

Draft Revised Recovery Plan for the Laysan Duck

(Anas laysanensis)



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

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U.S. Fish and Wildlife Service
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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 Laysan duck currently has the most restricted range of any duck in the world, with a single remaining population on Laysan Island in the Northwestern Hawaiian Islands. The species was extirpated from most other islands of the Hawaiian archipelago after the arrival of the first humans about 1,500 years ago. To date, Laysan duck bones have been found from extirpated populations on the islands of Hawai'i, Maui, Moloka'i, O'ahu, Kaua'i, and Lisianski. The total estimated population size on Laysan Island has fluctuated from 7 to 688 adult birds in the last century. The most recent (2001) population estimate of adult birds is 459. Viability models for small populations of isolated species predict a high risk of extinction due to catastrophic, environmental, genetic, and demographic stochasticity.

Habitat Requirements: The habitat requirements of the Laysan duck include vegetation in which to take cover, an abundant prey base of invertebrates, a source of fresh water, and protection from mammalian predators. On Laysan Island, 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 requirements for growth and initial inability to process saltwater. Duckling activities 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 it 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.

Prehistoric populations of the Laysan duck on the Main Hawaiian Islands were most likely extirpated by a combination of human hunting, habitat destruction or degradation, and predation by introduced mammals, especially rats (*Rattus exulans*). Introduced mammalian predators would pose the most severe threat to new populations of Laysan ducks in the Main Hawaiian Islands (Factor C). Alien species indirectly harmful to the historical Laysan and/or extirpated Lisianski populations through habitat alteration include rabbits, mice, invasive weeds, and possibly predatory insects (Factor A). Storms, drought-related food reductions, disease, and limited carrying capacity are among the factors limiting the Laysan population today (Factors C and E). High duckling mortality in 1999 and 2000 suggests a lack of sufficient brood rearing habitat on Laysan (Factor A). Inbreeding depression may be a limiting factor, but additional information is required to evaluate this possibility (Factor E). Long-term threats include the accelerated filling of Laysan's freshwater seeps and lake (Factor A); these changes result from 20th century revegetation of the islands by rabbits and may be exacerbated by sea level rise due to global warming. Sea level rise resulting from global climate change may result in the loss of terrestrial habitat (Factor E). The actions proposed in this plan are designed to address these threats to the Laysan duck and to reestablish multiple populations on additional islands in order to achieve recovery objectives for the species.

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 reduce risks to the Laysan Island population; 2) protection and enhancement of suitable habitat; and 3) actions to reduce or eliminate threats sufficient to allow successful reestablishment of additional wild populations.

Recovery Criteria: At this time we have developed only interim downlisting criteria for the Laysan duck due to the data limitations and potential uncertainties associated with attempting to define realistic criteria for delisting, particularly in regard to target population sizes. Because our knowledge of Laysan duck population biology and ecology is restricted to observations from the unique environment of Laysan Island, we

currently have no reliable biological basis for setting target population sizes for delisting on other islands with very different habitats and potential threats. Delisting criteria, when developed, must be based on new information that can only be accumulated as we begin to implement the recovery actions outlined in this plan and learn about the population dynamics and growth rates of Laysan ducks in new habitats on islands other than Laysan. For downlisting, the following conditions must be met:

Criterion 1. The Laysan Island population is stable or increasing (finite rate of population growth or λ greater than or equal to 1.0) when averaged over a continuous period of at least 15 years.

Criterion 2. A total of at least 920 potentially breeding adult birds exist in at least 5 stable or increasing populations on a combination of predator-free Northwestern Hawaiian Islands (including Laysan) and predator-controlled sites on Main Hawaiian Islands. The population on Laysan Island should remain at a level of from 400 to 500 birds; the remaining 4 or more newly established populations should occur on a combination of predator-free Northwestern Hawaiian Islands and predator-controlled sites on the Main Hawaiian Islands, and should number approximately 130 breeding adult birds each (depending on the size of the habitat available on each island).

Criterion 3. A successful captive or semi-captive breeding program is established using wild source eggs. These captive populations are managed primarily for reintroductions to the Main Hawaiian Islands.

Criterion 4. A plan for achieving gene flow between wild source populations through long-term inter-island translocations is developed and implemented.

Criterion 5. Island-specific management plans for each population are created that identify actions (such as supplementation, habitat improvement and predator control) sufficient to reduce threats and increase the populations to recovery levels.

Date of Recovery: Downlisting could occur by 2019 if criteria have been met. Due to the many uncertainties regarding the data needed to develop sound delisting criteria, we have determined that further research is needed before such criteria may be defined, therefore at this time we cannot estimate when delisting might occur.

Total Estimated Cost of Recovery: The estimated cost for recovery actions over the next 5 years is \$9,325,000.

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I. INTRODUCTION AND OVERVIEW

A. Status Overview and Structure of the Recovery Plan

(U.S. Fish and Wildlife Service [USFWS] 2002).

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, Giffen 1993, Pyle 1997). Following human colonization of the Hawaiian Islands in approximately 400 A.D., endemic species declined markedly in numbers and distribution (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 2 seabirds. In addition to birds, Hawai'i's remaining flora and fauna are also vulnerable to extinction. Hawai'i is home to 322 of the 1,258 animal and plant species federally listed as threatened or endangered nationwide, roughly 25 percent of all listed species

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. Of the 30 species or subspecies of birds currently listed as threatened or endangered, 10 may already be extinct. These numbers indicate that roughly half of the Hawaiian land and water birds that were present at the time of European contact have disappeared in the last two centuries (Scott *et al.* 2001).

The Laysan duck (*Anas laysensis*), also known as the Laysan teal, is one of six extant waterbird species that are endemic to Hawai'i. The Laysan duck currently has the most restricted range of any duck in the world, with a single population estimated at 459 adult birds on the small island of Laysan in the Northwestern Hawaiian Islands (Figure 1). In recorded history, only one other population of Laysan ducks was known, on adjacent Lisianski Island (Olson and Ziegler 1995). However, that population had been extirpated by the early 1800's, leaving only the remnant population on Laysan Island.

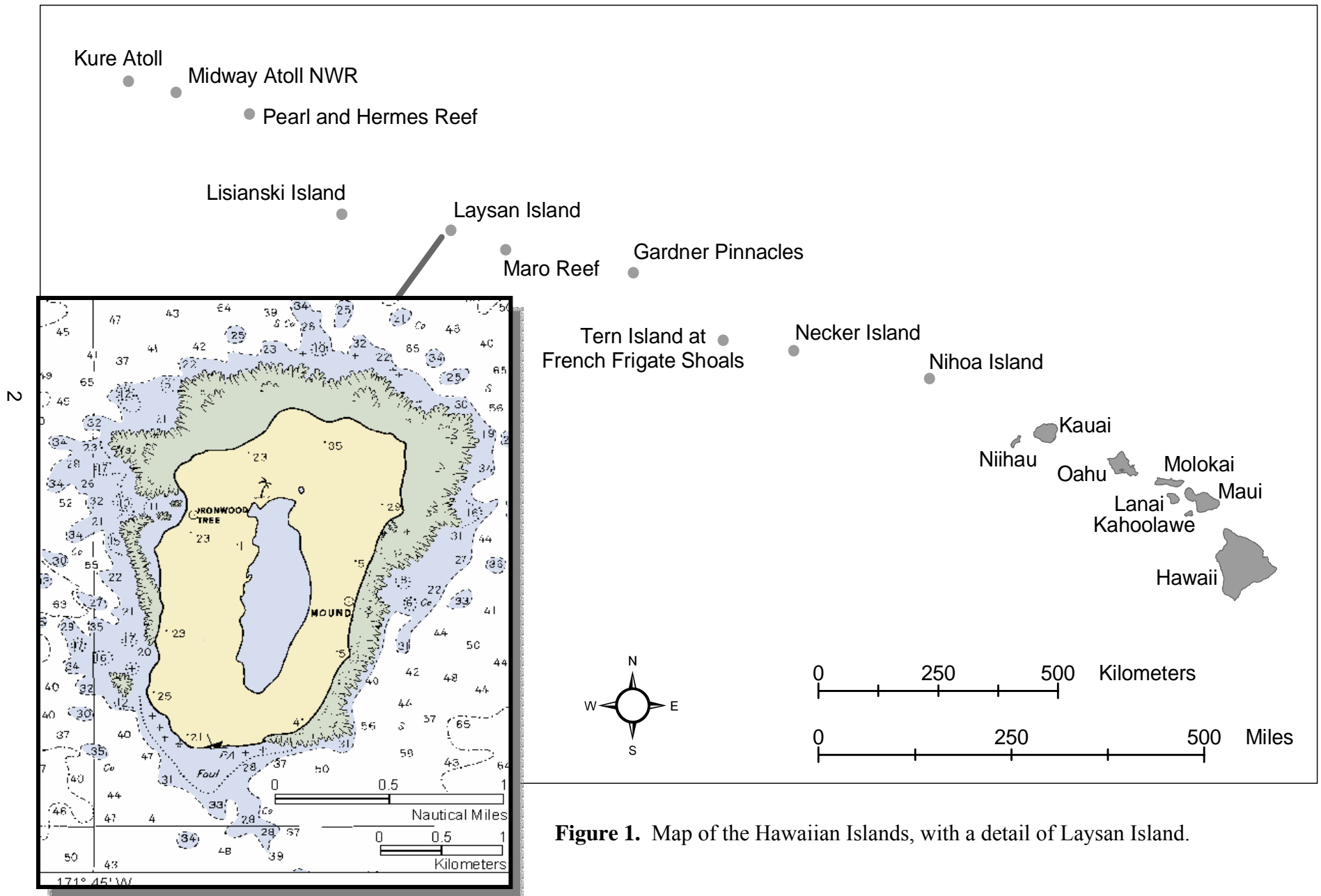


Figure 1. Map of the Hawaiian Islands, with a detail of Laysan Island.

We have only recently learned through subfossil evidence that the Laysan duck 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 rats (*Rattus exulans*), habitat loss, and predation by humans, and possibly introduced dogs (*Canis familiaris*) and pigs (*Sus scrofa*).

The Laysan duck was federally listed as endangered in 1967 (USFWS 1967). Sixty-five of the world's 231 species of waterfowl are endangered; of these, the Laysan duck is one of the most critically endangered (Black 1998). 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 1C; 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 human activities. Critical habitat has not been designated for the Laysan duck.

The strategy to recover the Laysan duck consists of maintaining the population on Laysan, reducing or eliminating the current threats to the species, and reestablishing populations on several other islands at levels capable of withstanding random environmental and demographic fluctuations. Populations large enough to tolerate environmental uncertainties will also be able to withstand demographic uncertainties. Based on the results of population viability analyses, we estimate that the establishment of multiple populations on a combination of Northwestern and Main Hawaiian islands, managed to ensure periodic gene flow between them, will ensure the long-term persistence of the Laysan duck.

The original recovery plan for the Laysan duck was issued in 1982 (USFWS 1982). In the subsequent 20+ years, we have learned a great deal about this species. In addition to providing a recovery strategy for the Laysan duck, this revised recovery plan also provides a synthesis of our current knowledge of the ecology of the duck and its recent and prehistoric distribution.

This recovery plan is divided into four main 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 both 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 effective adaptive management in advancing the recovery of the Laysan duck, as many variables remain unknown and long-term planning without inherent flexibility is unlikely to succeed. These short-term implementation plans will be prepared every 5 years to reflect the knowledge gained and refine the management program accordingly 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 2002). Males are heavier than females in most seasons, but females tend to be heavier than males during the pre-breeding and laying stages. Other morphometric characteristics (wing chord, tarsus, and bill length) are on average slightly larger for males (Moulton and Marshall 1996).

As with other waterfowl, Laysan ducks molt 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 terrestrial predators, this vulnerability is most likely heightened during the molt.

Ducklings are precocial (hatched with down and eyes open; able to walk, but are led by hen and taught how and

where to forage) and 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 a 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 (clutch size averages 3.8 eggs). 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 compared 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 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. Once thought to be closely related to the North American mallard group and the Hawaiian duck or koloa (*Anas wyvilliana*), new 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 origins.

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 415 hectares (1,025 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 187 hectares (462 acres) of vegetated habitat and 105 hectares (259 acres) of interior lake and mudflat area (Morin 1992). The remaining area consists of coastal dune and beach (Moulton and Marshall 1996). The one large interior lake is characterized by high salinity, high nutrient content, and low species diversity. The lake's salinity is 3 to 4 times oceanic salinity. 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 was 6.5 meters (21

feet) in 1984 (USFWS data); in the early 20th century the lake was much deeper than it is today.

The island's highest point is 12 meters (39 feet) above sea level (Morin and Conant 1998). There are coastal reef flats and tide pools around the perimeter. Fresh and brackish (0.0 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 79 centimeters (31.1 inches) per year from 1992 to 2000 (range 38 to 120

centimeters [15 to 47 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 a Coral Reef Reserve (USFWS 1982, National Oceanic and Atmospheric Administration [NOAA] 2001).

