggs of four unidentified parasite taxa were also detected (Work *et al.* 2004). Additional sample analysis and research is needed to assess the occurrence and prevalence of echinuriasis and other parasites in the Laysan duck and evaluate their potential impacts.

Factor E

(i) Alien Competitors. An introduced vertebrate, the snake-eyed skink (*Cryptoblepharus* spp.), may adversely affect native invertebrates and be a food competitor (Morin and Conant 1998). The role of introduced predatory arthropods and their competition for terrestrial prey has not been studied on Laysan.

(ii) Contaminants. Pacific Ocean currents often carry debris to Laysan's shores. In 1988 a contaminated site (known informally as the "dead zone") was discovered on the island's northern coast. Dead insects, crabs, and birds were recorded within the zone's perimeter (Morin and Conant 1998), including one Laysan duck in 1987 (B. Becker, National Marine Fisheries Service, pers. comm. 2002). A container of the pesticide carbofuran was identified as the cause. The contaminated substrate was excavated and removed from the island in 2002 (L. Woodward, U.S. Fish and Wildlife Service, pers. comm. 2002).

Oil from spills has also washed up on the island. The most recent known spill was in the winter of 2000, when numerous tar balls were seen on the western coast. That winter eight oiled birds were found on the island: seven Laysan albatross (*Phoebastria immutabilis*) and one red-footed booby (*Sula sula rubripes*) (Eggleston and Gellerman 2000). Although no Laysan ducks were known to be affected by that spill, an oiled Laysan duck was seen in 1999 (M. Berry, pers. comm. 1999; M. Reynolds, pers. obs.). Future contaminants washing ashore could pose a serious threat to the Laysan duck. Even small amounts of contaminants can affect vital rates through decreased egg production, reduced fertility and hatchability, and lower sperm counts (USFWS 1987).

(iii) Global climate change and sea level rise. Because Laysan is a low island (12 meters [40 feet] at its highest point) it is especially vulnerable to sea-level rise. Atmospheric temperatures are expected to increase between 1.4 and 5.8 degrees Celsius (2.5 and 10.4 degrees Fahrenheit) in the next century, with a concomitant rise in sea level of 21 centimeters (8.3 inches) by the year 2050 (IPCC [International Panel on Climate Change] 2001). An examination of topographic models of the Northwestern Hawaiian Islands under various scenarios of sea-level rise (Baker *et al.* 2006) suggests that some islets, such as those comprising Pearl and Hermes Reef and French Frigate Shoals, will lose considerable land area or disappear entirely. The elevation of Laysan and of Midway is predicted to result in longer persistence of these land masses relative to other low islands in the chain (Baker *et al.* 2006), but this analysis did not include secondary effects of sea-level rise, such as increased salinity of ground water, that would have significant negative effects on habitat for Laysan ducks at Laysan and Midway. Another anticipated effect of global climate change is increased frequency and severity of storms (IPCC 2001; see Storms section, below), which could reduce survival and nesting success.

(iv) Field camp on Laysan. A permanent field camp is set up on the northwestern coast of the island. Staff must be cautious in their use of pesticides and monitor the effects of water use and discharge on the island's aquifer. Hens that nest in *Eragrostis variabilis* near camp may lead ducklings into camp; therefore, staff should always be aware of ducks in camp and take care not to disturb or fragment broods.

(vi) Human Disturbance and Interaction at Midway. Activities associated with refuge management and infrastructure maintenance at Midway Atoll may pose a threat to Laysan ducks. Some habitat restoration projects in the atoll involve the use of herbicides or other toxicants that may adversely affect ducks if they are exposed. Heavy equipment and other vehicles are used on a regular basis, especially on Sand Island, for a wide range of projects, and mortality from vehicle strikes is possible, although to date such mortality has not been observed. The human population in the atoll is approximately 65, plus roughly 15 visitors each week, and activities involving foot traffic as well as vehicle traffic have the potential to disturb ducks that are incubating eggs or tending young broods, which can result in abandonment. To minimize the likelihood of these threats posing a risk to the Laysan duck at Midway, all programmatic activities in the atoll that may affect Laysan ducks currently are under review through the Endangered Species Act section 7 consultation process.

(v) Environmental Catastrophes. Catastrophes are rare, irregularly-occurring events that may cause extreme changes in populations. The Laysan duck is currently vulnerable to at least three types of environmental catastrophes: severe droughts, major storms (such as hurricanes), and tsunamis. These are described in the following paragraphs. In addition, any of the diseases or anthropogenic threats described above could be catastrophic if severe enough.

Population monitoring from 1991 through 2001 suggests that droughts negatively affect reproduction and, sometimes, adult survival. El Niño Southern Oscillation events can disrupt normal rainfall patterns, causing droughts in some years. El Niño Southern Oscillation events in 1987, 1993, 1998, and 2002 resulted in droughts on Laysan that caused reproductive failure or poor reproductive performance (Marshall 1989; Reynolds 2002; Agness and Payne 2002). In 1993, during a period of high population density, Laysan experienced its worst drought in 20 years, resulting in a severe die-off of adult birds (see Disease section, above). Lake levels shrank to their lowest levels since 1973 (USFWS data). Not only would fresh water availability be limited, but the abundance of the arthropods that form the bulk of the Laysan duck's diet would be sharply reduced under such drought conditions.

Tropical depressions and hurricanes are frequent events in the central Pacific Ocean. Most of the Northwestern Hawaiian Islands are low-lying and lack protection from high winds and waves. A hurricane could devastate ducks on these islands, as well as in coastal areas in the Main Hawaiian Islands. Storms have reduced breeding success on Laysan in recent years (Moulton and Marshall 1996; Reynolds 2002).

(vii) Tsunamis. Tsunamis are series of long waves generated in a body of water by an impulsive disturbance, such as an earthquake, volcanic eruption, or landslide. Tsunamis occur in all oceans but are most common in the Pacific because of the high level of tectonic and other seismic activity in the region. The last significant, Pacific-wide tsunami occurred in 1964. Tsunamis travel rapidly (up to 805 kilometers [500 miles] per hour) across the open ocean and upon reaching land can develop wave heights of up to 16.6 meters (55 feet; Pacific Tsunami Museum 2001). A wave of that magnitude would be higher than most of the Northwestern Hawaiian Islands. Though no records exist of tsunamis yet hitting the island (a warning of a tsunami likely to hit Laysan was issued in 2003), the possibility further emphasizes the risks faced by the Laysan duck, which survives today only on low, coralline islands.

II. RECOVERY STRATEGY

The greatest current threat to the Laysan duck is its small total population size and distribution limited to two locations on low-lying islands that are vulnerable to catastrophic events. Ensuring the long-term viability of the Laysan duck depends upon (1) maintaining the source population and its habitat on Laysan Island, (2) maintaining the new population at Midway and improving habitat there, and (3) establishing the species on additional islands. The immediate goal is to reduce the threats to the Laysan duck to the point that we can consider downlisting the species from endangered to threatened status. The long-term goal is to recover the species; that is, to ensure that the threats to its persistence have been reduced so that it no longer requires protection under the Endangered Species Act and may be delisted. This plan outlines the recovery actions that will reduce the risk of extinction for the Laysan duck by addressing the threats to the Laysan population, protecting and enhancing habitat quality, and reestablishing additional wild populations on other islands that are managed to ensure the long-term viability of those populations.

A. PAST AND CURRENT CONSERVATION MEASURES

A comprehensive restoration plan has been developed for Laysan Island (the Laysan Island Ecosystem Restoration Plan) that details the measures necessary to restore the ecosystem: weed control; alien invertebrate identification and control; vegetation, invertebrate, and vertebrate monitoring; propagation and outplanting of native plants; plant and invertebrate restoration; pollen core studies; vertebrate restoration (including the Laysan duck); and snake-eyed skink eradication (Morin and Conant 1998). Funding, time, and logistical constraints have prevented initiation of most of these projects, although some are underway. This section presents those restoration projects and monitoring efforts designed specifically for the Laysan duck. Recommendations for further recovery actions specifically geared to benefit the duck are presented in later sections of this recovery plan.

1. Laysan Duck Population Monitoring

The Laysan duck is a difficult species to monitor (Sincock and Kridler 1977). The duck’s nocturnal and cryptic habits and seasonal differences in their use of the lake contribute to the difficulty of estimating the population size. Line transect methods are unsatisfactory because of the negative impact on the ducks (*e.g.*, flushing incubating females from nests, leaving eggs vulnerable to predators; Marshall 1992b) and the tendency to underestimate the population size (Sincock and Kridler 1977; Moulton and

Weller 1984; Marshall 1992b). Other negative effects of line transects include the inadvertent destruction of seabird burrows and disturbance of other ground-nesting birds.

Lake counts on Laysan were used to generate an index of the population size in the last century and as recently as 1998. Although not an effective method to estimate population size because use of the lake by Laysan ducks is seasonally and environmentally variable, these lake counts do provide an index of fluctuation in the population (Seavy *et al.*2009) and therefore are an efficient and useful tool for monitoring gross changes in numbers. . Marshall (1992b) and others determined that the most accurate way to estimate the population size is by calculating ratios of marked to unmarked ducks at the lake at dusk. This method requires that a portion of the population be marked. Fall and winter yield the highest numbers of lakeside ducks for population estimates, although year-round monitoring is useful (Reynolds 2002). Intensive banding was conducted most recently in 2004 and 2005, in order to follow broods and individual juveniles in preparation for translocation. A percentage of the Laysan duck population on Laysan currently is marked with color bands. Individuals have unique band combinations.

The geographic isolation of the Laysan ducks on small islands (Laysan and Midway) makes the species well suited to a mark-resight method of population estimation (Lincoln-Peterson Index; see Table 2) because the population meets the "closed population" assumption of such a model. There is no possibility of emigration or immigration, and during intensive monitoring and with high adult survivorship in this species, the mark-resight methods also meet the assumption of no births or deaths during the sampling period (Bibby *et al*. 1992).

Two monitoring methods are now used twice each month on Laysan Island to generate data that can be used in calculating Lincoln-Peterson estimates and measuring other population parameters: census walks and resighting surveys. Field staff determine the ratio of marked to unmarked Laysan ducks during a 1-hour census walk around the lake before sunset (Marshall 1992b). Birds are recorded as banded, unbanded, or unknown. The numbers of broods and ducklings and the age class of ducklings are recorded. Band reading is conducted for one to two hours before sunset. Observers note the sex and band combination of each bird. All ducklings and hens are identified, and the ducklings are assigned an age class.

Along with the census walks, individual survival histories are used to determine the number of marked individuals in the population for Lincoln-Peterson estimates. Resighting surveys provide data that can be used to determine population parameters such as survivorship, sex ratio, individual histories, brood production and breeder identification.

A protocol to monitor the status of the duck population at Midway is under development. This project includes mark-resight methods to determine detection probabilities for comparison with all-wetland counts, and to calculate an initial population estimate.

2. Ecosystem Conservation and Monitoring

(a) Weed control and vegetation monitoring.

In 1991 we initiated a program to eradicate the nonnative grass *Cenchrus echinatus* on Laysan Island. Full-time crews of one or more technicians have maintained these eradication efforts year-round. *C. echinatus* is highly invasive, forming dense mats that crowd out the native bunchgrass *Eragrostis variabilis*, which is the preferred nesting habitat for the duck on Laysan. Eradication efforts have been highly effective. No *C. echinatus* has been found on Laysan since April 2002 (C. Rehkemper, USFWS, pers. comm. 2008).

Beginning in 1999, seeds of the endangered plant *Mariscus pennatiformis* ssp. *bryanni* were collected and propagated on Laysan. Seeds and cuttings of another endangered plant, *Chenopodium oahuense,* also were gathered. Seeds of the native palm *Pritchardia remota* were obtained from Nihoa Island and taken to Laysan for propagation, and work has begun on the propagation of the bunchgrass *Lepturus repens* (Depkin and Lund 2001). Current native plant propagation efforts on Laysan include the following species: *Capparis sandwichiana, Chenopodium oahuense, Lepidium bidentatum* var. *o-waihiense, Lepturus repens, Mariscus pennatiformis* ssp. *bryanni*, *Pritchardia remota, Santalum ellipticum,* and *Solanum nelsonii*.

At Midway Atoll, extensive habitat restoration was undertaken in preparation for Laysan duck reintroduction, including propagation and outplanting of native species such as *Eragrostis variabilis*, *Scaevola sericea*, and various sedge species.

(b) Invertebrate monitoring.

Arthropod sampling and identification were conducted opportunistically in 1999 and 2000 by Nishida (1999, 2000). Continued incursion of alien arthropods was documented.

In 2007, extensive invertebrate sampling was conducted on Laysan as part of efforts to characterize habitat for future translocation of the endangered Nihoa millerbird (*Acrocephalus familiaris*) to the island (MacDonald 2008). These collections, when analyzed, may provide additional information about the available prey base for Laysan ducks.

(c) Ant control experiment.

A pilot project to remove introduced ants from Spit Island, Midway Atoll, was conducted in 2001 and 2002. Fire ants (*Solenopsis geminata*) were thought to be eliminated but began to reappear 1 year after the pesticide was applied (C. Swenson, U.S. Fish and Wildlife Service, pers. comm. 2002). As Midway is a reintroduction site for the Laysan duck, the successful eradication of fire ants would be beneficial to the success of that program. Methods to eradicate ants from other islands would improve opportunities for ecosystem restoration, which would also benefit Laysan ducks.