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 1800's described the native flora and fauna in some detail (Morin and Conant 1998, Schauinsland 1899 in Rauzon 2001). 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, land birds, seals, and turtles were much more abundant. The introduction of rabbits (*Oryctolagus cuniculus*) around 1903 altered the floral and faunal composition of the island drastically. The seabirds recovered following the eradication of the rabbit population 20 years later, but 3 of 5 land birds 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, notably *Cenchrus echinatus*, a noxious 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 southwest 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 11 meters (36 feet) high at its highest point (Rauzon 2001). 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 an onslaught of mice, with devastating consequences for the vegetation on the island. 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 rabbits soon depleted after they were 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 *C. echinatus* has become established, however, and is spreading in the native vegetation and along the coast (Starr and Martz 1999, Reynolds and Kozar 2000a).

It is difficult to determine to what extent Lisianski's invertebrate fauna has changed since human contact, but extensive alteration is likely. A recent survey listed 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) and one was deliberately introduced (Nishida 1999). In addition,

Reynolds and Kozar (2000a) found the native *Agrotis* moths and abundant larvae on Lisianski (both serve as prey for Laysan duck), which were not noted in Nishida's 1999 species list.

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).

3. Prehistoric Habitat

Recently acquired subfossil evidence reveals that Laysan ducks formerly occurred on most of the major Hawaiian Islands (Olson and Ziegler 1995; Cooper *et al.* 1996; H. James, pers. comm. 2000; Figure 2). Remains of adult and flightless juvenile Laysan ducks have been found on Hawai'i Island at high elevations including sites on Mt. Hualalai (at 1,244, 1,792, 1,189, and 1,128 meters [4,080, 5,878, 3,900 and 3,700 feet] above sea level), Mauna Kea, and Mauna Loa (1,524 meters [5,000 feet]). Remains from lower elevations (61 meters [200 feet]) were found near the coast at Hawai'i's 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

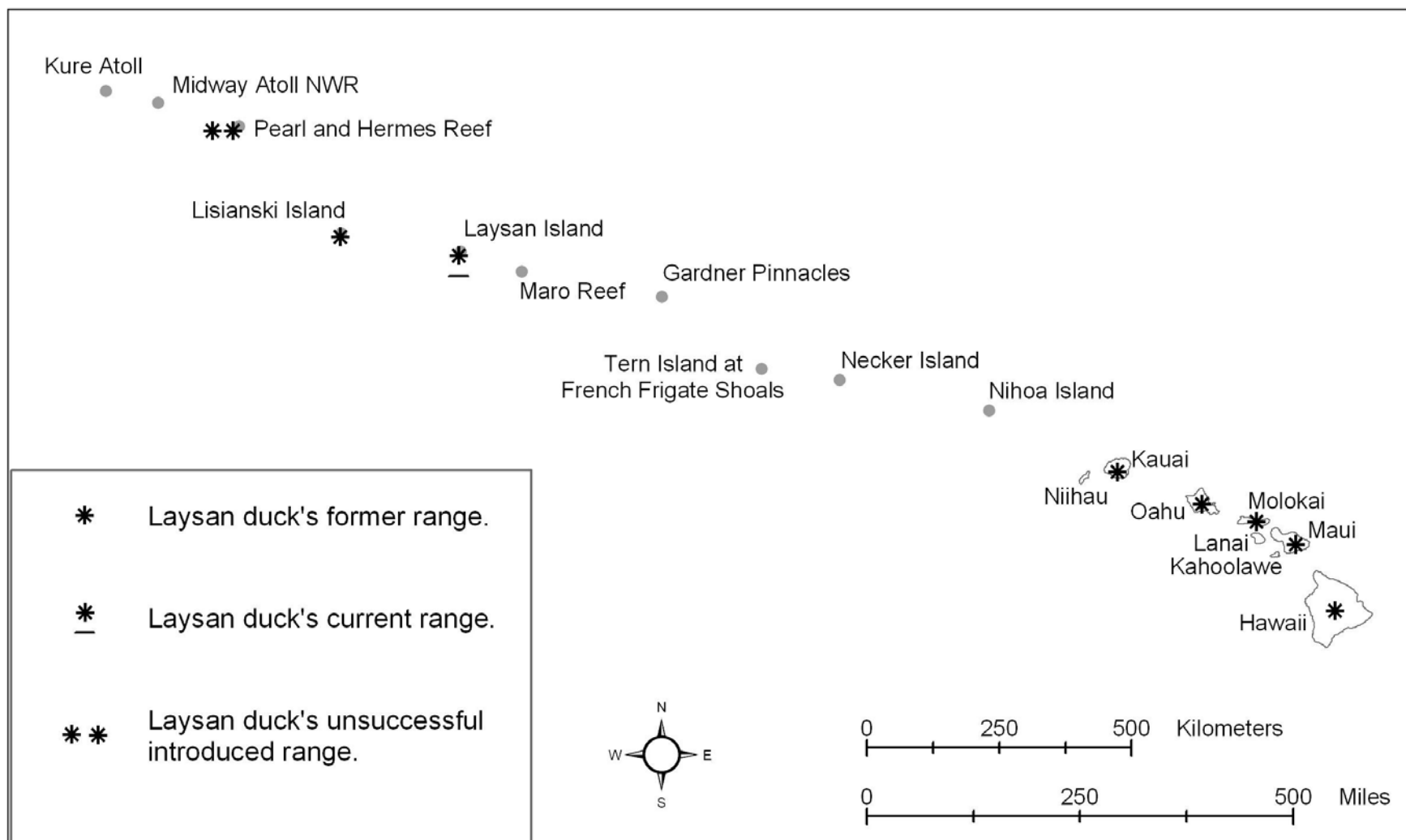


Figure 2. Map of the Hawaiian Islands showing the Laysan duck's known former range, current range, and site of unsuccessful translocation attempt in 1967.

Kalaeloa (Barbers Point) on O`ahu, and on Kaua`i at Poipu, Makawehi, and Kealia dunes (H. James, pers. comm. 2000).

The Laysan duck's prehistoric habitat on these high elevation islands was likely 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 systems exist in the main islands, indicating Laysan ducks were not historically dependent on this type of habitat.

D. General Biology and Ecology

1. Habitat Use

Prior to the discovery of bones in very diverse habitats on other islands, the Laysan duck was believed to be endemic to the Northwestern Hawaiian Islands, and particularly specialized for Laysan Island. Many factors have contributed to its current isolation, including introduced mammalian predators on the Main Hawaiian Islands and habitat loss due to introduced mammals on Lisianski combined with overexploitation by humans. The relevance of current habitat use is 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 ecological conditions on Laysan may not be ideal for this species.

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. Warner (1963), however, 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 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 surrounding the camp.

Radio telemetry and behavioral observations were used in 1998 through 2000 to quantify habitat use in these four zones and the activity budgets of adult ducks on Laysan during three breeding seasons and one winter season (Reynolds 2002). Tracking data

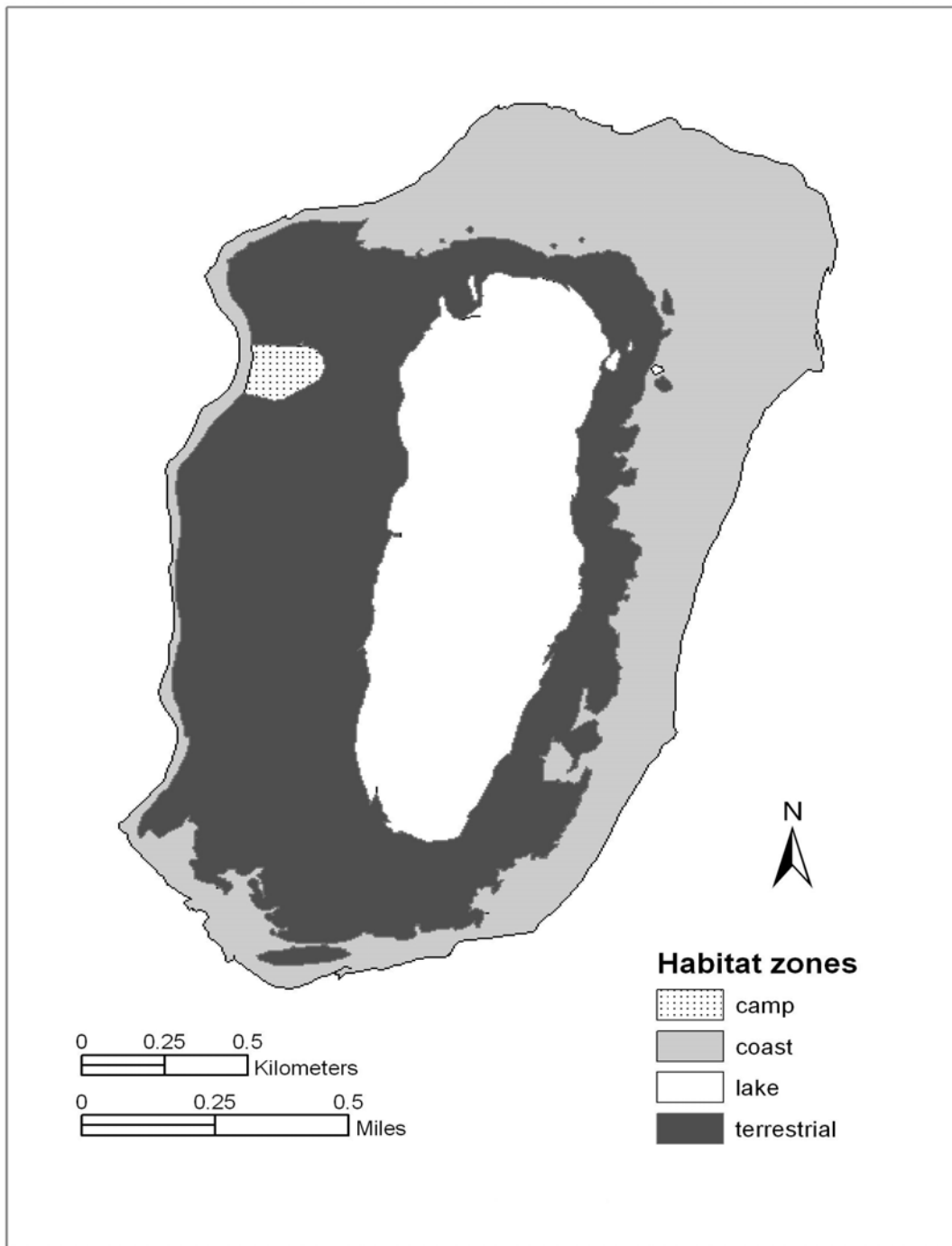


Figure 3. Map of habitat zones on Laysan Island.

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 habitats (1 percent). Time budgets for activities within each habitat are given in Figure 4 (Reynolds 2002).

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 evidence of selective habitat use by time of day (Reynolds 2002), as detailed below.

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 (*E. variabilis*) or shrubs (*S. 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 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 diurnally and nocturnally. At dusk birds moved actively between habitat zones. Some ducks visited coastal reef flats and coastal freshwater seeps in the late afternoon, and many

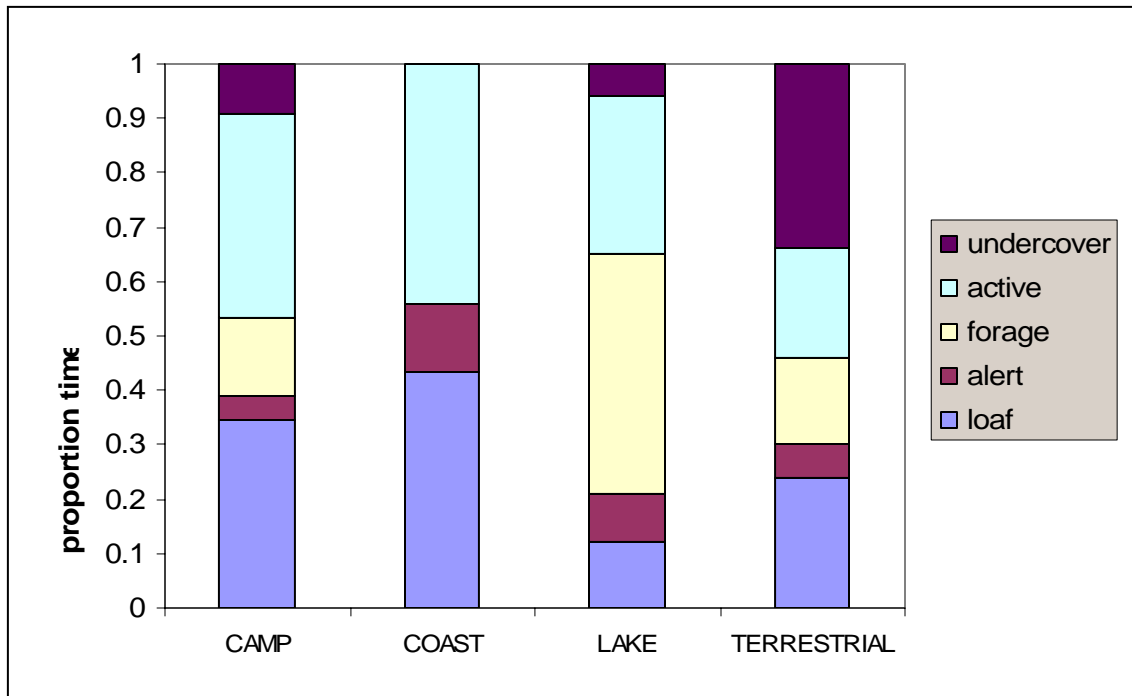


Figure 4. Time activity budget of Laysan ducks in habitat zones of Laysan Island (n = 402 observations; 8,511 minutes).

birds visited the lake zone. The ducks rarely foraged on the coast.