(d) Mosquito control at Midway.

Mosquito control on Sand Island at Midway has been underway since the fall of 2003 (J. Klavitter, Midway Atoll National Wildlife Refuge, pers. comm. 2009). The primary breeding sites for the insects are the sewer and septic tanks of the waste water system. Secondary sites include discarded metal and wood holding water in the junkyard near the Seaplane Hangar, abandoned buildings with leaky roofs, and the drinking water storage tanks. In the spring and summer of 2003 the mosquito population was observed to be relatively high, as evidenced by several thousand Laysan albatross chicks with severe infections of avian poxvirus, which is spread by mosquitoes. In the fall of 2003, shade cloth was used to create physical barriers to prevent mosquitoes from accessing the waste water and drinking water systems in an effort to prevent breeding. In addition, the majority of items holding standing water in the junkyard and in abandoned buildings were removed or permanently drained. After management actions were performed, mosquito numbers have decreased dramatically as has the incidence of avian pox in Laysan albatross. From 2004 to the present, fewer than 100 albatrosses each year have been affected by pox.

As a precaution to prevent mosquitoes from breeding in the wetlands created in preparation for Laysan ducks, mosquito fish (*Gambusia* sp.) were introduced to approximately one-third of the wetlands beginning in 2003, and "mosquito dunks" (*Bacillus thuringienis israelensis*) were used in the remaining wetalnds. This management was effective and was used until 2006. After 2006, mosquito dunks were not needed; the population of Laysan Ducks rapidly increased and now appear to be effectively controlling mosquitoes in the wetlands.

(e) Lake and brine fly sampling.

Every other week the salinity, water temperature, and water depth are measured in the lake at the permanent depth gauge along the east edge, as well as in two adjacent freshwater seeps (USFWS 2001). Brine flies are monitored as an index of food abundance for the duck. Fly abundance at the lake serves as a predictor of duck breeding.

3. Captive Populations

In the late 1950s, 33 ducks were removed from Laysan and transferred to captive breeding facilities around the world. Offspring from those birds were used to found a colony at the former Pohakuloa Endangered Species Facility in Hawai`i, and seven wild Laysan ducks were later added to that flock in an effort to improve breeding. This program was discontinued in 1989 because of costs and because at that time, prior to the discovery of subfossils throughout the Hawaiian Islands, little justification existed for releasing Laysan ducks on other islands. Some of the birds were shipped to mainland facilities, and individuals older than 8 years were euthanized (Reynolds and Kozar 2000b).

The birds produced by mainland zoos were deemed unsuitable as candidates for reintroduction to the wild because of the potential loss of adaptations for life in the wild (McPhee 2003) and loss of genetic diversity (Frankham 1995) as well as poor breeding records, the possibility of hybridization in captivity (Reynolds and Kozar 2000b), and the risk of introducing new pathogens and parasites to wild Laysan ducks. Surveys of zoos and private collections in 1999 indicated that 211 Laysan ducks were held in 32 collections worldwide, all descended from fewer than 19 founding pairs (Reynolds and Kozar 2000b). Initially, birds bred well in captivity, but over time breeding success has decreased, possibly as a result of inbreeding depression. Average clutch size for captive broods declined from 7.3 eggs in 1984 (Marshall 1992; Moulton and Marshall 1996) to 4.9 in 1999 (Reynolds and Kozar 2000a). Some captive populations may also suffer from genetic "pollution"; birds have been kept in mixed flocks, and Laysan ducks in three facilities are known to have hybridized with a koloa, a northern shoveler (*Anas clypeata*), a cinnamon teal (*Anas cyanoptera*), and a wood duck (*Aix sponsa*). Only 15 percent of facilities surveyed kept pedigrees for their Laysan ducks (Reynolds and Kozar 2000a). For additional discussion, see Hybridization and Introgression section below.

4. Pearl and Hermes Reef Translocation

Aware of the threats facing the Laysan duck, 40 years ago biologists attempted to establish a new population on Pearl and Hermes Reef, approximately 440 kilometers (273 miles) northwest of Laysan (see Figure 2). In March of 1967, five males and seven females were captured on Laysan Island and transported to Pearl and Hermes Reef for release. The first two birds released flew directly out to sea and disappeared. The remaining 10 ducks had their wings clipped to prevent flight until after the annual molt (Berger 1981). An expedition in May discovered two dead Laysan ducks, cause of death unknown. In July a female was found incubating a nest of six eggs, but the nest later failed. Only two ducks were seen during a visit to the island in September of that year, and none were seen on successive trips (Sincock and Kridler 1977). Inadequate monitoring of the released birds prevented identification of causes of mortality. However, a combination of factors probably doomed the effort: the marginal habitat and lack of permanent sources of fresh water, small number of founding birds, and random factors. No further translocations were attempted until the 2004 translocation to Midway.

5. Midway Atoll Translocations

In the 2004 and 2005 breeding seasons, duck broods on Laysan were closely monitored and juvenile ducks selected as candidates for translocation to Midway. These ducks were fitted with radio transmitters so that their condition could be tracked through the summer and fall, and to facilitate their capture in early October. Twenty and 22 ducks were successfully moved from Laysan to Midway in 2004 and 2005, respectively. Following the 2-day trip by sea, the ducks were placed in field aviaries to ensure their recovery to pre-capture body condition, acclimate them to their new home, and familiarize them with local food sources. After several days, ducks were released two or three at a time into wetlands created for them. In 2005, seven months after the first translocation, the first Laysan duck nests were found at Midway. Successful breeding seasons in 2005, 2006, and 2007 led to rapid growth of the population. As of 2007 Midway harbored an estimated 200 Laysan ducks (Reynolds *et al.* 2007a), and the 2008 breeding season produced a large number of fledged juveniles as well. Unfortunately, a botulism outbreak in August of 2008 resulted in the loss of more than 150 ducks at Midway, and although at this writing it is generally agreed that the refuge harbors at least 200 ducks, we do not have a new estimate of population size in the atoll. This event has necessitated a re-evaluation of wetland management at Midway to facilitate rapid response to future botulism outbreaks and minimize the mortality of Laysan ducks.

The translocation protocols were designed to address the issues discussed in the previous section. Some analyses of reproductive, demographic, and other data collected during radio-tracking and other monitoring efforts at Midway have been provided in reports by the USGS Pacific Island Ecosystems Research Center (*e.g.*, Reynolds *et al.* 2006a) and peer-reviewed publications (*e.g.*, Reynolds *et al.* 2007a, 2008); more are forthcoming.

B. TRANSLOCATION: A PRIMARY RECOVERY TOOL

Translocation is the deliberate release of animals to the wild to establish, reestablish, or augment a population (Griffith *et al.* 1989). It is used as a conservation tool to mitigate threats to a species by placing individuals at locations that are free of those threats, as a short-term or long-term means of increasing a species' chance of survival, or as part of a program to restore a particular biotic community. There is an urgent need to translocate Laysan ducks to additional islands and establish new populations, especially for the first two of these reasons. The restoration of the Laysan duck as a component of the native ecosystems on these islands is also desirable.

1. Justification for Translocation within Hawai`i

The discovery of Laysan duck bones on the Main Hawaiian Islands and our knowledge that the species previously inhabited Lisianski Island provide a sound biogeographic foundation for reintroducing the Laysan duck to additional islands throughout the archipelago (Olson and Ziegler 1995; Cooper *et al.* 1996). Ecosystem restoration and the reestablishment of wild Laysan ducks on other islands are needed to reduce the risk of extinction. Reintroduction of the Laysan duck also would represent the restoration of a missing component of the Hawaiian avifauna on these islands. The restoration of Laysan ducks to additional islands will reduce the risk of extinction from events and processes that may affect the species in the two locations in the Northwestern Hawaiian Islands where it presently occurs and restore the species to ecosystems where it previously existed.

The Laysan duck has proven to be an excellent candidate for translocation. The species is adapted to a harsh environment, flexible in its foraging and breeding behavior, large enough to carry radio transmitters with high battery capacity (to facilitate monitoring of released birds), and the flight feathers can be trimmed to prevent dispersal from the release site. On a predator-free island, clipping flight feathers does not compromise the duck's survival, foraging, or breeding, and the feathers are replaced with the next molt. With adequate food, water, cover, and protection from mammalian predators, the Laysan duck breeds well in the wild. The birds are unlikely to affect rare invertebrates at translocation sites because the ducks seem to select the most abundant prey available (Reynolds *et al.* 2006b).

2. Hybridization and Introgression

Hybridization is the interbreeding of individuals from genetically distinct populations, and introgression is gene flow between populations of individuals that hybridize (Rhymer and Simberloff 1996). There is some concern that Laysan ducks might hybridize with koloa or mallards. Hybridization and introgression with mallards has contributed to the decline of other duck species in New Zealand, Australia, and Hawai`i (notably the koloa; Rhymer and Simberloff 1996). However, Laysan ducks are genetically distinct from mallards and koloa (Rhymer 2001), and they may have co-existed with koloa on the main islands in the past, factors that suggest Laysan ducks are less likely to hybridize in the wild (Reynolds and Kozar 2000a; Pratt and Pratt 2001), although they may hybridize in captivity. As a precaution, however, mallards should be eliminated at translocation sites to prevent hybridization or competition of mallards with either of the native endangered duck species. A multi-agency group is developing a comprehensive statewide approach to the feral mallard problem, and research is currently underway to develop reliable criteria for distinguishing between koloa, hybrids and female mallards. A program to remove feral mallards and hybrids, including public education and outreach, will be proposed by the group once identification and removal methods have been refined and tested in the field.

3. Source Population

The existing captive flocks of Laysan ducks are unsuitable for release into the wild for several reasons: (1) the pedigrees of these birds are unknown because studbooks have not been maintained; (2) careful breeding to maintain genetic diversity has not taken place; (3) these captive populations have become increasingly adapted to captivity over multiple generations (more than 40 years); (4) captive ducks on the mainland may be reservoirs for diseases to which Hawaiian birds have no immunity; and (5) captive Laysan ducks kept in mixed-species flocks have been documented to hybridize with other species (see Prospects for Reintroduction of Captive Birds, below). Unless a new captive flock is created that is managed specifically for the purpose of establishing additional wild populations, only wild-source individuals should be used for translocation (Reynolds and Kozar 2000a). Translocation success with wild-caught animals often is greatest when animals are removed from high density and increasing source populations (Griffith *et al.* 1989). These conditions are rare for endangered species, but such conditions do occur periodically on Laysan Island.

Of primary concern to managers, then, is the population trend on Laysan and whether the population can withstand the removal of individuals to reestablish the species elsewhere in Hawai`i. For the first translocations, to Midway, the best age class and the number of ducks to remove from the source population were explored with population simulations for several removal scenarios using the RAMAS AGE program (version 2.0; Reynolds and Kozar 2000a). The program simulates age-structured population fluctuations and can be applied to predict population size and persistence. Simulations incorporating translocation removals show that removal of up to 20 percent of juvenile birds for 5 years had the least significant impact on population projections. Removal of breeding birds accelerated the time to extinction and caused a greater decline in the population than removal of juveniles. Removal of adult females from Laysan, especially during periods of lower population density, could exacerbate decline in the source population by decreasing production. Therefore, only juvenile ducks should be removed from Laysan Island, and they should be removed during periods of high density or population growth to avoid adverse effects to the source population.

Duckling mortality on Laysan is often attributable to trauma, and is correlated with the density of adult females (Reynolds and Work 2005, Reynolds *et al.* 2007). Thus, limited brood rearing habitat is suspected to increase mortality from overcrowding, potentially contributing to the density dependence that has been observed in population fluctuations (Seavy *et al* 2009). Habitat enhancement and other management should be explored to increase duckling survival and to provide more juveniles for translocation.

4. Founding Population

Translocation of fledged juveniles from different broods is ideal to maximize the genetic representation of the species in the new population. The genetic variability in Laysan ducks is presumed to be low, but currently we have no data to validate that assumption.

The age and sex of the translocated birds are important variables in producing a self-sustaining population. As mentioned above, fledged juveniles are the preferred candidates for translocation, based on population viability analysis and the behavior of birds during the 2004 and 2005 translocations to Midway. Also, an equal or slightly male-biased ratio would be preferable, as a slight bias toward males promotes male-male competition and female choice, an important stimulant for breeding activity in many dabbling duck species (McKinney and Brewer 1989).

Birds selected for translocation should be treated for echinuriasis and other diseases before removal to the transfer sites. *Echinuria uncinata* is unknown in waterbirds in the Main Hawaiian Islands, and the risk to those species would be substantial if juvenile birds from Laysan harboring the parasite were transferred to the main islands either for release or for propagation of a captive flock (T. Work, pers. comm. 2002). The anti-parasite medication ivermectin is known to eliminate nematodes in other waterfowl, and has been used successfully in other endangered duck species during translocation in New Zealand (Gummer 1999).

When logistics permit, the ideal release procedure includes a period of acclimation in an on-site enclosure. This type of release may restore loss of body condition during interisland transport, may encourage recognition of novel prey, and improve site fidelity (Kleiman 1989). An aviary on or near the release site is ideal for temporarily housing translocated birds. Laysan ducks are known to be aggressive towards one another, and separate pens may be necessary for some individuals.