During the dusk 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 a frequently used nocturnal foraging area, 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 after dark (Reynolds 2002).

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 as a result of reduced prey abundance (brine flies) at the lake. Data from resighting color-banded individuals suggest that time spent in camp by some birds (“camp specialists”) increased from early spring to mid-summer. Time spent in camp by radio-tagged birds was correlated with an increase in moth abundance in camp (Reynolds 2002).

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 2002). The tidepools at the south 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).

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). In the 1999 and 2000 breeding seasons, some individuals rarely used the lake zone (Reynolds 2002). Moulton and Weller (1984) also found that some Laysan ducks did not use the lake.

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 underdeveloped salt glands (Wobeser and Howard 1987). Although the adult Laysan duck has an efficient salt gland, the concentration of adults and ducklings at brackish seeps, freshwater seeps, and ephemeral freshwater wetlands implies these sources of low-salinity water are important (Lenz and Gagne 1986, Marshall 1989b, 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 source of fresh water, Laysan ducks can opportunistically take water from a variety of sources. 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 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 is a primary factor involved in regulating populations and influencing reproductive success of birds (Lack 1970). The Laysan duck's current foraging ecology on Laysan, like its habitat use, probably is quite different than its prehistoric foraging ecology on the main 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 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 1989a). 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 in the 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 2002). 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. It is also possible that native arthropods were more diverse and abundant in the past, prior to the introduction of alien predators such as ants, such that more terrestrial arthropods may have formerly been available as prey for the Laysan

duck. Warner (1963) hypothesized that the shift in diet to greater reliance on brine flies was triggered by the introduction of a parasitic wasp (order Hymenoptera) that feeds on moth larvae, but no research has been carried out on the issue (Kear 1977).

Diet Composition

The Laysan duck is primarily insectivorous, but feeds opportunistically on seeds, leaves, and algae (Reynolds 2002). Behavioral observations indicate that adult and larval lepidopterans, adults and larval terrestrial dipterans, blatteria (cockroaches), grass seeds, sedge achenes, and succulent leaves are taken while foraging in terrestrial habitats (Reynolds 2002). 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 insects, which have hard parts that are able to 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 2002; Table 1). Based on the birds' behavior, and because so many specimens passed through the digestive system completely

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 2002).

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
		<i>Artemia</i> 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 (<i>Neoscatella sexnotata</i>)	(brine fly)	39
		Artemia	(brine shrimp)	32
		Lepidopteran larvae	(moth or butterfly larvae)	32
		Dictyoptera	(cockroaches and mantids)	21
		Dipteran larvae (<i>N. sexnotata</i>)	(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

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

Foraging Behavior

Laysan ducks utilized a variety of foraging behaviors and foraging 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 near the house of the guano mining company's director, looking for moths (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 brine fly 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 on brine flies, suggesting a preference for brine flies only when they are very abundant (more than 1,000 flies per unit area). Twenty-one percent of the total foraging effort at the lake before sunset was dedicated to feeding on brine flies during this early part of the breeding season (Reynolds 2002).

Invertebrate Abundance

The role of food availability in the population dynamics of dabbling ducks is not well understood (Owen and Black 1990). The number 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; see Figure 5). 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 1989b, Reynolds 2002).

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. Many factors ultimately are responsible for

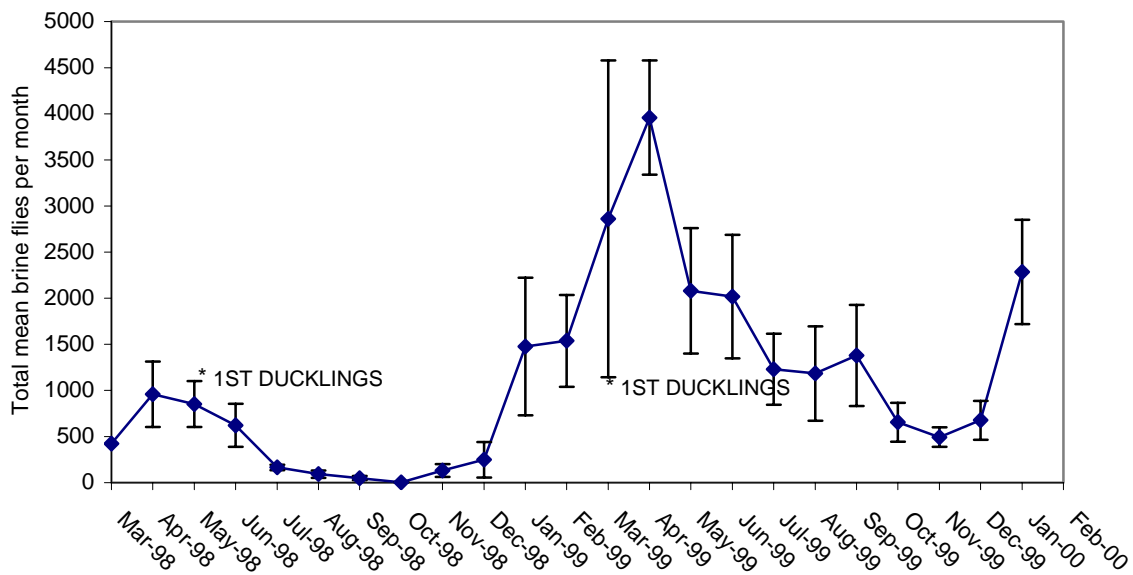


Figure 5. Seasonal brine fly (*Neoscatella sexnotata*) abundance reported as monthly mean with standard error, and first brood sightings of Laysan ducks 1998 to 1999 (Reynolds 2002).

producing optimal 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 depth 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 (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 exclusively on *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.

Terrestrial Zone. Comparisons of arthropod abundance in terrestrial vegetation types indicate 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.

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 and prey abundance in 1999 (Reynolds 2002).

3. Reproductive Biology

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, 69 percent of mated pairs (n = 26 marked pairs) reunited once molt and brood rearing were complete (Reynolds 2002).

Nesting

Many ecological features affect waterfowl breeding, such as climate, hydroperiod, and temporal availability of suitable food (Baldassarre and Bolen 1994), therefore the Laysan duck's productivity is highly variable from year to year. The nesting season for the duck on Laysan generally runs from April through July, but reproductive response is flexible according to habitat conditions (Moulton and Marshall 1996). Early broods were produced in December 1996 and 2000 (Bernard *et al.* 1996, Depkin and Lund 2001); abundant rainfall occurred during those years, and an abundance of prey was observed in 2000 as well (Reynolds 2002).

Compared to other dabbling ducks, Laysan ducks have a reduced clutch size (average 3.8 eggs) and very large eggs for their 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).

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 the 26 total nests monitored, 92 percent occurred in the native *E. variabilis* (Moulton and Weller 1984, Reynolds 2002).

Incubation lasts 28 to 29 days (Marshall 1992a). 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 may have been elevated by human disturbance of nests. More recent studies, using methods modified to prevent nest disturbance by researchers, showed 13 percent of eggs scavenged or depredated by birds, 18

percent infertile or undeveloped eggs, and 6.5 percent incomplete hatches. The fates of 8 percent of eggs were undetermined. Hatching success of 61 eggs from 17 nests was 48 percent (Reynolds 2002). Our understanding of the nesting biology of the Laysan duck would benefit greatly from additional study.

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 1989b). Ducklings follow the hen very closely for the first 4 days. During this period, hens lead ducklings from upland nesting sites to wetland brood rearing areas. Brood rearing areas are characterized by high densities of invertebrates, fresh or brackish 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 (mixed 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 she 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 repaid 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 8 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 not a benefit to young or adults (Williams 1974, Bedard and Munro 1977 in Batt *et. al.* 1992, Kehoe 1989). None of these possibilities has been investigated on Laysan. As 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, compared with 33 percent in 2000 (Reynolds 2002). Complete reproductive failure occurred in 1987 and 1993 (Marshall 1989a, Moulton and Marshall 1996).

4. Demography

Population Size

Laysan duck populations have undergone severe fluctuations this century, with estimates from as few as 7 adults in the early 1900's to perhaps as many as 688 adult birds in 1961 (USFWS 1982), although this high number is believed to be an overestimate (Marshall 1992b). Sincock and Kridler (1977) described the Laysan duck as the most difficult to survey of the four endangered birds of the Northwestern Hawaiian Islands. In the past decade alone, duck estimates have varied from fewer than 100 to approximately 600 individuals (Reynolds 2002).

Previous researchers have 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 using the Lincoln-Peterson index (Lancia *et al.* 1996), and field studies initiated in 1998 emphasized methods to more accurately determine population size. Since 1998, these estimates indicate that the population on Laysan Island has increased from 288 to 459 adult birds as of 2001 (Table 2; Reynolds 2002). For a more detailed discussion of current monitoring

Table 2. Estimates of Laysan duck population size on the island of Laysan using line-transect and mark-resight methods.

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 -434	Lincoln- Petersen Index	Adult estimate	100	Reynolds 2002
1999	292	263 - 321	Lincoln- Petersen Index	Adult estimate	158	Reynolds 2002
2000	322	290 - 354	Lincoln- Petersen Index	Adult estimate	220	Reynolds 2002
2001	459	391 - 537	Lincoln- Petersen Index	Adult estimate	260	Reynolds 2002

methods, see *Laysan Duck Population Monitoring*, below.

Sex Ratio

The sex ratio of Laysan ducks on Laysan Island typically 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.

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*) is the only potential resident predator on ducklings. Frigatebirds have been observed to take the chicks of terns and other seabirds (A. Marshall, pers. comm. 2002), but because frigatebirds have never been observed to take ducklings, the total impact of great frigatebird predation on ducklings is presumed to be minimal. The ducks are alert to great 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)

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 (see *Diseases*, below). Data from carcasses incidentally collected in 1993 and 1998 through 2001 revealed that factors contributing to mortality were quite different for adults and juveniles. Of the 86 carcasses found, 45 were suitable for exam and cause of death could be determined definitively in 33 cases; the remaining 12 cases represent educated

guesses. Most adult mortalities were caused by starvation and infestation by the nematode *Echinurea uncinata* (echinuriasis) (n = 14). An adult female was found egg-bound and also suffering echinuriasis. Two adults were found dead from starvation (no sign of nematodes), and one adult died of bacterial encephalitis (National Wildlife Health Research Center [NWHRC] 1993, 1998, 1999, 2000, 2001). Moulton and Weller (1984) reported adult mortality by sexual 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 (T. Work, pers. comm. 2003).

Most ducklings, in contrast, died of traumatic injuries (n = 27). 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 in Johnson *et al.* 1992). Ducklings are also susceptible to trauma from aggression by albatross and other large seabirds, which are abundant on Laysan. In 1992 our field staff found 10 ducklings with

crushed skulls. Great frigatebird attacks were suspected as the cause of death (Newton and Chapelle 1992).

Of the 27 duckling carcasses suitable for exam, 7 exhibited no obvious signs of trauma, starvation, or disease; these deaths were attributed to exposure to adverse weather. Duckling mortality 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. Seven of 13 downy-stage duckling carcasses examined contained yolk sac remains, indicating these birds did not die of starvation (NWHRC 1998, 1999, 2000, 2001; Figure 6).

Mortality trends. Brood monitoring data and the age structure of incidental carcasses found between 1998 and 2000 (n = 86) reveal that the downy-stage ducklings are the most vulnerable, especially during the first 6 days after hatching. Most carcasses (76 percent) found were ducklings in the downy plumage stages less than 18 days old (Figure 7). Duckling carcasses from 1998 through 2001 were found mostly in the spring and summer after the peak of hatching (Reynolds 2002). Of the carcasses recovered in 1998 through 2000, adults comprised 16 percent of the specimens, 57 percent of which were females. 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

Delisting through elimination or reduction of threats and population restoration is the recovery goal for the Laysan duck. To reach this goal, it is necessary to achieve viability for the 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 in an environment subject to random, naturally occurring (stochastic) 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 collectively the constituent populations function 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 (Hu 1998). A population that becomes sufficiently reduced in size becomes vulnerable to stochastic forces, which often lead to its extinction (Meffe and Carroll 1997).