On Laysan, reproduction is highly variable, and few or no ducklings are produced in some years, so planning for multi-year translocations may be required. The target number of founders for Midway was 50 individuals; this number was thought to be a reasonable minimum to reduce the risk of inbreeding depression and improve the chances of establishing a healthy, growing population (USFWS 2004). Of the original 42 founders, only about 25 of these, and fewer females than males, are known to have bred. Nonetheless, the rate of population growth at Midway (see Reynolds *et al.* 2007a) suggests that this number was sufficient to establish a healthy, self-sustaining population. Post-hoc analyses of translocations of other island species provide corroboration for this conclusion. Study of a similar situation (small number of founders, strongly male-biased sex ratio) in a translocated population of New Zealand robins (*Petroica australis*) determined that supplementation with additional founders was not necessary (Armstrong and Ewen 2001). The study of genetic variability and success of translocations in the South Island saddleback described above (Taylor and Jamieson 2008; see the Genetic Considerations section) suggests that, although more founding breeders is preferable to fewer, target numbers of individuals for founding new populations of wide ranging and genetically diverse (*e.g.*, continental) species may not apply to island species that already have undergone multiple, severe bottlenecks.

Supplemental translocation may occasionally be required in reintroduction programs to ensure population persistence by increasing population growth, responding to a catastrophic decline, and/or maintaining or improving genetic variability. However, the status of the nascent population and necessity of such additional translocations must be assessed before undertaking them (Armstrong and Ewen 2001). It is important to consider the potential for translocations of additional founders not only to be unnecessary, but to result in the use of scarce conservation resources that would be better applied to other projects (Armstrong and Seddon 2008). In the case of the Laysan duck, translocation is a costly undertaking that necessitates trade-offs on other fronts. We acknowledge that declaring the Midway translocation a complete and unqualified success is premature (*e.g.*, Seddon 1999); we don't know what threats to this new population may crop up in the future. For example, although we were aware of isolated cases of botulism in migratory birds at Midway, we could not have predicted an outbreak in Laysan ducks of the magnitude that occurred in August of 2008. However, based on initial assessments of the translocation (Reynolds *et al.* 2006a, 2007a), the Laysan ducks at Midway do not appear to exhibit demographic indications (*i.e.*, slow or no population growth owing for example to reduced hatchability or reduced duckling survival) that additional translocations are necessary now to ensure the population's persistence (B. Bowen, University of Hawaii, pers. comm. 2008).

5. Selecting and Evaluating Release Sites

For a translocation to be successful, the primary threats that led to the species' initial decline or extirpation must be controlled. Poor habitat quality is the most common reason for the failure of translocations (Griffith *et al.* 1989; Veitch 1995). In the case of the Laysan duck, mammalian predators on the main islands need to be controlled at proposed translocation sites. Sufficient food, water sources, vegetative cover, and breeding sites also must be available at the release location. Each site must be carefully evaluated for the presence and quality of these resources, and appropriate restoration or enhancement, as well as predator removal or control, is a prerequisite for translocation. Translocation plans for each proposed restoration island or site should be developed to suit the logistical feasibility of the site and the status and availability of source birds.

The presence of mammalian or other introduced predators will seriously jeopardize the success of any translocation effort (Armstrong and McLean 1995; Veitch 1995; Towns *et al.* 1997). Only habitats where mammalian predators are absent or sufficiently controlled should be considered for translocation sites. Possible methods for control of predators at translocation sites in the Main Hawaiian Islands include fences, toxicants, trapping, and shooting, or some combination of these. Predator exclusion fences are under development but not yet in regular use in Hawai`i; research and trials are taking place, however, in Hawai`i, New Zealand, and elsewhere in the Pacific. In addition, even the predator-free Northwestern Hawaiian Islands will require varying degrees of restoration in the form of pest and weed control, or freshwater seep creation or restoration. Depending on the condition of the release site and the status of resources necessary to support Laysan ducks (fresh water, prey base, vegetative cover), translocation of ducks to a temporary aviary setting prior to release can occur simultaneously with some habitat restoration efforts. Intensive management of Laysan ducks at translocation sites, such as the provision of supplemental food and water, may be required until habitat restoration efforts are complete.

Literature reviews and site visits to areas where Laysan ducks might be reintroduced were conducted in 1998 and 1999 (Reynolds and Kozar 2000a). Biological characteristics and non-biological suitability features of these sites are summarized in Appendices 1 and 2. Biological factors considered included habitat assessment, vegetation characteristics, invertebrate abundance, fresh water presence or absence, potential predators, and the need for restoration and/or predator control efforts. Non-biological features included physical characteristics of the island, logistical feasibility (*e.g.*, ease of post-release monitoring), and existing infrastructure or management. Twelve Northwestern Hawaiian Islands and eight Main Hawaiian Islands were assessed in terms of their suitability for the reestablishment of the Laysan duck (Appendix 1). Of the 20 islands considered, eight sites were judged to be promising potential translocation sites in the short- to medium-term: Midway Atoll National Wildlife Refuge, Lisianski Island and Nihoa Island (Hawaiian Islands National Wildlife Refuge), and Kure Atoll (State of

Hawaii) in the Papahānaumokuākea Marine National Monument (Northwestern Hawaiian Islands), and the islands of Kaho`olawe and Kaua`i in the Main Hawaiian Islands (Appendix 2). Descriptions of all eight sites and brief discussions of their biological and physical suitability and management needs are presented in the next section.

In 2003, 13 scientists and land managers participated in a structured ranking of these sites to determine an initial location where Laysan duck translocation would be most feasible, cost effective, and likely to succeed. Logistical feasibility and cost are especially critical considerations in the remote Northwestern Hawaiian Islands, and these factors weighed as heavily as biological suitability in the site ranking.

Through this process, Midway Atoll was identified as the best site for trial releases of Laysan ducks, and two translocations were carried out, as described in the previous section, "Past and Current Conservation Measures." Here we provide additional details about our evaluation of Midway as a translocation site, and of current concerns now that Laysan ducks have become established there. This discussion provides an example of the process and types of considerations that would be undertaken for any release site.

Midway Atoll lies at 28° 12' N, 177° 22' W, approximately 1,840 kilometers (1,143 miles) northwest of Honolulu (Figure 1). The atoll's land area covers 625 hectares (1,544 acres) and is composed of two main islands, Sand Island (467 hectares [1,154 acres]) and Eastern Island (156 hectares [385 acres]), and a smaller islet, Spit Island (2 hectares [5 acres]). Like Laysan, Midway Atoll is a National Wildlife Refuge managed by our agency and, with its surrounding waters, is included in the Papahānaumokuākea Marine National Monument, co-managed by our agency, the National Oceanic and Atmospheric Administration, and the State of Hawai`i. Midway is staffed by permanent USFWS personnel and can support chartered air service from Honolulu. Rehabilitation of habitat at Midway and close monitoring of translocated ducks was therefore more logistically feasible than it would be on an uninhabited island.

In 1998, 1999, and 2001, biologists traveled to Midway to evaluate the atoll as a potential release site for Laysan ducks, and specifically to evaluate the creation of wetland habitat to provide the fresh water essential to supporting a self-sustaining population of Laysan ducks (Reynolds and Kozar 2000a). The water table is less than 2 meters (6.6 feet) below the land surface in some parts of the atoll, providing suitable conditions for the creation of additional wetlands. Since 2002, several small wetlands have been created on Sand and Eastern Islands. Two of these wetlands on Sand Island and two on Eastern served as release sites for translocated ducks.

Midway has experienced many introductions of highly invasive nonnative plant species over the years, including *Verbesina encelioides* and *Cenchrus echinatus*. The invertebrate fauna on Midway Atoll is dominated by exotics. Vegetation restoration is a high priority and is ongoing in selected parts of the atoll, but if broad-scale herbicides, pesticides, and heavy equipment are used, Laysan ducks could be negatively affected; close coordination between Refuges and Ecological Services programs of USFWS will be necessary to ensure that conflicts between habitat restoration and Laysan duck recovery at Midway are resolved efficiently.

Many introduced invertebrates likely are prey items for the Laysan duck (Reynolds and Kozar 2000a). However, introduced predatory arthropods such as fire ants and big-headed ants may need to be controlled until techniques for ant eradication are developed (or the impacts of ants on the duck's prey base and nests are judged to be insignificant). Fire ants were discovered at Midway Atoll in 2000. Results of a pilot project to eradicate ants from Spit Island using bait treated with the toxicant Maxforce (hydramethylon) indicate that fire ants can be controlled by periodic (possibly annual) applications of granular ant toxicants (C. Swenson, U.S. Fish and Wildlife Service, pers. comm. 2001).

Although rats have been eradicated from Midway, mice (*Mus musculus*) have not, and their abundance (they occur on Sand Island only) has increased markedly since rats were removed in the mid 1990s. Mice currently don't appear to have any impact on Laysan ducks or Midway's seabirds, but they may become a problem for birds in the future. On Gough Island in the South Atlantic Ocean, for example, mice have developed the capacity to prey on and kill albatross chicks, and have a significant effect on their reproductive success (Wanless *et al.* 2007). Sand Island should be monitored for evidence of adverse impacts of mice on Laysan ducks: direct impacts such as predation and/or indirect effects such as limitation of food resources.

6. Other Prospective Translocation Sites

(a) Northwestern Hawaiian Islands.

(i) Lisianski Island.

Lisianski Island is Laysan's nearest neighbor in the northwest Hawaiian chain, and is known to have previously supported Laysan ducks. Loss of plant cover in the mid-1800s resulted in shifting sands that filled the island's freshwater source. Since Laysan ducks occurred previously on Lisianski, we know that with adequate management the island can support the species, thus Lisianski is a potential translocation site. In the event that Lisianski is chosen as a translocation site for Laysan ducks, wetland habitat must be restored to provide a source of fresh water, and development of a

Lisianski ecosystem restoration plan is recommended. The restoration of the wetland on Lisianski would pose logistical challenges, as the remote location of the island would preclude use of the heavy construction equipment that would normally be used for such an operation. A brief pilot study took place in 2006 to evaluate the hydrology of Lisianski and the feasibility of hand excavation to restore small fresh water seeps (Meyer 2006). Only one of 11 test pits (maximum depth 7 feet [2 meters]) excavated in this initial effort struck groundwater, and this was a very thin layer; the conclusion of the pilot study was that hand-excavation to create perennial seeps on Lisianski is not feasible (Meyer 2006). Using heavy equipment to excavate a wetland on Lisianski may be possible, but presents significant logistical and regulatory hurdles to overcome. Other options, such as catchment ponds or pumping groundwater from a lens that may exist at greater depth, have yet to be investigated.

(ii) Nihoa Island. Nihoa Island also is considered a potential translocation site after experimental translocations are made to other islands. At 68 hectares (168 acres), the island is large enough to support small numbers of Laysan ducks. Native plants and arthropods are abundant. Freshwater seeps occur naturally on Nihoa, eliminating the need to develop water sources or conduct other restoration for Laysan ducks. Nihoa is considered the most pristine of the Northwestern Hawaiian Islands, and an assessment of the potential impacts of Laysan ducks on the island's terrestrial biota should be conducted prior to translocation (Reynolds and Kozar 2000a). For example, the endemic cone-headed katydid *Banza nihoa* already may be negatively affected by the introduced grasshopper *Schistocerca nitens* and perhaps by several ant species (E. Flint, pers. comm. 2006). Laysan ducks are likely to eat the most abundant palatable prey available at any translocation site and so may not affect *Banza nihoa*, but the risk to the katydid of predation by Laysan ducks should still be considered. We suspect, however, that human impacts to Nihoa (associated with a translocation effort) are the primary risk. Technology for remote or automated post-release monitoring to eliminate the need for human presence on Nihoa should be explored.

(iii) Kure Atoll. Kure Atoll consists of two separate islets comprising 100 hectares (247 acres) of land area. Kure Atoll once supported a U.S. Coast Guard LORAN (long range navigation) station, but little of the infrastructure remains. The atoll is managed by the State of Hawai`i, which eliminated rats on the islets in 1994. The islands support a large number of arthropods and have a moderate amount of nesting cover for ducks (Reynolds and Kozar 2000a). Further restoration work is necessary before the atoll would be a suitable translocation site for Laysan ducks. In 2005, laboratory tests found groundwater from Kure to be free of contaminants, and in 2006 the State's field crew created a small freshwater seep and outplanted native wetland plants in and around it (C. Vanderlip, Hawaii Division of Forestry and Wildlife, pers. comm. 2009). Additional sources of fresh water, perhaps from rainwater catchments or additional excavated wetlands such as those at Midway, could be created to sustain Laysan ducks there. The State currently plans to investigate the ecological impacts of big-headed ants (*Pheidole megacephala*) at Kure and is seeking support for a comprehensive weed control program to eliminate or control the spread of *Verbesina encelioides* in the atoll. Because alien species control necessarily involves extensive physical disturbance and the use of pesticides, the majority of such work should take place before Laysan ducks are released in the atoll (C.Vanderlip, pers. comm. 2009).

(b) Main Hawaiian Islands.