Population persistence models were employed to forecast possible population fates for the Laysan duck resulting from the effects of a variety of

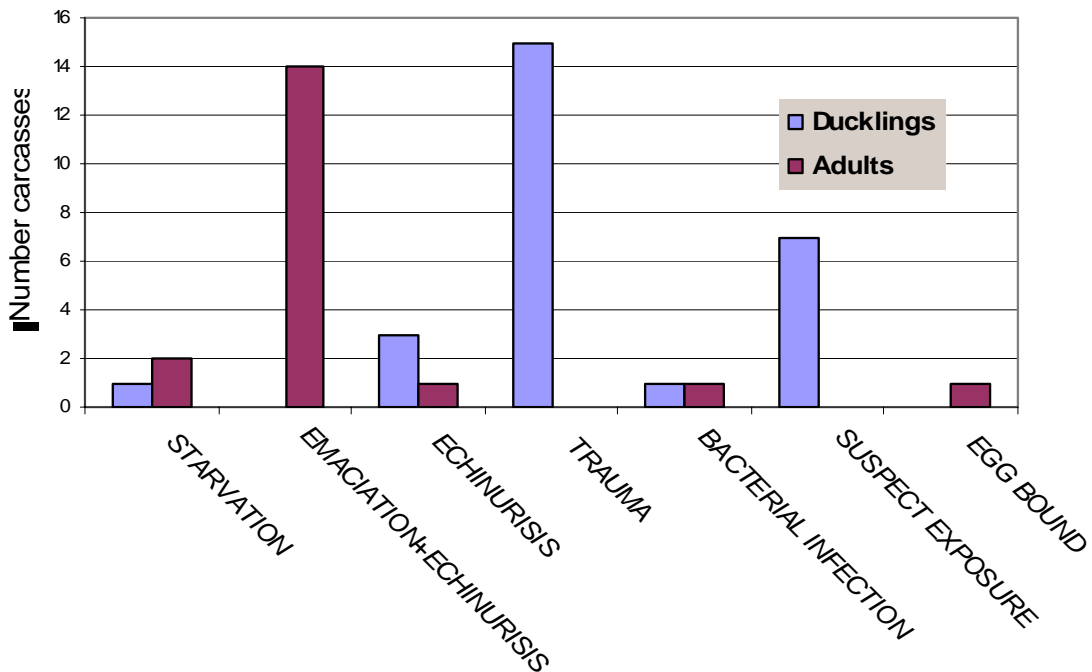


Figure 6. Causes of mortality for Laysan duck adults and ducklings found dead 1993 to 2001 (n = 45).

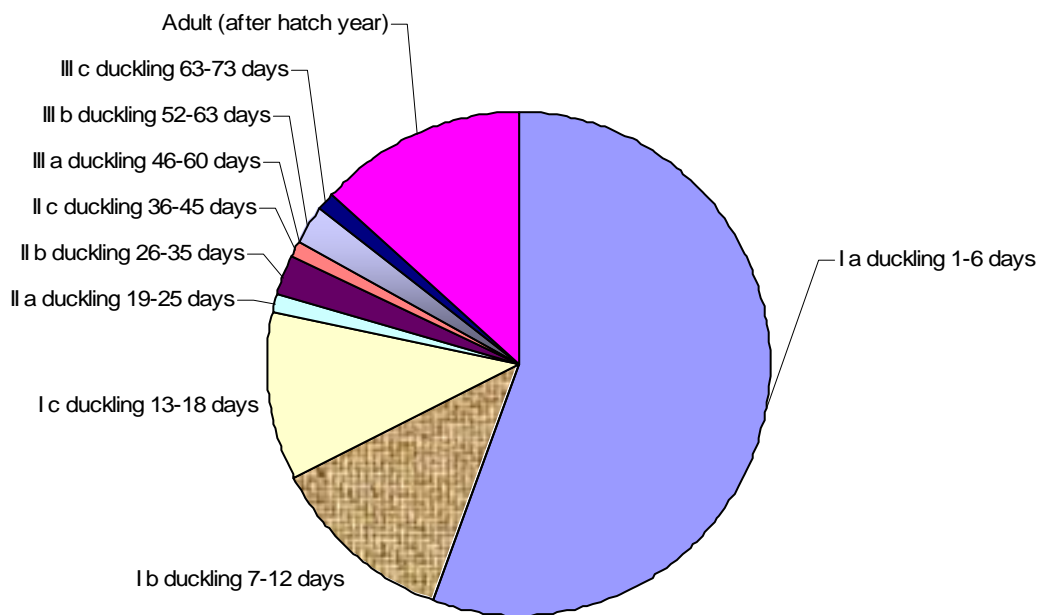


Figure 7. Laysan duck carcass age class breakdown from 1998 to 2001 (n = 86).

scenarios. These models, called population viability analyses (often abbreviated as PVA), are widely used to evaluate extinction risk and to assess management options for species recovery. Factors included in the simulation included demographic, environmental, catastrophic, and genetic threats. Information on the Laysan duck's birth and survival rates, population size, estimated habitat capacities of different islands, and the frequency of threats were put into the program VORTEX (Version 8.41; Lacy 1993) and projected forward in time. Information entered into the population viability model was based on population data from Laysan, published life history characteristics, and best estimates for other parameters (the parameters used are provided in Appendix 3). Some variables, such as the rate of population growth and the carrying capacity of potential translocation sites, were estimated based on data collected on Laysan; these conditions (or population parameters) may vary considerably from island to island. We assumed no inbreeding depression in the population on Laysan, but this may not be realistic. Real values of genetic heterozygosity (a measure of genetic variability) should be considered in future models once genetic data are available. These were the weakest components of the model. Data collected from a well-monitored experimental translocation flock will improve demographic, genetic, and carrying capacity estimates needed to improve estimates of population persistence.

The simulation was run 100 times for a 100-year time period and forecast a low (57 percent) chance of long-term persistence for the Laysan duck population under current conditions. Of these 100 simulations, the Laysan duck went extinct on Laysan 43 times, with a mean time-to-extinction of 38.7 years. The viability of the species was also simulated under possible scenarios that included additional populations on other Northwestern and Main Hawaiian Islands. Each additional population improved the potential for the species' persistence. Five populations representing a combination of sites on the Northwestern and Main Hawaiian Islands and a mean final population size of 611 (\pm 308 SD) birds yielded the greatest probability (99 percent) of Laysan ducks persisting for 100 years. Longer time projections were not considered in these exercises, as shorter time projections minimize the propagation of errors in such models and allow for evaluation of conservative extinction probabilities (Beissinger and Westphal 1998). The detailed results of the population viability analyses modeled for the Laysan duck are summarized in Appendix 3.

The entire species of the Laysan duck is now limited to one small population on an island with limited carrying capacity, and the risks to that population are considerable. In addition to protection of the Laysan population, an appropriate management strategy to attain long-term viability for the Laysan duck includes restoration and

management of habitat, removal of introduced predators in suitable habitats in the Main Hawaiian Islands, and the establishment of additional wild populations that are managed to maintain genetic variability.

As a first step, an aviary-held or semi-captive (supplemented) Laysan duck population should be established at one or more suitable sites on other islands while habitat restoration proceeds. Ideally restored habitats are expected to support wild populations that do not require intensive management; however, intensive management will be required in some areas.

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 population size 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).

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) (Diamond 1984a in Hu 1998). The extirpation of Laysan ducks from the Main Hawaiian Islands is estimated to have occurred about 1,500 years ago. Harmful species introductions, human exploitation, and habitat loss are suspected as the primary factors responsible for their decline. The disappearance of the Laysan duck is coincident with the appearance of rats in Hawai'i's chronological subfossil record (Burney *et al.* 2001). The devastating effect of introduced rats on ground-nesting Hawaiian birds is well documented (Berger 1981). Evidence indicates that Polynesian rats (*Rattus exulans*) were more widely distributed than humans during the period of early human colonization, suggesting that rats were a primary cause for the duck's extirpation (Burney *et al.* 2001). This threat is still present on most 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 catus*), dogs, pigs, and Indian mongooses (*Herpestes auropunctatus*; Scott *et al.* 1986).

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 demographic and environmental stochasticity, and may be vulnerable to genetic drift and inbreeding (genetic stochasticity, 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 in the population. Environmental stochasticity refers to unpredictable 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 warming, 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) having many populations

geographically spaced to decrease the chance of a catastrophe simultaneously affecting all populations; 2) reestablishing birds on larger 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.

Genetic Considerations. The viability of isolated populations may be threatened by genetic stochasticity, especially if the population is small. Decreasing population size eventually leads to inbreeding, and possibly to inbreeding depression (the reduction of reproductive fitness and vigor through breeding with close relatives). The effects of genetic drift (changes in allele frequencies through chance fluctuations, rather than selection [an allele is an alternative form of a gene]) is also amplified in small populations. Random mutation produces 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 reducing the genetic variability required to adapt in response to new selective pressures.

The Laysan duck may have suffered an initial genetic bottleneck after the species first became isolated on Laysan, and very likely suffered another when the population fell to only 12 individuals (7 adults and 5 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. The reduction in fitness from inbreeding depression is often expressed as low reproductive success, reduced hatchability, and lower disease resistance (Friend and Thomas 1990). We have no indication that Laysan ducks exhibit these signs, but a comprehensive study of their breeding biology on Laysan has never been conducted, and nothing is known of their disease resistance. Genetic samples were collected from approximately 200 wild individuals in the years 1998 through 2000; analysis of these samples is needed. Individuals or their offspring with high levels of genetic variability would be desirable as founders, immigrants, and for captive breeding stock.

The susceptibility of island populations to the negative effects of inbreeding is uncertain, and the conservation genetics of the Laysan duck have not been studied. It is possible that many deleterious alleles have already been purged over time and reduced genetic variation will not manifest itself as inbreeding depression in this remnant population. However, 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

(S. Jarvi *et al.* in prep.). Furthermore, 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 successfully respond to environmental change (Fisher 1930, Allendorf and Leary 1986).

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 the Northwestern Hawaiian Islands, but we now have new information on the wider historical and prehistorical distribution of the species in Hawai'i. Recent 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

Northwestern Hawaiian Islands

The range of the Laysan duck within historical times has been limited to the islands of Lisianski and Laysan. The 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 population 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). Today the species is found only on Laysan Island.

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 overpopulated and devegetated both islands. The duck underwent a severe population bottleneck 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 the population had climbed to around 500 birds, which seems to be about the present carrying capacity of the island (Moulton and Weller 1984, Moulton and Marshall 1996).

Prehistoric distribution

The Hawaiian Islands are the most isolated archipelago in the Pacific, with a unique faunal history and late colonization by humans (1,400 to 1,600 years before the present; Kirch 1982). Anthropogenic predation and habitat change since human settlement have had severe impacts on native birds of islands (Cooper *et al.* 1996), and Hawai'i provides graphic examples of human-caused extinction and extirpation events. Waterfowl were conspicuous casualties of human impact on indigenous fauna (Williams 1996). Subfossils represent at least eight species of extinct Hawaiian waterfowl, the largest unique assemblage of waterfowl known. Hawai'i's extinct waterfowl include the moa-nalo, large flightless herbivorous

duck species, and a large flightless goose (Olson and James 1991). Only three species of endemic waterfowl remain in the islands, and all three have been listed as endangered since the first list of endangered species was published in 1967: the nēnē (*Branta sandvicensis*), the koloa, and the Laysan duck (USFWS 1967). Subfossil evidence has recently revealed that Laysan ducks formerly occurred on most of the major Hawaiian Islands, including Hawai'i, Maui, Moloka'i, O'ahu, and Kaua'i (Olson and Ziegler 1995, Cooper *et al.* 1996, H. James, pers. comm. 2000; see Figure 2).

2. Current Threats

The small number of Laysan ducks in the single remaining population and their highly restricted geographic range on an island with limited carrying capacity is the greatest ultimate threat to this species. The Laysan Island duck population experiences periodic crashes due to chance events, and given the small size of the population, such events pose a significant threat to its existence. The most recent population crash was in 1993, when the island suffered a severe drought. Laysan Island is vulnerable to severe storms, and global warming could increase the frequency and intensity of storms. Alien plant and insect species continue to invade the island, and the likelihood of additional introductions is high, as is the chance of oil spills or other contaminants washing ashore. Parasite outbreaks have occurred, and other diseases are a potential problem that remains

unassessed. All of these factors pose particularly grave risks to the Laysan duck as the risks posed by stochastic events increase as population size decreases. 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 each 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.

Anthropogenic Threats

Alien Species (Factors A and C).

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). The role of introduced predatory arthropods and their competition for terrestrial prey has not been studied on Laysan. Ants, which are not native to Hawaiian ecosystems, are extremely destructive to native species. Researchers believe big-headed ants (*Pheidole megacephala*) caused mortality of nestling Laysan finches (Conant and Rowland 1994). An introduced vertebrate, the snake-eyed skink, could also be a food competitor and may adversely affect native invertebrates (Morin and Conant 1998).

Future accidental introductions also pose a serious risk. Other islands in the northwestern Hawaiian chain 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 south shore. An investigation of the ship found evidence of rats aboard, though none were ever discovered on the island (USFWS 1982). Three boats have wrecked off Kure Atoll in the past 5 years. 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).

Although not currently a problem on Laysan Island, the introduced mammalian predators that were in large part accountable for the extirpation of the Laysan duck throughout most of its former range still pose the greatest direct threat to the recovery of the species (Factor C). Recovery of the Laysan duck will require reestablishment of the species on at least some of the Main Hawaiian Islands, nearly all of which are inhabited by numerous alien predators, including cats, dogs, pigs, 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 they also tend to run or freeze in place rather than fly as an escape response, having evolved in the absence of terrestrial predators.

Filling of lake and seeps (Factor A). The 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). 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 turn of the 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 southwest 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 and 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.

Contaminants (Factor E). Pacific Ocean currents often carry debris to Laysan's shores. In 1988 a contaminated site (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, 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, 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 west 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). Future contaminants washing ashore could pose a serious threat to the Laysan duck population. Even small amounts of contaminants can affect vital rates through decreased egg production, reduced fertility and hatchability, and lower sperm counts (USFWS 1987).

Global warming and sea level rise (Factor E). Because Laysan is such a low island (12 meters [39 feet] at its highest point) it is especially vulnerable to a rise in sea level. 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 levels of 21 centimeters (8.3 inches) by the year 2050 (IPCC [International Panel on Climate Change] 2001). Even a slight rise in sea levels would destroy a large portion of the duck's current habitat

through increased flooding of the terrestrial upland habitats and increased salinity of the groundwater supply. Another anticipated effect of global warming is increased frequency and severity of storms (IPCC 2001) (see Storms, below).

Field camp (Factor E). A permanent field camp is set up on the northwest coast of the island. Staff must be cautious in their use of pesticides and monitor the possible effects of a new well on the island's aquifer. Hens that nest in *E. variabilis* near camp may lead ducklings into camp; therefore, staff should take care not to disturb or fragment broods.

Diseases

Viruses, bacteria, and invertebrate and fungal parasites can all affect bird populations. Depending on its severity, a disease outbreak can be considered a natural 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, but the threat of other diseases is currently unevaluated. 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 create a threshold

population size for density-dependent diseases. A severe epizootic could diminish the population to the point at which demographic stochasticity could cause extinction (Mangel and Tier 1994).

Echinuriasis (Factor C).

Echinuria uncinata, a roundworm (nematode) that infests the gizzard (proventriculus), 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. 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 as well, a severe outbreak in 1993 coincided with drought and high population density. 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 based on 16 specimens suitable for examination (USFWS data, NWHRC 1993). It is estimated that the Laysan duck population dropped from more than 600 to approximately 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 *E. uncinata*. Tapeworm (cestode) eggs were found in 18 birds (81 percent of samples) (USGS, unpublished data). Eggs of four unidentified parasite taxa were also detected (T. Work, pers. comm. 2000). Additional sample analysis and research is needed to assess the prevalence of echinuriasis and other parasites in the population and evaluate their potential impacts.

Other diseases (Factor C).

Laysan lies in the Pacific flyway and is

often visited by continental migrants. 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). 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. The first documented case of avian botulism was discovered in the carcass of an adult duck in 2003 (T. Work, pers. comm. 2003); this disease could potentially devastate the Laysan duck population.

Environmental Stochasticity and Catastrophes

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

Drought (Factor E). 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, and 1998 resulted in droughts on Laysan that caused reproductive failure (Marshall 1989b, Reynolds 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, above). Lake levels shrank to their lowest levels since 1973 (USFWS data). Not only would fresh water availability be limited, but the abundance of insect prey that form the bulk of the Laysan duck's diet would be sharply reduced under such drought conditions.

Severe storms (Factor E). Tropical depressions and hurricanes are frequent events in the western Pacific Ocean. Laysan is a low-lying island lacking protection from high winds and waves. A hurricane could devastate the duck population. Storms have reduced breeding success in recent years

(Moulton and Marshall 1996, Reynolds 2002).

Tsunamis (Factor E). 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 due to the high level of geologic activity in the region. The last Pacific-wide tsunami occurred in 1964. Tsunamis travel rapidly (up to 805 kilometers [500 miles] per hour) across 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 the island of Laysan. 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 sole remaining population of the Laysan duck.

II. RECOVERY STRATEGY

The greatest current threat to the Laysan duck population is its reduction to a single population of limited size on a low-lying island vulnerable to catastrophic events. Ensuring the long-term viability of the Laysan duck depends upon maintaining this source population and its habitat on Laysan Island and establishing multiple new populations 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 and 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 directed specifically at 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 were used to index the population size in the last century and as recently as 1998. Direct lake counts are not an effective method to estimate population size because use of the lake by Laysan ducks is seasonally and environmentally variable. It is not possible to calculate the relationship between direct counts and the total population size. Marshall (1992b) and others determined that the most accurate way to monitor the population is by calculating ratios of marked to unmarked ducks at the lake at dusk. Fall and spring yield the highest numbers of lakeside ducks for population estimates, although year-round monitoring is ideal. This method requires that a portion of the population be marked. A percentage of the population should be banded by qualified personnel once a year.

Two different monitoring methods are now used twice each month: 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. Birds are recorded as banded, unbanded, or unknown. The numbers of broods and ducklings and the age class of ducklings are recorded.

A known percentage of the Laysan duck population is currently marked with color bands. Individuals have unique band combinations. Resighting surveys provide data that can be used to determine population parameters such as

survivorship, sex ratio, individual histories, brood production and breeder identification. Band reading is conducted for 1 to 2 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.

The geographic isolation of the Laysan duck on a small island makes it well suited to a mark-resight method of population estimation such as the Lincoln-Peterson Index (see Table 2), as 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 meet the assumption of no births or deaths in the population as well (Bibby *et al.* 1992).

2. Ecosystem Conservation and Monitoring

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 (USFWS data 2002, 2003).

Native plant propagation and outplanting

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*.

Invertebrate monitoring

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

Ant control experiment

We initiated a pilot project to remove introduced ants from Spit Island, Midway Atoll, 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, pers. comm. 2002). As Midway is under consideration as a potential reintroduction site for the Laysan duck, the successful eradication of fire ants prior to translocation 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.

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). A hydrological assessment would benefit freshwater seep restoration efforts as well as aquifer use by the field camps. Brine flies are monitored as an index of food abundance for the duck. Fly abundance at the lake may serve as a predictor of duck breeding.

3. Captive Populations

In the late 1950's, 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 Pohakuloa Endangered Species Facility in Hawai'i, and seven wild Laysan ducks were later added to that flock in an effort to improve breeding. The birds produced

by this program were unsuitable as candidates for reintroduction to the wild due to poor breeding records and possible hybridization in captivity, consequently the captive breeding of Laysan ducks was discontinued in Hawai'i in 1989. Some of the birds were shipped to mainland facilities, and individuals older than 8 years were euthanized (Reynolds and Kozar 2000b).

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 1992b, 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).

4. Pearl and Hermes Reef Translocation

Aware of the threats facing the Laysan duck population, 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 for failure. However, we suspect a combination of factors doomed the effort: the release methods, marginal habitat, the small number of founding birds, and stochastic factors. No further translocations have been attempted since this time.

B. Translocation

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 Immediate Translocation

The discovery of Laysan duck bones on the Main Hawaiian Islands and our knowledge that it previously inhabited Lisianski Island provides a sound biogeographic foundation for establishing Laysan duck populations on additional islands (Olson and Ziegler 1995, Cooper and Anderson 1996). Ecosystem restoration and the reestablishment of additional wild Laysan duck populations on other islands are needed to reduce the risk of extinction. These duck populations would also represent the restoration of a missing component of the Hawaiian avifauna on these islands. In 2000 a feasibility study was carried out to evaluate the possible translocation of Laysan ducks to other sites (Reynolds and Kozar 2000a). It was predicted that restoration of Laysan ducks to additional islands may:

- i. reduce overcrowding on Laysan during periods of high population density through ongoing translocations;
- ii. reduce the risk of extinction from stochastic events that affect the single population on Laysan; and

- iii. restore the species to ecosystems where it previously existed.

The Laysan duck is an excellent candidate for translocation. The species is adapted to a harsh environment, flexible in its foraging 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 would not compromise the duck's survival, foraging, or breeding, and the feathers would be 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 invertebrate populations at translocation sites, as they seem to select the most abundant prey available (Reynolds 2002).

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 the United States (notably the koloa;

Rhymer and Simberloff 1996). However, Laysan ducks have not hybridized often in captivity, they are genetically distinct from mallards and koloa (Rhymer 2001), and they may have co-existed with koloa on the main islands in the past, all factors that suggest Laysan ducks are less likely to hybridize in the wild (Reynolds and Kozar 2000a, Pratt and Pratt 2001). As a precaution, mallard populations should be controlled at translocation sites to prevent hybridization of mallards with either of the native endangered duck species.

3. Source Population

The existing captive flocks of Laysan ducks are unsuitable for release into the wild because the pedigrees of these birds are unknown. Studbooks have not been maintained, careful breeding to maintain genetic diversity has not taken place, and Laysan ducks have been kept in mixed-species flocks and have possibly hybridized with other species (see Prospects for Reintroduction of Captive Birds, below). Until a new captive population 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 from high density and increasing source populations (Griffith *et al.* 1989). These conditions are rare for endangered species, but such conditions do occur periodically in the duck population 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. 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. Juveniles from the Laysan source population should be removed during periods of high population density or during periods of population growth.

Additional research is needed to determine causes for the low number of females breeding successfully and the high levels of duckling mortality currently observed. Limited brood rearing habitat is suspected to increase mortality from overcrowding. Management to increase duckling

survival should be explored to ameliorate the possible negative effects of removals for translocation and to provide more juveniles for translocation.

4. Transfer Population

The best practices to prevent genetic drift within a transfer population are to maximize the number of founding individuals and to add new birds regularly from the source population. A minimum of 50 randomly selected founders is recommended to maintain short-term fitness (Franklin 1980). If few individuals are available, selection criteria will depend on how many high-quality birds of the proper age and sex classes are available. Additional founding birds could be introduced from subsequent years' recruits for each translocation site. Further population supplementation may occasionally be required to increase population growth and to maintain or improve genetic variability. On Laysan, reproduction is highly variable, and few or no ducklings are produced in some years, so planning for multi-year translocations is required.

The age and sex of the translocated birds are important variables in producing a self-sustaining population. As mentioned above, fledged juveniles would be the preferred candidates for translocation, based on analysis of population fluctuation. 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* is unknown in waterbirds in the Main Hawaiian Islands, and the risk to those populations 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), but the potential toxicity of this drug to Laysan ducks is not known. Safety trials should be conducted on Laysan ducks to determine if they will react adversely to ivermectin (T. Work, pers. comm. 2002).

We recommend a "soft" release, in which birds are gradually acclimated to their environment in an on-site enclosure. This type of release reduces stress on birds and increases site fidelity, lowering the chance of birds dispersing from the release site (Kleiman 1989). An aviary on or near the release site would be ideal for temporarily housing translocated birds. Laysan ducks do well in captivity and should easily adjust to aviary life. Birds are known to be aggressive towards one another,

therefore separate pens maybe required for some.

5. Selecting and Evaluating the Release Site

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 and competitors on the Northwestern Hawaiian Islands were the primary limiting factors and need to be controlled at proposed translocation sites. Sufficient food, water sources, cover, and breeding sites also must be available at the release location.

Despite the duck's prehistoric distribution in forested areas of the Main Hawaiian Islands, only habitats where mammalian predators are absent or sufficiently controlled should be considered for translocation sites. The presence of predators would seriously jeopardize the success of any translocation effort (Armstrong and McLean 1995, Veitch 1995, Towns *et al.* 1997). Possible methods for control of predators at translocation sites on the Main Hawaiian Islands include fences, toxicants, trapping, 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 islands of the Northwestern Hawaiian Islands will require some restoration in the form of pest and weed control, or freshwater seep creation or restoration.

Site visits were made to areas where Laysan ducks might be reintroduced (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 8 Main Hawaiian Islands were assessed in terms of their suitability for the reestablishment of Laysan duck populations (Appendix 1). Of the 20 islands considered, 6 were considered promising potential translocation sites: Eastern Island (Midway Atoll National Wildlife Refuge), Lisianski Island and Nihoa Island (Hawaiian Islands National Wildlife Refuge), and Kure Atoll (City and County of Honolulu) in the Northwestern Hawaiian Islands, and the islands of Kaho'olawe and Kaua'i in the Main Hawaiian Islands (Appendix 2). Descriptions of these islands and brief discussions of their biological and physical suitability and management

needs as translocation sites are presented below (not in order of priority).

It is critical to note here that augmentation of these discussions with fiscal and management assessments is necessary to develop a prioritized list of translocation sites and to select an initial site where translocation will be most feasible, cost-effective, and likely to succeed. Working in such a remote island chain, the realities of translocation and reestablishment efforts are that logistical feasibility and cost will play an important role in site selection.

Northwestern Hawaiian Islands

Midway Atoll. 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 is surrounded by waters included in the Northwest Hawaiian Islands Coral Reef Ecosystem Reserve managed by the National Oceanic and Atmospheric Administration.

For many logistical reasons Eastern Island at Midway Atoll may be an excellent site for a trial release of Laysan ducks. Midway is home to permanent personnel with our agency and can support expensive chartered air service from

Honolulu. Rehabilitation of habitat on Midway is therefore more logistically feasible than it would be on an uninhabited island. Eastern Island has no human settlements and fewer anthropogenic hazards than Sand Island, and could be the best location in the atoll for an experimental release.