**(i) Kaho`olawe.** Kaho`olawe has great potential as a translocation site for Laysan ducks in the Main Hawaiian Islands. Translocation of Laysan ducks to Kaho`olawe already has been recommended by the Kaho`olawe Island Restoration Commission (Social Science Research Institute 1998). A former U.S. Navy bombing range, the island was transferred to the State of Hawai`i in 1994, and for the next 10 years the Navy worked to remove as much remaining live ordnance as possible and meet the State's objectives for preservation of archeological sites and environmental restoration on Kaho`olawe. The Navy's work on Kaho`olawe was completed in 2004. Goats were removed, and the planned ordnance removal was completed. Restoration of native vegetation is ongoing on the island, which now supports moderate nesting cover and a wide variety of arthropods. Ephemeral wetlands exist on Kaho`olawe but need significant enhancement to support Laysan ducks. Rats have not been seen on the island since 1971, but their bones have been found in owl pellets since then (Snetsinger 1994). The presence of rats may be equivocal, but the presence of cats is certain. If cats and other mammalian predators are removed, Kaho`olawe will have excellent potential as a release site for Laysan ducks (Reynolds and Kozar 2000a).

**(ii) Kaua`i.** Of the other Main Hawaiian Islands, Kaua`i may be the best choice for reintroduction of the Laysan duck because it is the only island that may still be free of the Indian mongoose, a predator that would pose a major threat to Laysan ducks. Other significant predators, including rats, cats, and dogs, occur on the island and would have to be controlled prior to a release of ducks (and probably in perpetuity). Multiple sites on Kaua`i could be suitable for Laysan duck release (see Appendix 1), including two existing National Wildlife Refuges. These sites have extensive areas of suitable habitat and nesting cover and abundant sources of food and fresh water.

(iii) Other Main Hawaiian Islands.

Ni`ihau, O`ahu, Maui, Moloka`i, Lāna`i, and Hawai`i all have sites that potentially could support Laysan ducks. Managed wetlands occur on O`ahu, Maui, and Hawai`i, and of the five islands listed above, these three may provide the best opportunities for establishing self-sustaining Laysan duck populations. All of these islands, however, have significant problems with introduced mammalian predators which would have to be addressed through either control efforts or exclosures before they could be considered as suitable translocation sites for Laysan ducks.

7. Prospects for Reintroduction of Captive Birds

(a) General Issues.

The original Laysan duck recovery plan recommended maintaining captive flocks bred to ensure pure strains for eventual reintroduction to the wild (USFWS 1982). Unfortunately, this plan was never realized. Hybridization, incomplete population statistics, and harmful genetic change in captivity make the existing captive ducks and their future offspring poor candidates for reintroduction (Reynolds and Kozar 2000b). Genetic change in a captive environment can decrease reintroduction success in two ways: 1) genetic variation may be lost through limited breeding opportunities, and 2) animals may become adapted to the captive environment (Frankham 1995; McPhee 2003). In zoos, natural selection pressure on many features required for survival in nature, such as hunting and foraging abilities, is relaxed. Over long periods in captivity, natural selection acts to maximize fitness in a captive environment, thus the individuals surviving and breeding are those pre-adapted to captive conditions (Frankham 2008). A review of translocation efforts for various animal species from 1973 to 1986 found a vastly different success rate between wild-caught (75 percent) and captive-reared (38 percent) individuals (Griffith *et al.* 1989).

Captive breeders can minimize genetic adaptations to captivity by specifically managing captive flocks for reintroduction to the wild. Techniques to minimize genetic changes include reducing time spent in captivity, regularly introducing wild genes, using only the offspring of wild birds for release, and releasing birds into wild or semi-wild habitat temporarily, until suitable habitat within their previous range can be restored (Frankham 1994; Reynolds and Kozar 2000b).

Disease is an additional risk in translocating captive-reared birds, especially birds from mainland facilities. Confinement and mixing with other birds often increases the likelihood of disease transmission in captive flocks (Friend and Thomas 1990). The Avian Disease Working Group, an association of captive breeders and veterinarians, rejected the idea of reintroducing any captive mainland birds to Hawai`i based on logistical, fiscal, and quarantine restraints as well as the risk of disease introduction (USFWS 1994).

(b) Northwestern Hawaiian Islands. We believe it would be feasible to use captive-bred birds for introduction to the Northwestern Hawaiian Islands if these birds came from a new captive flock specifically managed for such releases, but considering the urgency of establishing another wild population, using wild, parent-raised fledglings from Laysan for reestablishment on other islands in the northwestern chain is more expedient, easier logistically, and perhaps more successful. A captive breeding program would take years to produce suitable numbers of offspring for release. Disease risks on the main islands are higher, and these risks may be minimized if translocations of birds to islands in the northwestern chain are of individuals from other northwestern islands.

(c) Main Hawaiian Islands. The single remaining natural population of Laysan ducks, on Laysan Island, is likely to remain the best source for founders of new populations, because in the timeframe for recovery of the species, Laysan will always harbor the greatest reservoir of the species' diversity; other populations will always be a subset of that reservoir. Translocation of wild birds from Laysan for the establishment of wild populations in the Main Hawaiian Islands may be feasible, but this possibility is limited by both the logistics and the "critical mass" needed for the establishment of large self-sustaining populations without depleting the source. If multiple populations are established in the Northwestern Hawaiian Islands and they reach carrying capacity, subsequent removal of hatch-year birds from more accessible Northwestern Hawaiian Islands (such as Midway) for Main Hawaiian Island populations may be a feasible option.

A captive breeding facility, managed for establishing additional wild flocks of Laysan ducks, is another possible strategy for establishing populations in the Main Hawaiian Islands. Eggs taken from Laysan Island may be the best way to found the captive flock because eggs are easier to transport than live birds, and egg removal would have the least impact on the population dynamics of the Laysan birds. First-generation (F1) offspring from those eggs would be released to found the new wild flocks on the Main Hawaiian Islands when other restoration requirements have been met at potential release sites.

III. RECOVERY CRITERIA AND ACTIONS

A. GOALS AND OBJECTIVES

The goal of our recovery program is to conserve and recover species to the point at which they can be downlisted from endangered to threatened status, and ultimately to remove them completely from the Federal list of threatened and endangered species when the protections provided by the Endangered Species Act are no longer necessary. Downlisting from endangered to threatened status is a near-term goal for the Laysan duck, and delisting or removal from the endangered species list is the long-term goal. This recovery plan identifies actions needed to achieve long-term viability for the Laysan duck and accomplish these goals. Recovery of the Laysan duck focuses on the following objectives: 1) management to reduce risks to the species on Laysan Island and at Midway Atoll, 2) protection and enhancement of suitable habitat, and 3) actions to reduce or eliminate threats sufficient to allow successful reestablishment of the species on additional islands. Accomplishing these objectives through the recommended actions has the highest likelihood of recovering this endangered species.

The emphasis in this recovery plan on the distribution of additional self-sustaining populations in the Laysan duck's putative historical range is based upon two widely recognized and scientifically accepted goals for promoting recovery of listed species. These goals are: (1) the creation of multiple populations so that catastrophic events do not result in extinction; and (2) the increase of population size to a level where the threats from genetic, demographic, and normal environmental uncertainties are diminished (Mangel and Tier 1994; National Research Council 1995; Tear *et al.* 1995; Meffe and Carroll 1997). By establishing and maintaining self-sustaining populations at multiple sites on multiple islands, the Laysan duck will have a greater likelihood of achieving long term survival and recovery.

Definitions:

Endangered Species — Any species which is in danger of extinction throughout all or a significant portion of its range.

***Threatened Species* —** Any species which is likely to become endangered within the foreseeable future throughout all or a significant portion of its range.

B. RECOVERY CRITERIA

The population targets for down- and delisting offered below should be considered as provisional recommendations and should be reviewed as the species is established on additional islands and we learn more about the population characteristics of Laysan ducks in new habitats and the potential carrying capacities of translocation sites.

1. Downlisting Criteria

For the Laysan duck to be downlisted from endangered to threatened, the following criteria must be satisfied:

Criterion 1. (Factor E, small population size) The Laysan Island population is stable or increasing when monitoring data (either quantitative surveys or demographic monitoring that demonstrates an average intrinsic growth rate (λ) not less than 1.0) are averaged over a period of at least 15 consecutive years to account for population fluctuations. The average population on Laysan Island ideally should remain at roughly 500 birds over this period.

Justification: Environmental variability affects Laysan Island's annual carrying capacity and year-to-year demographic rates, and the population experiences frequent fluctuations. Population change or growth thus should be evaluated according to the overall trend for a continuous 15-year period. This period will be sufficient to detect shifts in age structure (*e.g.*, a chronic lack of recruitment and the appearance of a stable population that primarily is composed of senescent ducks). This evaluation ideally will be based on both demographic monitoring and counts of ducks. Current estimates predict that El Niño Southern Oscillation events occur approximately every two to 10 years (Wolter 2009), thus a 15-year interval will allow for periodic fluctuations in response to these events as well as fluctuations that occur on shorter timescales. The target of an average population of 500 ducks on Laysan represents a rounded mean of 12 population estimates (Lincoln-Petersen indices; see Table 2) made over the past 25 years.

Criterion 2. (Factor C, predation; Factor E, small population size, limited distribution) A total of at least 1,800 potentially breeding ducks exist on a combination of predator-free Northwestern Hawaiian Islands (including Laysan and Midway) and at least one predator-controlled site in the Main Hawaiian Islands.

Each island or site should harbor a population of breeding adults that is stable or increasing when monitoring data (either quantitative surveys or demographic monitoring that demonstrates an average intrinsic growth rate (λ) not less than 1.0) are averaged over a period of at least 10 consecutive years to account for population fluctuations.

Justification: Ideally, all new populations on other islands should be of sufficient size to be self-sustaining.

However, in the interest of improving distribution and reducing the risk of extinction caused by catastrophes, it may be necessary to establish interim populations on small islands with limited carrying capacity (*e.g.*, Kure) as "insurance" while larger areas on other islands are undergoing restoration.

The likelihood that new populations of Laysan ducks will persist increases with increased carrying capacity and population size. Because we are only now learning about Laysan duck reproductive success, demography, ecology, and density in a habitat other than that of Laysan Island, we chose to be flexible in establishing this criterion. We recommend improved distribution and a total breeding population of at least 1,800 Laysan ducks for downlisting from endangered to threatened. The proportion of the total present at each site cannot be prescribed, but will reflect the extent of habitat and resources available at each site. As we learn more about Laysan duck biology and ecology in new environments, our knowledge of the habitat quality and area needed for self-sustaining populations will improve.

Reintroduction of the Laysan duck to the Main Hawaiian Islands is necessary for recovery over the long term because these islands can provide suitable habitat at higher elevation than most of the Northwestern Islands. The species' habitat in the Northwestern Hawaiian Islands is likely to be significantly diminished or lost within this century because of increased storm severity and sea-level rise resulting from global climate change (see for example Baker et al. 2006; Hansen 2007). For the conservation of this and other species in the Northwestern Hawaiian Islands, restoration of suitable habitat on high islands and translocation (as necessary) are essential.

Requiring one high-island population for downlisting obliges us to learn how to manage and sustain Laysan ducks in a landscape (e.g., on Kaua`i) or on one island (e.g., Kaho`olawe) in a cluster where predators are not absent, but can be controlled in or excluded from a specific area. Establishment of a first population in the main islands will provide experience and knowledge invaluable in the creation of others.

<u>Criterion 3</u>. (Factor A, habitat degradation; Factor C, predation and disease; Factor E, small population size and limited distribution) Island- or site-specific management plans for the Laysan duck are created and implemented. These plans will identify actions (such as monitoring to determine population establishment and collect data for modeling viability and persistence; water management; habitat improvement; removal of alien predators; and population supplementation as necessary to ensure viability) and emergency procedures sufficient to reduce threats and increase numbers to recovery levels. Alternative approaches for reducing or eliminating current threats to the Laysan duck and

increasing population growth should be identified in the management plan as well.

Justification: Comprehensive management plans will guide implementation of Laysan duck recovery actions for each island or site to ensure that the species does not become endangered again. A monitoring program that permits evaluation of the species' response to management actions is necessary to improve translocation efforts, habitat restoration, and management in the future.

Population supplementation: Human-assisted "immigration" (translocation of wild birds) may be needed to ensure population establishment and adequate growth at new sites. In the event of severe storms, epizootics, accidental introduction of predators, or other environmental catastrophes, assisted dispersal between populations can augment numbers and ameliorate local population declines. In addition, the potential exists for genetic drift (cumulative and fluctuations in allele frequencies) to give rise to nonadaptive mutations that can inhibit the growth and viability of small populations, and that risk must be assessed through close monitoring after translocation and as populations become established. If new populations fail to grow owing to inbreeding effects, the introduction of one migrant per generation from the source population may be sufficient to improve genetic variability of the translocated populations (*e.g.*, Mills and Allendorf 1996; Wang 2004). However, similar to rules of thumb for minimum viable population size, the one-migrant-per-generation rule one is based on continental species for which captive or small translocated populations are unlikely to capture a significant proportion of genetic variation in the species (see discussion below under deslisting Criterion 1). Because of the risk of disease, the mixing of birds from the Main Hawaiian Islands and the Northwestern Hawaiian Islands should be avoided, except in case of emergency or catastrophe to the source population. Introduction of new diseases is a threat to other endangered bird species in the Northwestern Hawaiian Islands as well as to the Laysan duck.