Midway has experienced many introductions of nonnative plant species over the years, including *Verbesina encelioides* and *C. echinatus*. Efforts are currently underway to control these exotics. The invertebrate fauna on Midway Atoll is dominated by exotics. On Eastern Island, intensive introduced weed control, particularly of *V. encelioides* and *C. echinatus*, is recommended. Vegetation restoration can take place after release of Laysan ducks, but if broad-scale herbicides, pesticides, and heavy equipment are used, Laysan ducks could be negatively affected. Fire ants and big-headed ants also should be controlled, or else supplemental feeding of translocated birds may be needed until techniques for removal of the ants are developed (or their impacts on the duck's prey base and nests are judged to be insignificant).

Predatory arthropods such as the big-headed ant may need to be controlled; other introduced invertebrates likely would be prey items for the Laysan duck (Reynolds and Kozar 2000a). Fire ants (*Solenopsis geminata*) were discovered on 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, pers. comm. 2001).

Currently no permanent standing sources of fresh water exist on Eastern Island. Wetland creation and watering devices are a necessary prelude to release of Laysan ducks on Eastern Island. Multiple sources of fresh water are recommended. In August 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 a source of fresh water (Reynolds and Kozar 2000a; A. Engilis, pers. comm. 1999; S. Reilly, pers. comm. 2001). 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 potential creation of a wetland. Wetland and vegetation restoration would improve opportunities for successful establishment of self-sufficient, self-sustaining wild populations of ducks.

Translocation of ducks to a temporary aviary setting on Sand Island in preparation for a soft release to Eastern Island can occur simultaneously with habitat restoration efforts. Intensive management of Laysan ducks at translocation sites, such as the provision of supplemental food and water, may be required until restoration efforts are complete.

Lisianski Island. Lisianski Island is Laysan's nearest neighbor in the northwest Hawaiian chain, and is known to have previously supported a population of Laysan ducks. Loss of plant cover in the mid-1800's resulted in shifting sands that filled the island's fresh water source. Since Laysan ducks existed previously on Lisianski, we know that with adequate management the island can support a population of the birds, 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, 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 the transport and use of the construction equipment that would normally be used for such an operation.

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 a small population of the birds. Native plants and arthropods are abundant. Freshwater seeps occur naturally on Nihoa, eliminating the need to provide water sources or 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, and the risk of predation by Laysan ducks should be considered (E. Flint, pers. comm. 2002). 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.

Kure Atoll. Kure Atoll consists of three 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 or none of the infrastructure remains. The atoll is managed by the State of Hawai'i, which eliminated rats on the islets in 1994 and has initiated a weed eradication program to control the spread of *V. encelioides*. The islands support a large number of arthropods and have a moderate amount of nesting cover for ducks. Sources of fresh water, perhaps from rainwater catchments, could be created to sustain a Laysan duck population there (Reynolds and Kozar 2000a).

Main Hawaiian Islands

Kaho'olawe. Kaho'olawe would be an ideal site for translocation of Laysan ducks to a main Hawaiian island. 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 past 10 years the Navy has been working to remove any remaining live ordnance and meet the State's objectives for preservation of archeological sites and environmental restoration on Kaho'olawe. Goats have been removed, ordnance removal is near complete, and botanical restoration is underway on the island, which now supports moderate nesting cover and a wide variety of arthropods. The Navy's work on Kaho'olawe is expected to be completed in 2004. Ephemeral wetlands exist on the island but need enhancement. Rats have not been seen on the island since 1971, leaving cats as the only mammalian predator. If cats were removed, Kaho'olawe would have excellent potential as a release site (Reynolds and Kozar 2000a).

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 is believed to be free of the Indian mongoose, a predator that would pose a major risk to a translocated duck population. 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.

Other Main Hawaiian Islands

Ni'ihau, O'ahu, Maui, Moloka'i, Lana'i, and Hawai'i all have sites that potentially could support Laysan ducks. Managed wetlands occur on O'ahu, Maui, and Hawai'i; of the five islands listed above, these three may provide the best opportunities for establishing 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 translocation sites for Laysan ducks.

6. Prospects for Reintroduction of Captive Birds

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 1994). 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. 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). Monitoring, examination, and treatment of birds are

essential to protect captive breeding programs. These measures have not been adopted for captive Laysan duck populations, further reducing their suitability as candidates for wild release. The Avian Disease Working Group, an association of captive breeders and veterinarians, rejected the idea of reintroducing captive mainland birds to Hawai'i based on logistical, fiscal, and quarantine restraints (C. Kuehler, pers. comm. 2000).

Translocation Planning

Translocated flocks should consist of wild-caught fledged juveniles, kept in an aviary in preparation for a "soft" release while habitat restoration is underway. We do not know if fledgling birds will be available for translocation when restoration is complete; therefore, birds should be removed from Laysan in the autumn even if restoration is unfinished and released in the spring. Having Laysan ducks ready for release may speed up restoration efforts. If juveniles are available on Laysan, a second cohort can be transferred and released the subsequent autumn.

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 population that was specifically managed for such releases, but considering the urgency of establishing a new wild population, using wild, parent-raised fledglings from Laysan for reestablishment on other islands in the

northwestern chain would be more expedient, easier logistically, and perhaps more successful. It would take years before suitable numbers of captive-bred offspring would be available 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.

Main Hawaiian Islands. A captive breeding facility, managed for establishing additional wild flocks of Laysan ducks, is needed 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 islands.

Translocation of wild birds from Laysan for the establishment of wild main island populations is also feasible, but this possibility is limited by both the logistics and the "critical mass" needed for the establishment of large viable populations without depleting the source. If multiple Northwestern Hawaiian Islands populations are established and they reach carrying capacity, subsequent removal of hatch-year Northwestern Hawaiian Islands birds for main island populations would be a good option.

III. RECOVERY CRITERIA AND ACTIONS

A. Goal and Objectives

The goal of the 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 Laysan Island population, 2) protection and enhancement of suitable habitat, and 3) actions to reduce or eliminate threats sufficient to allow successful reestablishment of additional wild populations. 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 viable populations in the Laysan duck's historical range is based upon two widely recognized and scientifically accepted goals for promoting viable populations of listed species. These

goals are: 1) the creation of multiple populations so that a single or series of catastrophic events do not result in species 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 maintaining population numbers and viable breeding 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

At this time we have developed only interim downlisting criteria for the Laysan duck due to the data limitations and potential uncertainties associated with attempting to define realistic criteria for delisting, particularly in regard to target population sizes.

Because our knowledge of Laysan duck population biology and ecology is restricted to observations from the unique environment of Laysan Island, we currently have no reliable biological basis for setting target population sizes for delisting on other islands with very different habitats and potential threats. Delisting criteria, when developed, must be based on new information that can only be accumulated as we begin to implement the recovery actions outlined in this plan and learn about the population dynamics and growth rates of Laysan ducks in new habitats on islands other than Laysan. Thus we believe that downlisting is the most conservative and scientifically defensible strategy to take in this recovery plan until more comprehensive information is available.

Some of the downlisting criteria presented below are based on the results of population viability analyses (see following “Rationale” section). It is important to note that such population models are management tools based on many assumptions and are subject to the limitations of existing data describing the species’ biology, requirements, and habitat. Population viability analyses use risk factors to evaluate probabilities, not certainties. Therefore, the results of such analyses should be interpreted as general guidance, not as inflexible goals for recovery (Reed *et al.* 1998). The population targets for downlisting offered below should be revised after translocations take place and we learn more about the population dynamics of Laysan ducks in new habitats and the

observed (versus projected) carrying capacities of planned translocation sites. The development of meaningful delisting criteria will also require this new data.

1. Downlisting Criteria

Criterion 1. The Laysan Island population is stable or increasing (finite rate of population growth or λ greater than or equal to 1.0) when averaged over a continuous period of at least 15 years.

Criterion 2. A total of at least 920 potentially breeding adult birds exist in at least 5 stable or increasing populations on a combination of predator-free Northwestern Hawaiian Islands (including Laysan) and predator-controlled sites on the Main Hawaiian Islands. The population on Laysan Island should remain at a level of from 400 to 500 birds; the remaining 4 or more newly established populations should occur on a combination of predator-free Northwestern Hawaiian Islands and predator-controlled sites on the Main Hawaiian Islands, and should number approximately 130 breeding adult birds each (depending on the size of the habitat available on the island).

Criterion 3. A successful captive or semi-captive breeding program is established using wild source eggs. These captive populations are managed primarily for reintroductions to the Main Hawaiian Islands.

Criterion 4. A plan for achieving gene flow between wild source populations through long-term inter-island translocations is developed and implemented.

Criterion 5. Island-specific management plans for each population are created that identify actions (such as supplementation, habitat improvement and predator control) sufficient to reduce threats and increase the populations to recovery levels.

2. Rationale for Downlisting Criteria

Criterion 1. Environmental variability will affect Laysan's annual carrying capacity and year-to-year demographic rates. Population growth thus should be evaluated according to the overall trend for a continuous 15-year period. Current estimates predict that El Niño Southern Oscillation events will occur approximately every 7 years in Hawai'i, thus a 15-year interval will allow for periodic population fluctuations in response to these events.

Criterion 2. We used the population viability analysis program VORTEX (version 8.41, Lacy 1993) to model the persistence of the Laysan duck over a 100-year timeframe under various management scenarios. For the purposes of downlisting, we chose to use as a guide the scenario that predicts a 99 percent probability of the species' persistence over 100 years. This scenario includes a substantial pool of

breeding ducks distributed across five populations on a combination of three Northwestern Hawaiian Islands, including the extant population on Laysan, as well as two populations on the Main Hawaiian Islands (see Appendix 3). To persist over the time period of 100 years, the model estimated a mean final total population size of 611 birds, ± 309 SD. Due to our limited information on the Laysan duck, especially in regard to factors such as its survivorship and productivity in any environment other than that of Laysan Island, the input for the population model necessarily required some assumptions and extrapolations from data collected on Laysan, such as the estimated carrying capacity for each potential translocation site and the currently known demographic parameters for the Laysan duck on Laysan Island. The actual carrying capacity of proposed translocation sites is unknown, but estimates for the VORTEX model were based on the carrying capacity of Laysan (one bird per 0.5 hectares, assuming 75 percent of the island's area contains suitable vegetated habitat; the exception was Sand Island, Midway Atoll, for which it was assumed that 50 percent of the land area was suitable). Because we lack information about Laysan duck reproductive success, demography, and ecology in habitats other than that of Laysan Island, we chose to be conservative and to use the upper end of the range of birds needed for long-term persistence according to the model (920, the sum of the mean final total

population size of 611 + the standard deviation of 309) as our interim target for recovery. We view this number of ducks as an absolute minimum.

Criterion 3. There are no captive Laysan ducks in the State of Hawai'i. A new population from wild source stock, managed primarily for reintroduction to the wild, should be established. It may be possible to establish all new Northwestern Hawaiian Islands populations with source birds from Laysan, and establish Main Hawaiian Island populations from (new) captive-hatched stock.

Criterion 4. Human-assisted "immigration" (translocation of wild birds) is needed to offset genetic losses resulting from founder effects, genetic drift, and close inbreeding. Genetic drift, the cumulative and nonadaptive fluctuations in allele frequencies, may inhibit population viability. Dispersal between populations can slow genetic losses due to genetic drift and can augment numbers following a local population decline. As few as one migrant per generation may be sufficient to improve viability of the translocated populations (*e.g.*, Mills and Allendorf 1996, Wang 2004). Population viability analysis incorporating movement between populations showed greater persistence in those populations. Because of the risk of disease, the mixing of captive birds from the main islands with wild populations in the Northwestern Hawaiian Islands should be avoided, except in case of emergency

or catastrophe to the source population. The risk posed by diseases introduced to the Northwestern Hawaiian Islands threatens the source population of ducks and other endangered bird species on Laysan. Wild source eggs should be added periodically to captive source populations to improve genetic diversity and reduce genetic drift. If wild source juvenile birds are added to the captive flock, these birds should first be treated for echinuriasis to prevent the introduction of *Echinuria* to other islands.

Criterion 5. A comprehensive management plan will guide implementation of recovery actions for each population to ensure that the species does not become endangered again. Population viability models indicated that supplementation greatly improved population growth rates and may be required to maintain long-term population viability. Other management options to reduce or eliminate the current threats to the Laysan duck and increase population growth should be identified in the management plan.

C. Outline of Recovery Actions

1. Address risks to the Laysan duck population on Laysan Island
 - 1.1. Population monitoring
 - 1.1.1. Population and reproductive monitoring
 - 1.1.2. Disease screening and prevention
 - 1.1.3. Field crew training
 - 1.2. Develop emergency contingency plans
 - 1.3. Further research
 - 1.3.1. Population parameters (including nesting success)
 - 1.3.2. Disease
 - 1.3.3. Genetics research
 - 1.4. Implementation of the Laysan Ecosystem Restoration Plan
 - 1.4.1. Plant monitoring, weed control, and native species restoration
 - 1.4.2. Alien invertebrate control and monitoring, and native invertebrate restoration, where possible
 - 1.4.3. Freshwater seep restoration
2. Hire or contract project leader for Laysan duck recovery
3. Translocations
 - 3.1. Complete site assessments and prioritize translocation sites
 - 3.1.1. Develop management plans for individual translocation sites
 - 3.2. Habitat restoration/creation in Northwestern Hawaiian Islands
 - 3.3. Habitat restoration in Main Hawaiian Islands
 - 3.3.1. Control predators
 - 3.3.2. Control of other alien species
 - 3.4. Set up holding facilities
 - 3.5. Arrange timely transportation to and from Northwestern Hawaiian Islands
 - 3.6. Select and transport fledged juvenile birds on Laysan
 - 3.7. Disease screening and treatment
 - 3.8. Acclimation and soft release
 - 3.9. Intensive post-release monitoring
 - 3.9.1. Radio telemetry, foraging behavior, and prey-base monitoring
 - 3.9.2. Body condition assessment and supplemental feeding
 - 3.9.3. Monitor reproduction of translocated birds
 - 3.10. Immigration translocations
4. Captive propagation
 - 4.1. Develop a captive propagation program
 - 4.2. Release captive-bred birds
5. Public outreach
 - 5.1. Outreach for translocations in Main Hawaiian Islands
 - 5.2. Exhibit with captive Laysan ducks on Main Hawaiian Islands
6. Update the recovery plan

D. Recovery Action Narrative

The following actions are those needed to achieve the recovery of the Laysan duck 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. Address risks to the Laysan duck population on Laysan Island

1.1. Population monitoring

Because the Laysan duck exists as a single isolated population, monitoring is essential for guiding the species' management and recovery. Accurate population estimates are needed to monitor 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.

1.1.1. Population and reproductive monitoring

Researchers have determined that to accurately measure population size a ratio of marked to unmarked birds is needed (Marshall 1992b). Band-reading and population surveys are performed every 2 weeks to provide data for estimates, but currently no program is in place to band birds on a regular basis. If the population size is to be estimated with accuracy, long-term banding efforts and subsequent data management for resight histories must be maintained. A large proportion of the population was marked in the years 1998 through 2001, and banding once per year by qualified personnel is sufficient to band an adequate percentage of fledglings. Population trends and recruitment must be assessed annually using data collected from field sites. Additional trend assessments and analysis should be conducted as needed.

1.1.2. Disease screening and prevention

Disease screening and preventive treatment are needed before Laysan ducks are translocated. Screening will serve 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* 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.

1.1.3. Field crew training

Conservation activities on Laysan Island depend in large part on the dedication of crews of technicians and volunteers that spend 4 or 5 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.

1.2. 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, and know how to respond to epizootics or contaminants washing ashore.

1.3. 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.

1.3.1. Population parameters

More information is needed on the parameters that drive population dynamics on Laysan, especially those factors that influence nesting success, hatchability, and brood survival.

1.3.2. 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 *Echinuria* parasite is unknown on Laysan. Research to determine the intermediate host and factors influencing the prevalence of echinuriasis and botulism is needed so epizootics can be prevented or managed (see also Action 3.3, Disease screening and treatment).

1.3.3. Genetics research

Because of their isolation and limited numbers, Laysan duck populations will require genetic management to prevent the loss of genetic diversity to random drift, founder effects, and close inbreeding. Analysis of heterogeneity and population structures of translocated, new captive, and source populations will benefit planning for species recovery.

1.4. Implementation of the Laysan Ecosystem Restoration 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).

1.4.1. 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, where warranted, reduce sand destabilization and filling of the lake and seeps.

1.4.2. 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. Control requires a qualified entomologist to implement eradication programs and to determine which other alien invertebrates need to be eliminated.

1.4.3. Freshwater seep restoration

The freshwater seeps on Laysan are believed to be crucial brood rearing habitat for the Laysan ducklings. Evidence suggests that 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 is crucial in areas where seeps or ponds existed previously or have been partially filled. 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. 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.

2. Hire or contract project leader for Laysan duck recovery

Dedicated staff is necessary to implement and coordinate the various aspects of Laysan duck recovery. 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. Translocations

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, however, and 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 main islands can, with adequate management, support the birds in sufficient numbers to ensure their long-term persistence.

3.1. Complete site assessments and prioritize translocation sites

The development of a prioritized list of translocation sites and selection of an initial release site will require some 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. This task will be undertaken by the project leader for Laysan duck recovery.

3.1.1. 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.

3.2. Habitat restoration/creation in the Northwestern Hawaiian Islands

At this time, only the Northwestern Hawaiian Islands lack mammalian predators, but most of those small islands will require habitat restoration to support the establishment of self-sustaining, minimally managed Laysan duck populations. We predict that the most intact native ecosystems will be the most likely to have adequate nesting cover, food resources, and fresh water. At such sites, additional management to promote the survival of translocated Laysan ducks will be minimal (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. 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).

3.3. Habitat restoration in the Main Hawaiian Islands

3.3.1. Control predators

Introduced mammalian predators 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 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 would greatly increase the risks associated with reintroduction. Before Laysan duck populations can be established on any of these islands, long-term predator control and/or predator-proof fencing is necessary.

3.3.2. 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 ducks, 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.

3.4. 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 aviary facilities 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.

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

Space on ships and transportation to 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.

3.6. Collect and transport fledged juvenile birds on Laysan

Reproductive success on Laysan varies considerably from year to year, so translocations may have to be spaced out over a number of 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, experimental techniques for supplementation or cross-fostering with younger ducklings or eggs harvested from Laysan should be explored 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 per year for the first 2 years, if enough suitable individuals exist. Immigrants should be added regularly thereafter from the source population. Fledglings could be selected and removed between July and October.

3.7. Disease screening and treatment

It is especially important to screen and treat birds prior to translocation to avoid transferring disease to transfer populations or translocation sites. Ivermectin is an anti-parasite medication known to eliminate roundworms, but the response of Laysan ducks to this drug is not known. If the risk to the ducks' health is deemed insignificant, safety trials should be conducted on captive Laysan ducks before ivermectin is widely administered to birds that will be translocated. It is also important to evaluate the disease risk at new sites prior to translocation.

3.8. Acclimation and soft release

Laysan ducks must 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 monitored for several weeks until they regain their pre-capture condition. During this period, the ducks will be closely monitored and offered a combination of wild forage items and supplements. Once the majority of birds appear healthy, those in good condition 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 re-attached so that post-release activity can be monitored immediately. Primary feathers will be trimmed to prevent flight dispersal from the release site. Birds will be released with their aviary mates, and a first group will be monitored for 2 to 3 days prior to releasing the next group. Supplemental food and water will be offered for up to 2 months post release at the release site to give the ducks time to explore their new foraging habitat.

3.9. 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.

3.9.1. Radio telemetry, foraging behavior, and prey-base monitoring

Radio telemetry is the most effective means of tracking individual birds and monitoring their activity and reproductive effort. Because the Laysan duck has been studied only on Laysan, knowledge of their foraging behavior in other environments is unknown. 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.

3.9.2. 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 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.

3.9.3 Monitor survivorship and reproduction of translocated birds

Translocated birds should be monitored for at least 2 years post-release to ensure the success of the translocation program and allow for adjustments in the protocol, if necessary. 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.

3.10 Immigration translocations

After the initial translocation, one bird per generation (or five birds every 5 years) should be transferred from Laysan to the newly established populations on other islands. Additional supplementation may be required to increase population growth. Immigration between the Northwestern Hawaiian Islands populations should continue over the long term because none of these islands will be able to support a very large population of Laysan ducks. Continued immigration thus is an important part of the project to reduce the effects of inbreeding and genetic drift.

4. Captive propagation

The existing captive flocks of Laysan ducks on the mainland and in international facilities are unsuitable for introduction to the wild. A new captive population, managed specifically for establishing additional wild populations, is needed in the Main Hawaiian Islands. Removal of eggs from Laysan would have the least impact on the source population. Removal and transport of eggs to the main islands may also be easier logistically. While preparations are made for captive

propagation, wild-source fledgling individuals may be translocated to suitable habitats on other islands to establish insurance populations.

4.1. Develop a captive propagation program

Captive propagation for Laysan ducks, including planning, facility development, and staffing, should be pursued through contracts with non-profit organizations.

4.2. Release captive-bred birds

Similar to wild translocated birds, Laysan ducks raised in captivity will need disease screening prior to release and close monitoring afterward.

5. Public outreach

5.1. 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.

5.2. Exhibit with captive Laysan ducks

An interpretive exhibit (*e.g.*, at the Honolulu Zoo, Waikiki Aquarium, or Sealife 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.

6. Update the recovery plan

The recovery plan for the Laysan Duck should be reviewed and updated periodically, as necessary, as research and translocations progress and we gain further knowledge of the ecology and population biology of the Laysan duck in new environments. The need for data necessary to develop defensible delisting criteria for this species is recognized as a high priority. Although revision may occur earlier, if appropriate, this plan should be revised within 5 years, since the actions and cost estimates presented in the implementation schedule are currently for only a 5-year timeframe due to the numerous uncertainties associated with this species.

IV. IMPLEMENTATION SCHEDULE FOR 2004 TO 2008

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 single remnant population that occurs in a relatively unusual habitat dominated by a hypersaline lake. Because we don't know how well our current knowledge of Laysan duck biology may apply to the management of this species in other habitats, 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 implementation plan outlines the actions needed to advance the recovery program for the Laysan duck over the next 5 years; new implementation plans will be prepared every 3 to 5 years to reflect the lessons learned and refinements to our management strategy. 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.

Time projections for recovery are based on the assumption that habitat restoration work will begin in fiscal year (FY) 2004, the first translocation will take place in September 2004, and subsequent soft releases will begin in the spring of 2005 (depending on the progress of habitat restoration). The second translocation and release to the initial site will take place between 2005 and 2006. Undertaking translocation efforts depends on a healthy, increasing population on Laysan. We estimate that between 15 and 20 hatch-year birds can be removed from the Laysan population during increasing or stable years.

Acronyms used in the Implementation Schedule:

BRD	U.S. Geological Survey-Biological Resources Division
DLNR	Hawai'i Division of Land and Natural Resources
DU	Ducks Unlimited, Inc.
HINWR	Hawaiian Island National Wildlife Refuge
KIRC	Kaho'olawe Island Reserve Commission
MHI	Main Hawaiian Islands
NWHI	Northwest Hawaiian Islands
NWHRC	National Wildlife Health Research Center
PL	Project leader for Laysan duck recovery, affiliation to be determined
USFWS	U.S. Fish and Wildlife Service
WRD	U.S. Geological Survey-Water Resources Division

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

Recovery Action Priority	Action Number	Listing Factor	Action Description	Action Duration	Responsible Parties	Estimated Costs (x \$1,000)					
						Total Cost	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008
1	1.1.1	A, E	Population and reproductive monitoring	O	USFWS/BRD	200	40	40	40	40	40
1	1.1.2	C	Disease screening and prevention	C	USFWS/NWHRC	22	6	4	4	4	4
1	1.2	E	Develop emergency contingency plans	TBD	USFWS/PL/private contractor	35.5	35.5				
1	2	A, C, E	Hire or contract project leader for Laysan duck recovery (PL)	C	USFWS/BRD/ private contractor	3,315	66.3	66.3	66.3	66.3	66.3
1	3.1	A, E	Complete site assessment and prioritize translocation sites	C	USFWS/PL	37	37				
1	3.2	A, E	Restore and/or create habitats on NWHI that are potential translocation sites (<i>e.g.</i> , Eastern Island at Midway Atoll)	C	USFWS/DLNR/ DU/other private contractor	3,500	840	840	840	490	490
1	3.3.1	C	Control predators at potential MHI translocation sites (<i>e.g.</i> , Kaho'olawe, Hanalei NWR, Kaua'i)	C	USFWS/DLNR/ KIRC	750	150	150	150	150	150
2	1.1.3	E	Train Laysan field crews in survey methods	O	USFWS	27	5.4	5.4	5.4	5.4	5.4

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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 2004	FY 2005	FY 2006	FY 2007	FY 2008
2	1.3	C, E	Conduct research on Laysan duck population parameters, genetics, and disease susceptibility	O	USFWS/research institutions	300	60	60	60	60	60
2	1.4.1	A	Control and monitor weeds and restore native vegetation on Laysan	O	USFWS	1,000	200	200	200	200	200
2	1.4.3	A	Restore seeps on Laysan	C	USFWS/DU/WRD	250	75	75	50	50	
2	3.9.2	E	Conduct body condition assessment and supplemental feeding of translocated ducks	TBD	USFWS/BRD/ research institutions	140		35	35	35	35
2	4.1	A, E	Develop captive propagation program, incl. planning, facility development, and staff	C	Private contractor	490	130	90	90	90	90
3	1.4.2	A, E	Control and monitor invasive invertebrates and restore natives on Laysan	C	USFWS	375	75	75	75	75	75
3	3.1.1	A, E	Develop management plans for individual translocation sites	C	USFWS/PL/BRD	90		30	30	30	
3	3.3.2	A, E	Control alien species (<i>e.g.</i> , weedy plants, feral mallards) at MHI translocation sites	C	USFWS/DLNR/ KIRC	432	144	72	72	72	72