2. Delisting Criteria

For delisting, the following criteria must be met:

<u>Criterion 1</u>. (Factor E, small population size, limited distribution) A total of at least 3,000 potentially breeding adult birds exists in five or more stable or increasing populations on a combination of predator-free Northwestern Hawaiian Islands (including Laysan and Midway) and at least two predator-controlled sites in the Main Hawaiian Islands.

Each island or site should harbor a minimum of 500 potentially breeding adults, and numbers each island should be stable or increasing when monitoring data (either quantitative surveys or demographic monitoring that demonstrates an average intrinsic growth rate (λ) not less than 1.0) are averaged over a period of at least 15 consecutive years to account for population fluctuations. Ideally, these populations will be self-sustaining and require no intervention other than for ongoing management and monitoring of threats and response to new threats, epizootics, and catastrophic declines.

Justification: We set a preliminary target of 3,000 potentially breeding ducks distributed among five or more self-sustaining populations for delisting; we expect that at least some of these populations will maintain numbers higher than the minimum size of 500 potentially breeding adults. This target should be reevaluated as more populations are established and new population viability models are constructed (see Criterion 2, below).

An oft-cited rule-of-thumb is that 500 individuals is the effective population size (*i.e.*, the number of mature individuals sharing a similar probability of contributing their genetic material to the next generation) necessary to maintain genetic diversity and so improve the likelihood of persistence (*e.g.*, Lande and Barrowclough 1987:94). More recent definitions and analyses of viable populations have yielded far higher figures (*e.g.*, approximately 7,000 for a 99 percent probability of persistence for 40 generations; Reed *et al.* 2003). In these and other cases, the estimates of minimum viable population sizes have been based primarily on models of continental species, which have typically large populations and widespread distributions encompassing a range of environmental conditions, and thus have far greater genetic diversity than most island species (Carson 1981). Therefore, assumptions about the relationship between small population size, inbreeding depression, and an extinction "vortex" (see for example Foose *et al.* 1995) do not necessarily work well when applied to oceanic island species. The Laysan duck provides a useful example of this point, having persisted in a single, isolated, and fluctuating population on Laysan for at least a century, and putatively as two such populations (on Laysan and Lisianski) for a millennium or longer. We note that the "magic" of theoretical thresholds for viable populations has long been recognized as not universal across species or even within a single species through time (Foose *et al.* 1995); nonetheless, the traditional effective population size of 500 provides a reasonable working minimum for individual new populations of Laysan ducks until we build new population viability models.

<u>Criterion 2.</u> (Factor E, small population size and limited distribution) Population viability analysis projects that, under current conditions, the species will persist for at least 100 years.

Justification: Each new island where Laysan ducks are established will present the species with different habitat conditions. Monitoring data will improve our knowledge of variation in Laysan duck vital rates and ecology and of the carrying capacity of habitats in different places. These new data can be used to model the response of the species to various management actions and calculate with greater confidence persistence probabilities on individual islands and for the species as a whole. Results of these models may inform revision of the minimum size of the total breeding population described in Criterion 1, above.

<u>Criterion 3</u>. (Factor A, habitat degradation; Factor C, predation and disease; Factor E, small population size and limited distribution) Management plans for each island or site are evaluated on a regular basis and updated to include monitoring to detect demographic or new environmental threats to Laysan ducks.

Justification: Ensuring the long-term survival of the Laysan duck on multiple islands requires a management approach that can be adapted to incorporate new information and changing conditions.

C. OUTLINE OF RECOVERY ACTIONS

1. Assess status of and threats to the Laysan ducks on Laysan Island and Midway Atoll

- 1.1. Implementation of the Laysan Ecosystem Restoration Plan and Papahānaumokuākea Marine National Monument Management Plan
  - 1.1.1. Plant monitoring, weed control, and native species restoration
  - 1.1.2. Alien invertebrate control and monitoring, and native invertebrate restoration, where possible
  - 1.1.3. Freshwater seep restoration and maintenance
  - 1.1.4. Monitor impacts of other Refuge or Monument management activities on Laysan ducks
- 1.2. Population monitoring
  - 1.2.1. Population and reproductive monitoring
  - 1.2.2. Disease screening and prevention
  - 1.2.3. Field crew training
- 1.3. Develop emergency contingency plans
- 1.4. Further research
  - 1.4.1. Population parameters
  - 1.4.2. Disease
  - 1.4.3. Genetic research

2. Improve distribution and total population size

- 2.1. Complete site assessments and prioritize translocation sites
  - 2.1.1. Develop management plans for individual translocation sites
- 2.2. Habitat restoration/creation in the Northwestern Hawaiian Islands
- 2.3. Habitat restoration in the Main Hawaiian Islands
  - 2.3.1. Control predators
  - 2.3.2. Control other alien species
- 2.4. Conduct translocations
  - 2.4.1. Set up holding facilities
  - 2.4.2. Arrange timely transportation to and from the Northwestern Hawaiian Islands
  - 2.4.3. Collect and transport fledged juvenile birds on Laysan
  - 2.4.4. Disease screening and treatment
  - 2.4.5. Acclimation and release
- 2.5. Intensive post-release monitoring
  - 2.5.1. Body condition assessment and supplemental feeding
  - 2.5.2. Radio telemetry: survival, reproduction, and foraging behavior
  - 2.5.3. Prey-base monitoring
- 2.6. Immigration translocations

2.7. Population viability analyses

2.8. Release Laysan ducks at Main Hawaiian Island sites

2.9. Hire or contract project leader for Laysan duck recovery

3. Captive propagation

4. Public outreach

4.1. Outreach for translocations in the Main Hawaiian Islands

4.2. Exhibit with captive Laysan ducks

5. Update the recovery plan

D. RECOVERY ACTION NARRATIVE

The following actions are needed to achieve the recovery of the Laysan duck, and are presented in the form of a step-down narrative. Details of the ecology and management techniques relevant to these actions are described in Parts I and II of this plan.

1. Assess status of and threats to the Laysan ducks on Laysan Island and Midway Atoll

1.1. Implementation of the Laysan Ecosystem Restoration Plan and Papahānaumokuākea Marine National Monument Management Plan

Introduced species control and seep restoration are the most important components of the existing Laysan Ecosystem Restoration Plan (Morin and Conant 1998) for the recovery of the Laysan duck on that island. Without continued ecosystem restoration, the carrying capacity of Laysan may decline as freshwater seeps fill and nonnative species invade. Many of the goals set in the restoration plan have not yet been reached. Restoration projects are outlined and described in detail by Morin and Conant (1998). The draft management plan for the Papahānaumokuākea Marine National Monument references the Laysan restoration plan and includes specific strategies and actions for the management of endangered species throughout the Monument, including the Laysan duck at Midway.

1.1.1. Plant monitoring, weed control, and native species restoration

Continued vegetation monitoring and restoration are necessary to control and exterminate introduced species, restore native species that provide nesting and foraging habitat for the Laysan duck, and reduce sand destabilization and filling of the lake and seeps on Laysan and maintain the seeps at Midway Atoll.

1.1.2. Alien invertebrate control and monitoring, and native invertebrate restoration, where possible

Native terrestrial insects are essential components of a functioning ecosystem as well as an important seasonal food source for the Laysan duck. Trained personnel should conduct regular surveys to identify and collect specimens, and should assess the impacts of introduced ants and introduced parasitic wasps (which may affect lepidopteran larvae that are eaten by Laysan ducks). Control requires a qualified entomologist to implement eradication programs and to determine which other alien invertebrates need to be eliminated.

1.1.3. Freshwater seep restoration and maintenance

The freshwater seeps on Laysan and at Midway are crucial brood rearing habitat for Laysan ducklings. Brood rearing habitat is limited on Laysan; seep restoration thus would improve and increase available habitat. During droughts on Laysan, seeps could be excavated so that fresh water below ground is available to birds. Restoration on Laysan should be prioritized in areas where seeps or ponds existed previously or have been partially filled. Care should be taken so that water use for the camp and greenhouse operations on Laysan Island does not deplete fresh groundwater that feeds seeps during dry periods. A hydrological assessment also would inform wise aquifer use and wastewater discharge by the field camp. Where wetland restoration or creation is warranted on Laysan Island and at other potential translocation sites, a hydrologist should make a site visit and assessment, and develop a wetland hydrology plan. At Midway, dedicated management of water sources will be necessary to maintain adequate freshwater resources for the growing number of Laysan ducks there; furthermore, emergency plans for water management are needed to facilitate rapid response to botulism outbreaks and other water-borne epizootics.

1.1.4. Monitor impacts of other Refuge or Monument management activities on Laysan ducks

Managing the Northwestern Hawaiian Islands for the restoration and conservation of native biota, and the management, in some cases, of infrastructure and visitors, necessitates many types of activities, and some of these may have negative effects on Laysan ducks. For example, the control or eradication of invasive nonnative plant and animal species, restoration or enhancement of habitat for other native species, or implementation of a visitor program on islands where Laysan ducks occur, may result in disturbance, displacement, or incidental mortality of ducks. Refuge management activities should be monitored to determine impacts to Laysan ducks as well as other native species, and negative effects should be avoided or minimized. Close coordination between the National Wildlife Refuges System, Papāhanaumokuākea Marine National Monument, and the Ecological Services branch of USFWS will be necessary to ensure that conflicts between Laysan duck recovery and refuge management are addressed in a timely and efficient manner.

1.2. Population monitoring

Because the Laysan duck survives in two isolated populations, monitoring is essential for guiding the species' management and recovery. Tracking the species' status is necessary to determine responses to ecosystem restoration, gauge the health of the population, time translocation efforts during periods of population increases, and determine if recovery criteria have been met.

1.2.1. Population and reproductive monitoring

Accurate population estimates depend on long-term banding efforts and subsequent data management to maintain resight histories. For established populations, trends and recruitment ideally should be assessed annually with resight data. Additional trend assessments and analysis should be conducted as needed. In order to accomplish this level of monitoring, a percentage of the population should be banded annually by qualified personnel to maintain a marked population adequate for population estimation based on mark-resight data. Alternatively, banding once every 2 or 3 years is sufficient if intensive surveys to resight banded birds are conducted for four to six months annually. Banding of fledged juveniles will continue as logistics and funding permit, but other, less intensive methods for monitoring the general status of the species may be necessary.

A large proportion of the Laysan population was marked in the years 1998 through 2001, and additional intensive banding was conducted in 2004 and 2005 in preparation for translocation. Band-reading and population surveys are performed every two weeks on Laysan to provide data for estimates, but currently no program is in place to band birds on a regular basis. Maintaining a marked population there may be possible, resources permitting, as long as a field camp is staffed year-round there and a trained individual dedicated to duck surveys can be placed. At Midway as well, at least half of the population currently is banded. However, an annual regime of resight surveys may not be possible owing to staff and resource limitations. In 2008 and 2009, intensive resight surveys in post-fledging and pre-breeding seasons are being conducted by the U.S. Geological Survey, Pacific Island Ecosystems Research Center, to develop a monitoring protocol based on wetland counts of ducks conducted by Refuge staff.

Ultimately, a plan for post-delisting monitoring will be needed for the Laysan duck. Development of this plan will benefit from methods refined on Laysan, Midway, and as new populations are established on other islands. Monitoring after delisting should include continued surveillance for new threats as well as monitoring of population status.

1.2.2. Disease screening and prevention

Disease screening and preventive treatment are needed before Laysan ducks are translocated. Screening serves to select only healthy birds for removal and prevent spread of disease. Collection, preservation, and necropsy of suitable carcasses should be continued in coordination with the U.S. Geological Survey National Wildlife Health Lab. *Echinuria uncinata* has not been documented in Hawai`i outside of Laysan, and translocated Laysan ducks could introduce the parasite to other islands. Prevention of botulism outbreaks and strategies for preventing the introduction of new diseases to the Northwestern Hawaiian Islands should be explored.

1.2.3. Field crew training

Conservation activities on Laysan Island depend in large part on the dedication of crews of technicians and volunteers that spend five to six months on the island carrying out a range of projects. Because of staffing, logistical, and financial constraints, training of crews often is limited, and lack of continuity between crews can reduce the effectiveness of monitoring, restoration actions, and record keeping. Crews need adequate training in Laysan duck monitoring: sexing, ageing, and counting birds and reading bands. Additional effort is required for reproductive monitoring during the typical brood rearing season from March to August. An individual (technician or volunteer) devoted to collecting data for determining reproductive success is needed to adequately monitor the population. In addition, detailed documentation describing methods for surveys and other observations must be developed and updated regularly for field technicians to ensure consistency and high quality in data collection. As stated above, owing to limited staff and resources, intensive annual demographic monitoring of the Laysan duck at Midway by refuge staff may not be possible, although we anticipate continued study of the duck there by other scientists and their trained staff.

1.3. Develop emergency contingency plans

Given the destructive potential of introduced predators and competitors, and the likelihood of future introductions, a contingency plan is needed to deal with introduced species that might find their way to Laysan or translocation sites. Refuge managers should be prepared for possible introductions of rats, mice, or ants, know what to do in the case of a hurricane or tsunami, and know how to respond to epizootics or contaminants washing ashore.

1.4. Further research

Although much has been learned about the Laysan duck in the past two decades, further research is essential for directing and revising future recovery efforts.

1.4.1. Population parameters

More information is needed on the parameters that drive the species' population dynamics and the differences already noted between populations on Laysan and at Midway. Study should be undertaken of factors such as food and water resources that influence nesting success, hatchability, and brood survival.

1.4.2. Disease

Research is needed to determine how disease influences survival and recruitment in Laysan ducks. Parasitism rates and effects of other diseases are unknown. The ecology of the parasite *Echinuria uncinata* is unknown on Laysan, as is its occurrence at Midway. Research to determine the intermediate host and factors influencing the prevalence of echinuriasis and botulism is needed so epizootics, such as the echinuriasis outbreak on Laysan in 1993 and the botulism outbreak at Midway in 2008, can be prevented or managed efficiently. Avian pox occurs at Midway, and the risk to Laysan ducks posed by this and other mosquito-borne diseases is unknown. A study of mosquito-born diseases at Midway should be undertaken to assess this risk. See also Action 3.3, Disease screening and treatment.

1.4.3. Genetic research

Because of their isolation and limited numbers, Laysan duck populations may require genetic management to prevent the loss of genetic diversity, reduce the risk of inbreeding depression, and to foster healthy, growing populations that possess the genetic potential to adapt to new habitats. However, this will not be possible until we have information from molecular analysis about the heterogeneity that exists in the species. Analysis of heterogeneity and population structures of the Laysan, Midway, and future wild or captive populations will benefit planning for species recovery.

2. Improve distribution and total population size

Translocation will be the primary means of increasing total numbers of Laysan ducks and reestablishing their formerly archipelago-wide distribution. Because they lack mammalian predators, the Northwestern Hawaiian Islands provide attractive potential translocation sites for the Laysan duck in spite of significant logistical hurdles. These small islands have limited carrying capacity, and most of them face significant loss of land area and increased erosion resulting from sea level rise and increased storm intensity associated with global climate change. Therefore to delist the Laysan duck it will be necessary to establish self-sustaining populations of Laysan ducks on the Main Hawaiian Islands as well, in spite of the presence of predators. Only the high islands can, with adequate management, provide long-term habitat and support the birds in sufficient numbers to ensure their persistence into the foreseeable future.

2.1. Complete site assessments and prioritize translocation sites

Refinement of the existing prioritized list of translocation sites and selection of the next release site will require additional research. The biological and physical assessment of potential translocation sites in the Northwestern Hawaiian Islands and Main Hawaiian Islands must be augmented with an assessment of the costs and management feasibility of habitat creation or restoration, translocation, and monitoring

2.1.1. Develop management plans for individual translocation sites

Laysan ducks will benefit from the development of restoration and management plans for individual islands and sites. Ecosystem restoration will provide the best environment for self-sustaining, low-maintenance Laysan duck populations.

2.2. Habitat restoration/creation in the Northwestern Hawaiian Islands

At this time, within the State of Hawai`i only the Northwestern Hawaiian Islands lack mammalian predators, but as demonstrated at Midway, most of those small islands will require habitat restoration to support the establishment of self-sustaining, minimally managed Laysan duck populations. The most intact native ecosystems may be the most likely to have adequate nesting cover, food resources, and fresh water, although Lisianski, while harboring few alien species, currently has no fresh water resources. At such sites, the scope of additional management to promote the survival of translocated Laysan ducks will depend on the critical resources that must be enhanced or restored (see Appendix 2 for an island-by-island assessment). Many of the Northwestern Hawaiian Islands lack standing fresh water; thus, seeps, ponds, or artificial watering devices must be created and maintained to ensure the survival and reproduction of translocated Laysan ducks. These sources of freshwater must be created or managed to minimize the impact of botulism outbreaks on Laysan ducks. The Northwestern Hawaiian Islands harbor many introduced species of plants and animals, which may affect habitat quality for the Laysan duck. Control or eradication of these species and strict quarantine to prevent new introductions will improve the habitat and increase the likelihood of establishing a healthy, low-maintenance population. Degraded systems may require more intensive management to ensure Laysan duck survival, such as supplemental feeding, watering, and the creation of nesting cover (an example of intensive management for Laysan ducks is protection of hatching eggs from introduced fire ants using site-specific treatments at wild nests).

2.3. Habitat restoration in the Main Hawaiian Islands

2.3.1. Control predators

The combination of introduced mammalian predators, human hunting, and habitat loss probably were responsible for the disappearance of Laysan ducks from the Main Hawaiian Islands in prehistory. The most important aspect of management on the main islands for Laysan duck reintroduction will be control of predators. Rats, mongooses, pigs, dogs, mice, and feral cats are present in some combination on all of the Main Hawaiian Islands. All of these mammals pose a threat to the Laysan duck, and the presence of any predators at translocation sites will greatly increase the risks associated with reintroduction. Before Laysan ducks can be established on any of these islands, long-term predator control and/or predator-proof fencing is necessary.

2.3.2. Control other alien species

Translocation sites may need rehabilitation in the form of introduced weed or insect control (refer to Appendix 2 for a site-by-site evaluation of possible translocation sites and restoration needs at each site). Control of feral mallards, which hybridize with koloa, may also reduce potential hybridization risks to the Laysan duck. Additional experimental translocations in the Main Hawaiian Islands should be attempted where overlap with the koloa is minimal and mallards are absent.

2.4. Conduct translocations

2.4.1. Set up holding facilities

Individual holding and transport cages are needed to contain birds on Laysan and in transit. Translocated fledgling birds should be held in field aviaries at new sites prior to release. While the wild birds are held in the aviary facility, they can be acclimated to supplemental foods and their health and body condition enhanced before release.

2.4.2. Arrange timely transportation to and from the Northwestern Hawaiian Islands

Space on ships and transportation to and from the Northwestern Hawaiian Islands is extremely limited. These logistical constraints must be addressed or they could hamper the implementation of most aspects of the recovery plan.

2.4.3. Collect and transport fledged juvenile birds on Laysan

Reproductive success on Laysan varies considerably from year to year, so complete translocations may have to be spaced out over several years. Fledged juveniles are the best candidates for the initial translocations because the removal of juvenile birds has the least impact on the source population. After translocated birds begin breeding, if population growth is not adequate to maintain the genetic diversity of the founders and establish a healthy population, additional translocations may be necessary thereafter. Experimental techniques for supplementation or cross-fostering with younger ducklings or eggs harvested from Laysan could be explored as well, if necessary. The removal of birds from Laysan must be timed according to population trends. Birds should be transferred in multiple years, 15 to 30 fledglings at a time, if enough suitable individuals exist. Fledglings could be selected and removed between July and October. The naturally occurring population on Laysan is the preferred source for translocations, as reintroduced populations on other islands of necessity will be a subset (albeit likely a substantial subset) of the genetic diversity present in the species. However, genetic analyses comparing reintroduced populations against a Laysan Island baseline may guide decisions about using created populations as sources for additional translocations.

2.4.4. Disease screening and treatment

Screening and treating birds prior to translocation is especially important to avoid transferring disease to other sites. Screening and prophylactic treatment of ducks with ivermectin to ensure they did not carry the nematode *Echinuria uncinata* before translocation to Midway had no negative effects on the birds' survival. It is also important to evaluate the disease risk at new sites prior to translocation.

2.4.5. Acclimation and release

Laysan ducks should be acclimated to translocation sites prior to release to ensure that birds are healthy and are able and inclined to forage in their new environment. Birds will be housed in aviary pens at the release site and introduced to local foods. During this period, the ducks will be closely monitored and offered a combination of wild forage items and supplements. Once birds appear healthy, they will be prepared for release. Ideally, release will occur after birds have reached their pre-translocation weights, and are deemed in good body condition. Those not adapting to aviary life may be released prior to reaching their pre-translocation weights if deemed necessary. Radio transmitters will be attached so that post-release activity can be monitored. Primary feathers will be trimmed to prevent initial flight dispersal from the release site. Birds will be released with their aviary mates, and a first group will be monitored for one to two days prior to releasing the next group. Supplemental food and water will be offered for up to two months post release at the release site to give the flightless ducks time to explore their new foraging habitat and improve their chances of surviving the transition from Laysan Island.

2.5. Intensive post-release monitoring

To determine the efficacy of the release program, the fates of translocated birds must be followed closely. Findings will enable managers to adapt the translocation program during its development to ensure success.

2.5.1. Body condition assessment and supplemental feeding

Body condition should be used as an indicator of health and adequate food resources. Birds in poor condition may require treatment and conditioning in an on-site aviary, and may serve as indicators that improvements to the habitat quality at the release site are needed. Supplemental food and water should be offered to flightless birds after release and during periods of low seasonal availability as determined by prey base and post-release monitoring. Individuals in poor condition may require supplemental feeding.

2.5.2. Radio telemetry: survival, reproduction, and foraging behavior

Subsequent to release, translocated birds should be monitored using radio telemetry for a specified period of time to measure the success of the translocation program and allow for adjustments in the translocation protocol. Data gathered on survivorship and reproduction of birds in these new environments will be critical in the assessment of population viability and for the development of scientifically sound delisting criteria for this species. Radio telemetry is the most effective means of tracking individual birds and monitoring their activity and reproductive effort.

2.5.3. Prey-base monitoring

Monitoring the prey base of the ducks at translocation sites will enable managers to determine seasonal availability of food, preferred foraging habitats, and whether supplemental feeding is warranted.

2.6. Immigration translocations

Supplementation may be required to improve population growth rates and may be required to ensure viability on very small islands or islands with low carrying capacity. Such sites are not ideal choices for long-term recovery of the Laysan duck, but may be necessary in the near-term to improve the species' distribution overall while larger islands (*e.g.*, Kaho`olawe) or predator exclosures on the largest islands (*e.g.*, Maui or Kaua`i) are restored. Therefore, additional translocations to supplement new populations on some Northwestern Hawaiian Islands may be necessary because few of these islands will be able to support as many Laysan ducks as Laysan or Midway. The goal for recovery is to establish self-sustaining populations, but if proven necessary after the initial translocation, one bird per generation (or five birds every 5 years) could be transferred from Laysan to newly established populations on other islands. Continued immigration thus could be an important part of the project to reduce the effects of inbreeding and genetic drift, if new populations aren't sufficiently vigorous. Finally, the potential for outbreeding also must be considered; continual addition of new individuals from elsewhere may inhibit adaptation to local conditions over the long term. As stated above, analysis of the genetic diversity present in the species will help identify and correct potential problems.

2.7. Population viability analyses

Models should be developed that incorporate demographic data from Midway and other newly established populations (and, ideally, data describing genetic diversity from molecular analyses) to predict the viability of the populations and of the species. New analyses may help in assessing the long-term success of translocations, and inform a host of management decisions and future revisions of recovery criteria and tasks for the Laysan duck.

2.8. Release Laysan ducks at Main Hawaiian Island sites

The recovery and delisting of the Laysan duck ultimately depends on establishing self-sustaining populations on high islands. This will necessitate major predator control, exclusion, or eradication projects, as well as other habitat restoration to ensure that fresh water and other requirements are met. Laysan duck reintroductions in the Main Hawaiian Island will require intensive post-release monitoring to evaluate success, as well as ongoing monitoring of population status and threats.

2.9. Hire or contract project leader for Laysan duck recovery

Dedicated staff is the best way to implement and coordinate the various aspects of Laysan duck recovery, which are centered on translocation and habitat restoration. Laysan Island and translocation sites need professional expertise in devising and implementing restoration plans, restoring and manipulating hydrology, translocating birds, coordinating restoration and recovery implementation, and monitoring. A biologist from our agency or a contract scientist or group should be dedicated to oversee implementation of this recovery plan. This person or group would direct the prioritization of translocation sites, lead fundraising efforts, and coordinate all phases of research, translocation, and monitoring. The project leader also would be responsible for the management and analysis of data generated by recovery tasks, and would develop recommendations for modifications to the recovery strategy in response to new information.

3. Captive propagation

Translocation is the preferred method for establishing new populations of Laysan ducks. However, absent a sufficient supply of excess juveniles for translocation from Laysan or new populations, a captive flock, managed specifically for releases to the wild, may be needed in the Main Hawaiian Islands for establishment of the species there. The existing captive flocks of Laysan ducks on the mainland and in international facilities are unsuitable for introduction to the wild. Removal of eggs or fledged juveniles from the wild would have the least impact on the source population. Removal and transport of eggs to the main islands may be easier logistically. Additional wild eggs or animals should be added periodically to any captive flock to improve genetic diversity and reduce genetic adaptation to captivity. While preparations are made for captive propagation, wild fledglings may be translocated to suitable habitats on other islands to establish insurance populations. Captive propagation for Laysan ducks, including planning, facility development, and staffing, should be pursued through contracts with non-profit organizations. Similar to translocated birds, Laysan ducks raised in captivity will need disease screening prior to release and close monitoring afterward.

4. Public outreach

4.1. Outreach for translocations in the Main Hawaiian Islands
Any translocation effort on an inhabited island should include a public outreach program. Those responsible for implementing recovery actions on the islands should advertise the goals and objectives of the translocation, solicit responses, and address stakeholder concerns, ideally prior to the translocation. Opportunities should be pursued vigorously for public participation in restoration, monitoring, and other projects connected with the reestablishment of Laysan ducks in the Main Hawaiian Islands.