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

Recovery Action Priority	Action Number	Listing Factor	Action Description	Action Duration	Responsible Parties	Estimated Costs (x \$1,000)					
						Total Cost	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008
3	3.4	A, E	Set up holding facilities	TBD	USFWS/BRD/ private contractor	75		25	25	25	
3	3.5	A, E	Charter transportation to and from HINWR	TBD	USFWS	350	70	70	70	70	70
3	3.6	A, E	Capture fledged juvenile birds on Laysan	TBD	USFWS/BRD	80		20	20	20	20
3	3.7	C	Disease screening and treatment	TBD	NWHRC	40		10	10	10	10
3	3.8	A, C, E	Acclimation and soft release	TBD	USFWS/BRD	280		70	70	70	70
3	3.9, 3.9.1, 3.9.3	A, C, E	Conduct intensive post-release monitoring of translocated ducks: radio tracking, foraging behavior, prey-base	TBD	USFWS/BRD/ research institutions	140		35	35	35	35
3	3.10	E	Conduct immigration translocations to maintain genetic variability in new duck populations	TBD	USFWS/BRD/ research institutions	45			15	15	15
3	4.2	A, E	Release captive-bred Laysan ducks (includes intensive post-release monitoring) at MHI sites (<i>e.g.</i> , Kaho'olawe and Kaua'i)	TBD	USFWS/BRD/ research institutions	105			35	35	35

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

Recovery Action Priority	Action Number	Listing Factor	Action Description	Action Duration	Responsible Parties	Estimated Costs (x \$1,000)					
						Total Cost	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008
3	5.1	A, E	Conduct public outreach for reintroduction of Laysan ducks to MHI	C	USFWS/DLNR	75	15	15	15	15	15
3	5.2	A, E	Create interpretive exhibit using captive Laysan ducks	C	Private contractor	150	45	45	20	20	20
3	6	A, C, E	Update recovery plan	1 year	USFWS	5					5
					TOTALS	9,325	1,994	2,033	2,033	1,682	1,583

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B. Personal Communications

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VI. APPENDICES

Appendix 1. Habitat assessments of possible translocation sites for the Laysan duck.

I: Northwestern Hawaiian Islands

Island	Size (ha)	Elevation (m)	Annual		Cover	Predators	Prey base
			rainfall (mm)	Surface fresh water			
Kure Atoll	100	6	1100	Absent	Yes	Absent	Moderate
Midway Atoll	625	5	1121	-	Yes	Absent	Moderate
<i>Sand Is.</i>	467	5		Limited	Limited	Absent	Moderate
<i>Eastern Is.</i>	156	4		Absent	Limited	Absent	Moderate
<i>Spit Is.</i>	2	2		Absent	Limited	Absent	Limited
Pearl and Hermes	30	3	700- 1000	Absent	No	Absent	Limited
<i>South East Is.</i>		2		Absent	No	Absent	Limited
<i>North Is.</i>		3		Absent	Yes	Absent	Limited
<i>Kittery Is.</i>		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
Ni'ihau	25,500	390	Ni'ihau Playas	667	Abundant	Dogs, Cats, Rats
Kaua'i	157,400	1,585	Wainiha Valley	2000	Abundant	Dogs, Cats,
			Lumaha'i Valley	2500		Rats
			Hanalei NWR	2000		
			Wailua/Opaekaa Valley	1250		
			Hule'ia NWR	1250		
			National Tropical Botanical Garden (Lawa'i Valley)	----		
Oahu	162,400	1,233	Lualualei	625	Abundant	Dogs, Cats,
			'Uko'a Marsh	500		Rats,
			Kahuku Point	1250		Mongoose
			La'ie Wetlands	1500		
			Waihe'e Marsh	2000		
			He'eia Marsh	1750		
			Nu'upia Ponds	1250		
			Kawai Nui Marsh	1500		
Moloka'i	66,600	1,525	Moloka'i Playas	250	Abundant	Dogs, Cats,
			Kaunakakai Wetlands	375		Rats,
			Kakahai'a NWR	625		Mongoose
			Paialoa Pond	750		
Lana'i	35,500	1,437	Whole island	250-500	Abundant	Dogs, Cats, Rats
Kaho'olawe	12,100	450	Whole island	250-500	Limited	Cats

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

Appendix 2-A. 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
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	USFWS Wildlife Refuge and Historical Site	USFWS Wildlife Refuge	USFWS Wildlife Refuge	KIRC Cultural and Ecological	USFWS Wildlife Refuge	Privately owned Ranch

*DLNR = Department of Land and Natural Resources; USFWS = U.S. Fish and Wildlife Service; KIRC = Kaho'olawe Island Restoration Committee

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

Liabilities	Midway (Sand, Kure Eastern and (Green Island) Spit Islands)				Kaua'i Kaho'olawe (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. VORTEX population viability analyses: parameters and conditions used and summary of results.

I. Life history parameters used to run VORTEX population simulations for 100 years for Laysan duck viability (Version 8.41, Lacy 1993).

Non-territorial (Moulton and Weller 1984)

Monogamous breeding system (Moulton and Marshall 1996)

Breeding age: 2 years (MHR/USGS 1998-2000 data)

Maximum breeding age: 10 (assumption)

Clutch size: 3 to 4 (mean 3.8) (Moulton and Marshall 1996)

Maximum brood size: 6 (MHR/USGS 1998-2000 data)

25% (SD 12.5) of females produce ducklings each year at carrying capacity (Moulton and Marshall 1996)

50% of females produce ducklings for populations below carrying capacity¹

Of breeding females (MHR/USGS 1998-2000 data),

- 21% produce broods of 1 duckling
- 23.5% produce 2 ducklings
- 22% produce 3 ducklings
- 13.5% produce four ducklings
- 11% produce 5 ducklings, and
- 9% produce 6 ducklings

Duckling broods per year: 1 (Moulton and Marshall 1996)

Sex ratio at birth¹: 1:1

Mortality: 70% for both sexes between ages 0 and fledging

2% mortality for both sexes from fledging to 1 year

1% adult mortality (MHR/USGS 1998-2000 data)

Habitat: On Laysan 267 hectares are used for foraging and nesting (Marshall 1992) (We assumed that with management 75% of the area of other NW Hawaiian Islands contain suitable habitat, except Sand Island, for which we assumed 50% suitable habitat because of human structures and habitat conversion); carrying capacity estimates are based on 1 bird per 0.5 hectare vegetated habitat (Warner 1963).

Carrying capacity of Laysan is 500 (Moulton and Marshall 1996).

II. Conditions for VORTEX simulations for Laysan duck viability. One hundred iterations were run for 100 years.

Parameters

5 populations modeled

No inbreeding depression

All males in breeding pool

Density dependent reproduction

Both males and females disperse (via translocation)

Rate of dispersal: 1% of population per generation

Minimum age at dispersal: 1 (hatch-year [HY])

Maximum age at dispersal: 2

Percent surviving during dispersal (translocation): 95

Initial population size of Laysan: 475

No Laysan supplementation or management to increase population growth

Stable age distribution for Laysan only

Northwestern Hawaiian Islands (NWHI) simulation only:

Correlation between environmental variation and reproduction: 0.7

Translocation dispersal = 1% per generation for all islands

Four catastrophes in NW Hawaiian Islands model (1.0 = no effect; 0 = total loss):

- Severe drought and disease: 4/100 years, 0 effect on reproduction, 0.5 on survival
- Hurricanes: 1/100 years, 0.5 effect on reproduction, 0.75 on survival
- Anthropomorphic or unknown disaster: 2/100 years, 0.5 effect on reproduction, 0.5 on survival
- ENSO events: 17/100 years, 0.0 effect on reproduction, 1.0 on survival

All catastrophes were local

Carrying capacity (~ 1 bird per 0.5 ha. of suitable habitat; based on Laysan estimate (Warner 1963):

- Laysan: 500
- Eastern and Sand Islands, Midway Atoll: 446
- Lisianski: 225
- Kure: 150
- Nihoa: 102
- Environmental variation in carrying capacity 30%

Main and Northwestern Hawaiian Island Simulation:

Correlation between environmental variation and reproduction: 0.5

Translocation dispersal: 1% per generation for all NWHI; none from Main Islands to NWHI

Four catastrophes in the main Hawaiian Islands model (1.0 = no effect; 0 = total loss):

- Severe drought and disease: 4/100 years, .5 effect on reproduction, .75 on survival
- Hurricanes: 1/100 years, 0.5 effect on reproduction, .5 on survival
- Anthropogenic or unknown disaster: 2/100 years, 0.5 effect on reproduction, 0.5 on survival
- ENSO events: 17/100 years, 0.5 effect on reproduction, 1 on survival

All catastrophes were local

Harvests from Laysan are every 2 years for 17 years: 15 hatch year (HY) birds per year

Initial population size for 2 new populations = 40 all HY captive-born birds

Supplementation of new main island populations also from captive source:

Kaho'olawe: 10 HY per year for 17 years

"Main Island Predator Exclosure": 10 HY every 2 years for 17 years

Carrying capacity

- Kaho'olawe : 800
- Predator exclosure on Main Island: 500

Environmental variation in carrying capacity 30%

III. Results summary VORTEX simulations for Laysan duck viability.

Northwestern Hawaiian Islands only:

Laysan population (assumes no supplementation, no other management to offset 20 years of harvests for translocation purposes)

Year 50 Probability of survival 0.76

Year 100 Probability of survival 0.57 (0.05 SE)

Mean time to first extinction 38.71 years (3.40 SE)

Midway populations (assumes 3 to 4 supplementations over 20 years)

Year 50 Probability of survival 0.98

Year 100 Probability of survival 0.66 (0.04 SE)

Mean time to first extinction 70.4 years (3.26 SE)

Lisianski populations (assumes 3 to 4 supplementations over 20 years))

Year 50 Probability of survival 0.89

Year 100 Probability of survival 0.63 (0.04 SE)

Mean time to first extinction 61.24 years (3.57 SE)

Kure population (assumes 3 to 4 supplementations over 20 years)

Year 50 Probability of survival 0.93

Year 100 Probability of survival 0.61 (0.04 SE)

Mean time to first extinction 69.45 years (2.90 SE)

Nihoa population (assumes 3 to 4 supplementations over 20 years)

Year 50 Probability of survival 0.96

Year 100 Probability of survival 0.63 (0.04 SE)

Mean time to first extinction 61.22 years (3.26 SE)

Northwestern Hawaiian Islands Metapopulation

Year 50 Probability of survival 1.0

Year 100 Probability of survival 0.94 (0.02 SE)

Mean time to first extinction 89.17 years (3.04 SE)

Within population means

Year 50 Probability of survival 0.90; number of extant populations 4.52 (0.70 SE)

Year 100 Probability of survival 0.62 (0.02 SE)

Mean time to first extinction 61.2 years (21.26 SE)

Years with harvest and supplementation mean growth rate (r) = 0.1796 (0.3123 SE)

Years without harvest or supplementation r = -0.0136 (0.2743 SE)

Across all years mean r = -0.01 (0.2843 SE)

All populations in decline at year 50; additional supplementation and adaptive management needed to increase populations to carrying capacity after catastrophes.

Northwestern Hawaiian Islands and Main Islands:

Laysan population (immigration between NWHI only, no supplementation)

Year 50 Probability of survival 0.86

Year 100 Probability of survival 0.57 (0.04 SE)

Mean time to first extinction 54.77 years (3.64 SE)

Midway populations (3 to 4 supplementations over 17 years)

Year 50 Probability of survival 0.86

Year 100 Probability of survival 0.62 (0.05 SE)

Mean time to first extinction 61.0 years (3.45 SE)

Lisianski populations (3 to 4 supplementations over 17 years)

Year 50 Probability of survival 0.97

Year 100 Probability of survival 0.81 (0.03 SE)

Mean time to first extinction 61.56 years (3.26 SE)

Kaho'olawe population (yearly supplementation from captive flock for 17 years)

Year 50 Probability of survival 1.0

Year 100 Probability of survival 0.98 (0.01 SE)

Mean time to first extinction 58.71 years (12.9 SE)

Main Island predator exclosure population (assumes supplementation alternate years from captive flock for 17 years)

Year 50 Probability of survival 1.0

Year 100 Probability of survival 0.98 (0.01 SE)

Mean time to first extinction 54.0 years (17.78 SE)

Summary of Results for Mixed Islands Metapopulation – Combination of populations on Northwestern Hawaiian Islands and Main Hawaiian Islands:

Mixed Islands Metapopulation

Year 50 Probability of survival 1.0

Year 100 Probability of survival 0.99 (0.01 SE)

Mean time to first extinction 92.0 years (0.001 SE)

Within Mixed population means

Year 50 Probability of survival 0.92; number of extant populations 4.62 (0.78 SE)

Year 100 Probability of survival 0.75 (0.02 SE)

Mean time to first extinction 58.27 years (28.80 SE)

Years with harvest and supplementation mean growth rate (r) = 0.1370 (0.2843 SE)

Years without harvest or supplementation r = -0.0016 (0.2873 SE)

Across all years mean r = 0.0081 (0.2907 SE)