4.2. Exhibit with captive Laysan ducks
An interpretive exhibit (*e.g.*, at the Honolulu Zoo, Waikiki Aquarium, and/or Sea Life Park) should be developed using some of the existing captive Laysan ducks from mainland captive stock, or nonbreeders from new captive flocks. Such an exhibit could provide information about the duck's status (updated as translocations and recovery progress) and about the Northwestern Hawaiian Islands in general.

5. Update the recovery plan
The recovery plan for the Laysan duck should be reviewed and updated periodically, as necessary, as field and laboratory research and translocations progress, and we gain further knowledge of the ecology and population biology of the Laysan duck in new environments. This update should include review of recovery criteria and new data by specialists in the genetic management of small populations to ensure that we protect the genetic diversity of the Laysan duck and provide opportunities for its enhancement.

IV. IMPLEMENTATION SCHEDULE FOR 2009 THROUGH 2013

Although we now know that the Laysan duck once occurred throughout the Hawaiian Islands and lived in a broad range of habitats, our understanding of this bird's ecology is limited to our observations of the species on Laysan in a relatively unusual habitat dominated by a hypersaline lake, and preliminary information from Midway, which is dominated by quite different habitats. Because we don't know how well our current knowledge of Laysan duck biology may apply to the management of this species on other islands, long-term planning for its reestablishment and recovery is difficult. The needs of the recovery program thus cannot realistically be projected beyond a relatively limited timeframe. As a consequence, we take an adaptive management approach to the recovery of the Laysan duck to permit the refinement of recovery actions as we learn more about the needs of this species through the recovery process. This recovery plan describes the overarching actions needed to advance the recovery of the Laysan duck; individual management plans will provide site-specific detail. These plans should be updated regularly to reflect the lessons learned and refinements to our management strategy. Along with periodic updates to this recovery plan, in this way, we will review and enhance the effectiveness of the Laysan duck recovery program.

The Implementation Schedule that follows outlines actions and estimated costs for the Laysan duck recovery program as set forth in this recovery plan. It is a *guide* for meeting the objectives discussed in Parts II and III of this plan. This schedule indicates action priority numbers (defined below), action numbers from the recovery action outline in Part III-A, action descriptions, anticipated duration of actions, the responsible parties, and lastly, estimated costs. The initiation and completion of these actions is subject to the availability of funds, as well as other constraints affecting the parties involved.

We have the statutory responsibility for implementing this recovery plan, and only Federal agencies are mandated to take part in recovery efforts for threatened and endangered species. However, recovery of the Laysan duck will require the involvement of the full range of Federal, State, private, and local interests. The expertise and contributions of additional agencies and interested parties is needed to implement certain recovery actions and to accomplish outreach objectives. For each recovery action described in the Implementation Schedule, the column titled "Responsible Parties" lists the primary agencies having the authority or responsibility for implementing recovery actions and other groups, such as State, private, and non-profit organizations, that also may wish to be involved in recovery implementation. The listing of a party in the implementation schedule does not require, nor imply a requirement, that the identified party has agreed to implement the action(s) or to secure funding for implementing the action(s). When more than one party is listed, the most logical lead agency (based on authorities, mandates, and capabilities), has been identified in bold type.

Definition of Action Priorities:

Priority 1 — An action that must be taken to prevent extinction or prevent the species from declining irreversibly in the foreseeable future.

Priority 2 — An action that must be taken to prevent a significant decline in species population or habitat quality, or some other significant negative impact short of extinction.

Priority 3 — All other actions necessary to meet the recovery objectives.

Definition of Action Durations:

Continual (C) — An action that will be implemented on a routine basis once begun.*Ongoing (O)* — An action that is currently being implemented and will continue until no longer necessary.

To Be Determined (TBD) **—** The action duration is not known at this time or implementation of the action is dependent on the outcome of other recovery actions.

Acronyms used in the Implementation Schedule:

BRD	U.S. Geological Survey-Biological Resources Discipline
DLNR	Hawai`i Division of Land and Natural Resources
DU	Ducks Unlimited, Inc.
HINWR	Hawaiian Islands National Wildlife Refuge
KIRC	Kaho`olawe Island Reserve Commission
MHI	Main Hawaiian Islands
NWHI	Northwest Hawaiian Islands
NWHRC	National Wildlife Health Research Center (USGS)
USFWS	U.S. Fish and Wildlife Service
WRD	U.S. Geological Survey-Water Resources Division

Table 3. Implementation Schedule for the Laysan duck revised recovery plan.

Recovery Action Priority	Action Number	Listing Factor	Action Description	Action Duration	Responsible Parties	Estimated Costs (x $1,000)					
						Total Cost	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014
1	1.3	E	Develop emergency contingency plans	TBD	USFWS/ private contractor	35.5	35.5				
2	1.2.1	A, E	Population and reproductive monitoring	O	**USFWS**/BRD	200	40	40	40	40	40
2	2.2	A, E	Restore and/or create habitats on NWHI that are potential translocation sites (*e.g.*, Lisianski Island, Kure Atoll)	C	**USFWS**/DLNR/ DU/other private contractor	3,500	840	840	840	490	490
2	2.3.1	C	Control predators at potential MHI translocation sites (*e.g.*, Kaho`olawe Island, Hanalei NWR, Kaua`i)	C	**USFWS/DLNR/ KIRC/** other private contractor	1,000	200	200	200	200	200
2	2.1	A, E	Complete site assessment and prioritize translocation sites	C	USFWS	37	37				
2	1.2.2.	C	Disease screening and prevention	C	USFWS/**NWHRC**	22	6	4	4	4	4
2	1.2.3	E	Train Laysan and Midway field crews in survey methods	O	USFWS	27	5.4	5.4	5.4	5.4	5.4
2	1.4	C, E	Conduct research on Laysan duck population parameters, genetics, and disease susceptibility	O	USGS-BRD/**research institutions**	300	60	60	60	60	60
2	1.1.1	A	Control and monitor weeds and restore native vegetation on Laysan	O	USFWS	1,000	200	200	200	200	200

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Recovery Action Priority	Action Number	Listing Factor	Action Description	Action Duration	Responsible Parties	Estimated Costs (x $1,000)					
						Total Cost	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014
2	1.1..3	A, C	Fresh water seep restoration and maintenance	C	**USFWS**/DU/WRD	250	75	75	50	50	
2	2.4	A, C, E	Conduct translocations within NWHI: set up holding facilities, charter transportation, select monitor, and capture fledged juveniles (on Laysan), screen for disease, acclimate and release at new site	TBD	**USFWS/BRD/** private contractor	450			150	150	150
2	2.5	A, C, E	Conduct intensive post-release monitoring of translocated ducks	TBD	**USFWS**/BRD/ research institutions	175	35	35	35	35	35
2	1.1.2	A, E	Control and monitor invasive invertebrates and restore natives on Laysan	C	USFWS	375	75	75	75	75	75
3	1.1.4	A, E	Monitor impacts of Refuge and Monument management activities on Laysan ducks	C	USFWS	75	15	15	15	15	15
3	2.1.1	A, E	Develop management plans for individual translocation sites	C	USFWS/ BRD	120	30	30	30	30	
3	2.3.2	A, E	Control alien species (*e.g.*, weedy plants, feral mallards) at MHI translocation sites	C	**USFWS/DLNR/ KIRC**	432	144	72	72	72	72
3	2.6	E	Conduct immigration translocations if necessary	TBD	**USFWS**/BRD/ research institutions	40	20			20	

Table 3. Implementation Schedule for the Laysan duck revised recovery plan.

Recovery Action Priority	Action Number	Listing Factor	Action Description	Action Duration	Responsible Parties	Estimated Costs (x $1,000)					
						Total Cost	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014
3	2.7	E	Build and analyze new population viability models that include data from Midway and other new populations	TBD	**USFWS**/BRD/ research institutions	35	15			10	10
3	2.8	A, E	Release Laysan ducks (includes intensive post-release monitoring) at MHI sites (*e.g.*, Kaho`olawe and Kaua`i)	TBD	**USFWS**/BRD/ research institutions	90				45	45
3	2.9	A, C, E	Hire or contract Laysan duck recovery implementation coordinator	C	**USFWS**/BRD	500	100	100	100	100	100
3	3	A, E	Develop captive propagation program, incl. planning, facility development, and staff	C	Private contractor	310			130	90	90
3	4.1	A, E	Conduct public outreach for reintroduction of Laysan ducks to MHI	C	**USFWS/DLNR**	75	15	15	15	15	15
3	4.2	A, E	Create interpretive exhibit using captive Laysan ducks	C	Private contractor	150	45	45	20	20	20
3	5	A, C, E	Update recovery plan	1 year	USFWS	5					5
					TOTALS	9198.5	1992.9	1811.4	2041.4	1726.4	1626.4

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VI. APPENDICES

APPENDIX 1. **Habitat assessment of possible translocation sites for the Laysan duck**

I: Northwestern Hawaiian Islands

Island	Size (ha)	Elevation (m)	Annual rainfall (mm)	Surface fresh water	Cover	Predators	Prey base
Kure Atoll	100	6	1100	Absent	Yes	Absent	Moderate
Midway Atoll	625	5	1121	-	Yes	Absent	Moderate
Sand Is.	467	5		Present	Yes	Absent	Moderate
Eastern Is.	156	4		Present	Yes	Absent	Moderate
Spit Is.	2	2		Absent	Yes	Absent	Limited
Pearl and Hermes	30	3	700-1000	Absent	No	Absent	Limited
South East Is.		2		Absent	No	Absent	Limited
North Is.		3		Absent	Yes	Absent	Limited
Kittery Is.		2		Absent	No	Absent	Limited
Lisianski	150	11	700-1000	Absent	Yes	Absent	Moderate
Laysan	415	12	700-1000	Limited-Moderate	Yes	Absent	Seasonally abundant
French Frigate Shoal	26	1-3	700-1000	Absent	No	Absent	Limited
Tern	10			Absent	No	Absent	Limited
Necker	18	83	500 - 750	Limited	No	Absent	Unknown
Nihoa	68	269	750	Moderate	Yes	Absent	Moderate

APPENDIX 1 (continued). Habitat assessments of possible translocation sites.

II: Main Hawaiian Islands.

Island	Size (ha)	Maximum Elevation (m)	Site	Annual rainfall (mm)	Surface fresh water	Predators	Prey base
Ni`ihau	25,500	390	Ni`ihau Playas	667	Abundant	Dogs, Cats, Rats	High
Kaua`i	157,400	1,585	Wainiha Valley	2000	Abundant	Dogs, Cats,	High
			Lumaha`i Valley	2500	Abundant	Rats	High
			Hanalei NWR	2000	Abundant		High
			Wailua/`Ōpaeka`a Valley	1250	Abundant		High
			Hulē`ia NWR	1250	Abundant		High
			National Tropical Botanical Garden (Lāwa`i Valley)	----	Abundant		High
O`ahu	162,400	1,233	Lualualei	625	Abundant	Dogs, Cats,	High
			`Uko`a Marsh	500	Abundant	Rats,	High
			Kahuku Point	1250	Abundant	Mongooses	High
			Lā`ie Wetlands	1500	Abundant		High
			Waihe`e Marsh	2000	Abundant		High
			He`eia Marsh	1750	Abundant		High
			Nu`upia Ponds	1250	Abundant		High
			Kawai Nui Marsh	1500	Abundant		High
Moloka'i	66,600	1,525	Moloka`i Playas	250	Abundant	Dogs, Cats,	High
			Kaunakakai Wetlands	375	Abundant	Rats,	High
			Kakahai`a NWR	625	Abundant	Mongooses	High
			Paialoa Pond	750	Abundant		High
Lāna`i	35,500	1,437	Whole island	250-500	Limited	Dogs, Cats, Rats	High
Kaho`olawe	12,100	450	Whole island	250-500	Limited	Cats	High

Island	Size (ha)	Maximum Elevation (m)	Site	Annual rainfall (mm)	Surface fresh water	Predators	Prey base
Maui	182,700	3,050	Kanahā Pond Sanctuary	500	Abundant	Dogs, Cats,	High
			Keālia Pond NWR	375	Abundant	Rats,	High
			Koanae Point	2000	Abundant	Mongooses	High
			Nu`u Pond	1500	Abundant		High
Hawai`i	1,045,800	4,150	Pololū Valley	1875	Abundant	Dogs, Cats,	High
			Waimanu Valley	2000	Abundant	Rats,	High
			Waipi`o Valley	2000	Abundant	Mongooses	High
			Loko Waka Ponds	3000	Abundant		High
			Ke`anae Pond	3000	Abundant		High
			Koloko Pond	250	Abundant		High
			`Ōpae`ula Pond	250	Abundant		High
			`Aimakapā Pond	250	Abundant		High
			Kona Refuge	---	Limited		High

Appendix 2-A. Assets of preferred sites evaluated for proposed reintroduction of the Laysan duck (from Reynolds and Kozar, 2000a).

Assets	Kure (Green Island)	Midway (Eastern and Spit Islands)	Lisianski	Nihoa	Kaho`olawe	Kaua`i (Hanalei)	Ni`ihau
Size of habitat	Small	Moderate	Moderate	Small	Large	Large	Large
Fresh water	Limited; creation feasible	Limited; creation feasible	Limited; restoration feasible	Available	Limited; ephemeral wetlands and gulches present; wetland enhancement proposed	Abundant	Abundant
Nesting cover	Moderate	Low, but restoration ongoing	Excellent	Good	Moderate with restoration ongoing	Good	Unknown
Predicted food abundance	Moderate	Moderate to high	Moderate	Good	Moderate	Abundant	Abundant

Appendix 2-A (continued). Assets of preferred sites evaluated for proposed reintroduction of the Laysan duck.

Assets	Kure (Green Island)	Midway (Eastern and Spit Islands)	Lisianski	Nihoa	Kaho`olawe	Kaua`i (Hanalei)	Ni`ihau
Logistical feasibility	Limited	High	Moderate	Difficult	Moderate	High	Difficult
Plant foods	Low	Moderate	Moderate	Moderate	Low	Abundant	Unknown
Infrastructure	Some	Good	None	None	Some	Good	Some
Land Management*	DLNR Wildlife Reserve, PMNM	USFWS-NWR, PMNM and Historical Site	USFWS-NWR, PMNM	USFWS-NWR, PMNM	KIRC Cultural and Ecological	USFWS-NWR	Privately owned Ranch

*DLNR = Department of Land and Natural Resources; PMNM = Papāhanaumokuākea Marine National Monument; USFWS-NWR = U.S. Fish and Wildlife Service National Wildlife Refuge; KIRC = Kaho`olawe Island Restoration Committee

Appendix 2-B. Liabilities of preferred sites evaluated for proposed reintroduction of the Laysan duck.

Liabilities	Kure (Green Island)	Midway (Sand, Eastern and Spit Islands)	Lisianski	Nihoa	Kaho`olawe	Kaua`i (Hanalei)	Ni`ihau
Human disturbance or hazards	Minimal	Minimal on Eastern & Spit; moderate on Sand	Minimal	None	Minimal, after ordnance removal	Moderate	Unknown
Food competitors (mice, predatory alien insects)	High	Low-moderate	Low	Low-moderate	Low-moderate	Moderate	unknown
Disease	Low?	Low?	Low?	Low?	Low?	Low?	Unknown
Predators	No	No	No	No	Yes	Yes	Yes
Management Required	Freshwater source	1) Revegetation 2) Freshwater source	Freshwater source	None	Predator removal	Predator removal	Predator removal
Management Beneficial	Weed and ant control	Weed, ant, mouse control	Weed and ant control	Unknown	Wetland restoration, mouse control	Upland vegetation restoration	Upland vegetation restoration

APPENDIX 3. **Summary of Comments Received on the Draft Revised Recovery Plan for the Laysan Duck**

In November 2004, we released the Draft Revised Recovery Plan for the Laysan duck for review and comment by Federal agencies, state and local governments, and members of the public. The public comment period was announced in the Federal Register (69 FR 64317) on November 4, 2004, and closed on January 3, 2005. More than 150 copies of the draft plan were sent out to interested parties for review during the comment period.

Four peer reviewers were contacted and agreed to provide comments on the draft plan; comments were received from all four scientific peer reviewers:

Pete McClelland, New Zealand Department of Conservation
Murray Williams, New Zealand Department of Conservation
Marie Morin, private consultant, Portland, Oregon
Paul Banko, U.S. Geological Survey, Biological Resources Discipline

In addition to comments from peer reviewers, we received six comment letters during the comment period, and some additional comments, information, and updates after the comment period ended. We carefully considered all comments received in finalizing this recovery plan. Many comments suggested additions or changes for clarification. A few comments suggested additional recovery actions. We thank all the commenters and peer reviewers for their time and interest in this recovery plan; the Revised Recovery Plan for the Laysan Duck was significantly improved as a result of the comments we received.

Summary of Comments and Service Responses

Issue 1: Downlisting criteria

Comment: Several commenters observed that an increasing population on Laysan Island is an unrealistic criterion for recovery. Even with habitat enhancement, Laysan has a limited carrying capacity for the Laysan duck, and the island's physiography and climate make the Laysan duck population there prone to frequent fluctuations. This criterion should be revised to describe a population that experiences such fluctuations but that is stable over the long term.

Response: The intent of this criterion is to ensure that the population is not declining, not to require that population be increasing continuously. Because the Laysan duck population on Laysan has experienced significant declines in the past and is likely to do so in the future, long periods of increase are an important feature of this population, and a realistic variable to include in this recovery criterion.

Comment: Two commenters asked for clarification of Downlisting Criterion #2 and the methods used to develop this criterion.

Response: We have substantially revised description of this criterion in the final plan.

Comment: One commenter suggested including review of recovery criteria by at least two population geneticists as a recovery action.

Response: We have added this review to recovery action 5, which describes review and update of the recovery plan.

Comment: One commented stated that the 100-year projection used in the population models was too short, and basing population sizes for recovery criteria on this projection would result in inadequate heterozygosity for the species to persist. The models should be re-run using a 1,000-year projection.

Response: We believe the 100-year projections were sufficient for the purposes of this recovery plan. Predicting environmental conditions in Hawai`i even 100 years from now is a sufficient challenge; conditions 500 or 1,000 years from now are impossible to guess. Models with a 1,000-year timeframe thus would not yield more informative results. We do not know what the current genetic variability is in the Laysan duck population. As we increase the total population of the species through establishment on additional islands, we may increase the chances that no existing variability is lost, but the likelihood of significantly increasing that variability on the timescale of species recovery is quite low, even if such an increase were demonstrably important (the Laysan duck shows no signs of inbreeding depression). Finally, we believe that other considerations, such as habitat restoration, are more pressing.

Issue 2: Recovery Actions (Restoration and Management)

Comment: One commenter noted that at present Kaho`olawe's wetlands are ephemeral, and asked how Laysan ducks would survive in this situation and whether they would be likely to fly to Maui in search of fresh water if they were released there.

Response: Laysan ducks have not yet been released on Kaho`olawe, and their release there within the next five years is highly unlikely. Permanent sources of fresh water would have to be established on Kaho`olawe before the island could support Laysan ducks. Fresh water is especially critical for ducklings, which cannot fly to another island. In addition, Kaho`olawe still harbors mammalian predators, and these will have to be eradicated or substantially controlled before Laysan ducks could be released on the island.

Comment: One commenter urged that the Service consider all alternatives before initiating a captive propagation program for the Laysan duck. The commenter cited the high expense and maintenance requirements of a captive propagation program, and the tendency for captive propagation to distract from addressing habitat restoration issues for the species involved.

Response: We agree. Especially in light of the excellent success of the first two translocations of juvenile ducks from Laysan to Midway, wild-to-wild translocation is our first choice. However, to supply a sufficient source for initiating new populations in the Main Hawaiian Islands, we may need to breed ducks at first, so as not to deplete any wild populations. When at least one Main Hawaiian Island population is established, it could be employed as a partial source for establishing more new populations and the captive program gradually phased out.

Comment: Two commenters felt that we did not adequately emphasize the importance of quarantine (between the Main Hawaiian Islands and the Northwestern Hawaiian Islands and among the Northwestern Hawaiian Islands) to address the risk of moving alien pathogens, parasites, plants, and invertebrates among islands.

Response: The Service's Refuges division maintains quarantine procedures for these islands. We have revised the recovery plan to place addition emphasis on the importance of quarantine in protecting the biotic integrity of the Northwestern Hawaiian Islands.

Comment: One commenter suggests that Laysan ducks in mainland zoos where pedigrees have been kept should be screened to assess the suitability of returning them or their eggs to Hawaii. These ducks may harbor important genetic diversity that has been lost from the wild population and be useful for initiating a captive propagation program. Another commenter stated emphatically that mainland ducks should not be returned to Hawaii.

Response: In order to assess genetic differences between wild and captive Laysan ducks (those that are certain not to have hybridized with other species), it will be necessary first to obtain a more detailed picture of genetic variability in wild Laysan ducks (in the extant birds and in museum collections) and review the histories of captive ducks to determine when their progenitors were taken into captivity. If founders were captured when the population was at ebb in the first half of the 20th century, the resulting captive populations are likely to exhibit no more, and possibly less, genetic variation than the wild population. In addition, alleles found in captive populations but not in wild ducks may be novel results of selection in captivity rather than historical variability in the species. This phenomenon has been well documented in recent years, and may be linked to behavioral changes in captivity that are maladaptive to life in the wild (see Frankham 2008). Finally, Laysan ducks that proved to be candidates for return to Hawai`i for genetic reasons also would have to be intensively screened for pathogens and parasites that could pose a threat to native Hawaiian birds. For this reason alone, we are disinclined to bring any mainland birds to Hawaii, especially in light of new concerns about West Nile virus and avian influenza.

We recognize the potential recovery value of some of the captive Laysan duck populations. However, until a full analysis of genetic variability in the wild population has been conducted, assessing the genetic status of captive populations probably will remain a low priority.

Comment: One commenter asked why we did not consider taking newly laid (unincubated) eggs from Laysan for translocation, thus triggering breeding pairs on Laysan to re-nest and resulting in perhaps the least impact on the Laysan Island population.

Response: We determined that moving fledged juvenile birds from Laysan was the best alternative for several reasons. Fledged juveniles have been raised by other ducks, whereas incubating eggs and raising ducklings at the translocation site would result in a founding population of ducks that have not imprinted on or been socialized by adults of their own species – circumstances that could have a host of unforeseen consequences for the animals. In addition, incubating eggs and hand-rearing ducks at the release site would be an order of magnitude more resource- and time-intensive than moving and releasing independent juveniles, especially on islands that lack the permanent staff and infrastructure that Midway has. Finally, we determined that translocations would only take place in years with high numbers of adults and a high rate of reproduction on Laysan; in such years, when the population on Laysan is at or near carrying capacity, survival of fledglings typically is low and therefore translocated birds would not be likely to have survived on Laysan.

Comment: One commenter suggested forming a recovery group to provide ongoing technical advice as new information becomes available.
Response: Although the Service has not elected to form an official Recovery Team for the Laysan duck, we have an informal group of scientists, land managers, and taxonomic experts that we depend upon to provide review and technical input as necessary.

Comment: Two commenters questioned whether we adequately consider genetic issues around the establishment of new Laysan duck populations and a population in captive propagation.
Response: We recognize that maintaining the existing genetic diversity in the Laysan duck may require periodic "immigration translocations" to newly established populations and careful breeding management in a captive population. These actions must apply the results of DNA analysis to be effective; this research need is identified in the recovery plan.

Comment: One commenter emphasized that detailed, written protocols for Laysan duck surveys and behavioral observations are necessary to ensure consistency and high quality in data collection.
Response: These protocols, as well as detailed documentation of translocation methods, are currently in development; the recovery actions have been revised to include this point.

Comment: One commenter stated that the recovery plan should place more emphasis on the potential threat of mosquito-borne diseases to Laysan ducks at Midway and recommended adding mosquito control and study of avian pox at Midway to the recovery actions.
Response: The threat of mosquito-borne diseases to the Laysan duck is poorly understood, and a study of avian pox at Midway has been added to the recovery actions. In addition, the recovery plan has been revised to include description of extensive mosquito control efforts at Midway.

Comment: One commenter observed that data from currently banded ducks will be useful for population monitoring for a limited time, and asked how often ducks should be banded and how many should be banded at a time.

Response: Ongoing banding efforts must be coupled with intensive resight surveys, and we have found that a volunteer or technician placed on Laysan Island who is dedicated to Laysan duck surveys obtains a high number of accurate resights. Because the probability of sighting (as contrasted with recapturing) banded birds is the same as sighting unbanded birds, the proportion of the population that is banded can be estimated from resights. Intensive banding efforts on Laysan took place most recently in 2004 and 2005 in conjunction with the two translocations to Midway. Ideally, all hatch year birds should be banded after fledging (during September-October), and we will endeavor to do this every other year as logistics and funding permit. Fledgling banding at this rate would allow estimates of fledgling success and maintain a high proportion of banded birds in the Laysan population to facilitate population estimates and annual monitoring of reproduction and survivorship.

Issue 3: Recovery actions (additional research)

Comment: Most commenters noted the importance of conducting research on the ecology, behavior, and life history of Laysan ducks at Midway. Several observed that this research should be used to inform the selection and preparation of additional translocation sites.

Response: We agree. The nascent population of Laysan ducks at Midway provides the first opportunity to study the species in an environment other than Laysan. We hope to document what aspects of the duck's biology and ecology are responsive to this new environment, which, arguably, may be more similar to other potential release sites than is Laysan Island.

Comment: One commenter suggested conducting additional paleoecological studies in the Main Hawaiian Islands, including analysis of stable carbon and nitrogen isotopes in subfossil bones of the Laysan duck and paleobotanical research at the excavation sites, to explore the trophic level of the species' diet and refine our knowledge of the habitats where the species occurred.

Response: Although this would be interesting information, we cannot prioritize such a study as necessary for the species' recovery. The Laysan duck has been extirpated from the Main Hawaiian Islands for many centuries, and founders for reintroductions ultimately will come from the Northwestern Hawaiian Islands. Observations from Laysan and Midway suggest that Laysan ducks have a diverse diet and are catholic in their use of various habitat elements.

Issue 4: Native Hawaiian traditional and cultural gathering and access rights

Comment: One commenter stated that any critical habitat designation in the state of Hawai`i must take into account the access and cultural gathering rights guaranteed by the state's constitution.

Response: At this time, no critical habitat is designated or proposed for the Laysan duck.

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