Control and eradication of the introduced grass, *Cenchrus echinatus*, at Laysan Island, Central Pacific Ocean

E. Flint and C. Rehkemper
US Fish and Wildlife Service, Pacific Remote Islands National Wildlife Refuge Complex, P.O. Box 50167, Honolulu, Hawaii 96850 USA, E-mail: Beth_Flint@fws.gov

Abstract The sandbur, *Cenchrus echinatus*, an annual grass native to Central America, was first documented occurring at Laysan Island, Hawaiian Islands National Wildlife Refuge, in 1961. The military or researchers visiting the island probably took it there inadvertently. By 1991 it had spread to become the dominant species in some 60 hectares or 30% of the vegetated area of the island. By displacing the native bunchgrass, *Eragrostis variabilis*, it diminished important breeding habitat for two endemic, endangered landbirds; the Laysan finch (*Telespiza cantans*) and the Laysan duck (*Anas laysanensis*), as well as several species of indigenous seabirds and terrestrial arthropods. In 1991 Refuge staff started a year-round control programme designed to eradicate *Cenchrus echinatus*. After experimenting with a range of techniques including heat and saltwater application, we found application of a herbicide (glyphosate) and mechanical control (hand pulling) to be most effective. Concurrent studies of the life history of the plant allowed continual adjustment and refinement of the eradication programme. Decline in the rate of finding new plants in a previously-cleared plot from as high as 85 plants per hour in Autumn 1994 to 0.043 plants per hour (or one plant per 23 hours searching) in Autumn 1999 is evidence that the seedbank is being depleted. *Cenchrus* is now so rare that it no longer has effect on the ecosystems of the island. Costs for the project include a monetary investment averaging US USD150,000 per year for staff, supplies, and vessel charter to this remote site (five days by boat from Honolulu); disturbance to nesting seabirds, and the risks of introducing new island pests despite stringent quarantine procedures.

Keywords invasive; restoration; glyphosate

INTRODUCTION

Laysan Island is a 411 hectare island in the north-western Hawaiian Islands at latitude 25°42'41"N and longitude 171°44'06"W. It was declared part of the Hawaiian Islands Bird Reservation by presidential order in 1909 and today makes up part of the Hawaiian Islands National Wildlife Refuge, managed by the U.S. Fish and Wildlife Service for the conservation of natural ecosystems and the protection and recovery of endangered species and migratory birds. The refuge consists of basalt islands, coral islands, atolls, and reefs; most of which are uninhabited. It stretches over 1370 kilometres to the north-west of the main Hawaiian Islands in the Central Pacific Ocean. Even though these remote islands were set aside for conservation relatively early, they did not escape all the exploitation and biological invasions to which oceanic islands are particularly vulnerable. Between 1887 and 1915 guano mining and feather hunting caused major disruption to the island's ecosystem (Spennemann 1998; Ely and Clapp 1973) but the most profound damage came after rabbits (*Oryctolagus cuniculus*) were deliberately introduced around 1903. The subsequent defoliation of the island due to this population of rabbits extirpated an unknown number of terrestrial invertebrates and plants, and caused the extinction of three land bird species before the last rabbit was killed in 1923. Scientists on the expedition in 1923 and again in 1930 replanted various plant species, some indigenous and some not (summarised in Ely and Clapp 1973 and Newman 1988). Today there are 17 native and 14 introduced plants on Laysan Island.

In 1961 biologists first detected *Cenchrus echinatus* or sandbur on Laysan Island. They killed *Cenchrus* plants found on that expedition but some survived, and by 1984 the species had spread to occur in 22 of 161 randomly located plots on Laysan Island or in 14.6% of sites (Newman 1988). At the peak of the infestation in 1991 *Cenchrus* grew on an area of 63.6 hectares representing 30% of the 212 vegetated hectares of the island. In 1990 the refuge manager decided the rapid spread of *Cenchrus* posed a threat to the health of the habitat and wildlife populations at Laysan and committed resources to a programme to eradicate the grass from the island. He chose to concentrate efforts on *Cenchrus echinatus* rather than the 13 other non-native plant species because this annual grass was obviously changing the ecosystem of Laysan Island. It seeds prolifically, forms mats, and it appeared to be displacing the native bunchgrass *Eragrostis variabilis* over large areas of the western part of the island. *Eragrostis* is a perennial bunchgrass and the dominant species on Laysan. It was seen in 117 of the 161 plots (77.5%) surveyed by Newman in 1984 (Newman 1988). This species is used by almost all the bird species breeding on Laysan as nesting habitat and cover. Of particular concern is its importance to the two endemic species of landbirds listed as endangered under the U.S. Endangered Species Act, the Laysan duck (*Anas laysanensis*) and the Laysan finch (*Telespiza cantans*). The Laysan duck prefers to nest deep within the clumps of *Eragrostis variabilis* (Moulton and Weller 1984). The Laysan finch at Laysan Island nests almost without exception in clumps of *Eragrostis* (Morin

Pages 110-115 In Veitch, C. R. and Clout, M. N. (eds.). *Turning the tide: the eradication of invasive species*. IUCN SSC Invasive Species Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK.

and Conant 1990). The finches also eat the seeds of the bunchgrass. *Eragrostis* is also important for most of the 17 species of breeding seabirds at Laysan that nest on or under the ground by providing cover for nests and giving structural stability to the soil to prevent burrow collapse. Whereas *Eragrostis* continues to provide cover and retains its physical structure even after it dries up, the *Cenchrus* leaves almost nothing when the plant dies.

The objectives of the management programme initiated in June 1991 were to locate, map, and kill all *Cenchrus echinatus* on Laysan. A regime was then established in which all areas could be visited and cleared of newly sprouted *Cenchrus* before seeding could occur. The manager made a commitment to continue this until the seed bank was completely depleted and eradication achieved. In addition to plant control, the staff monitored the plant community to assess progress and effects of the vegetation management and measured aspects of the life history of *Cenchrus* in order to refine control methods. Prior to the eradication programme the staff usually visited Laysan once per year. In June of 1991 a field camp was established that has been continuously occupied by at least two biological technicians since then.

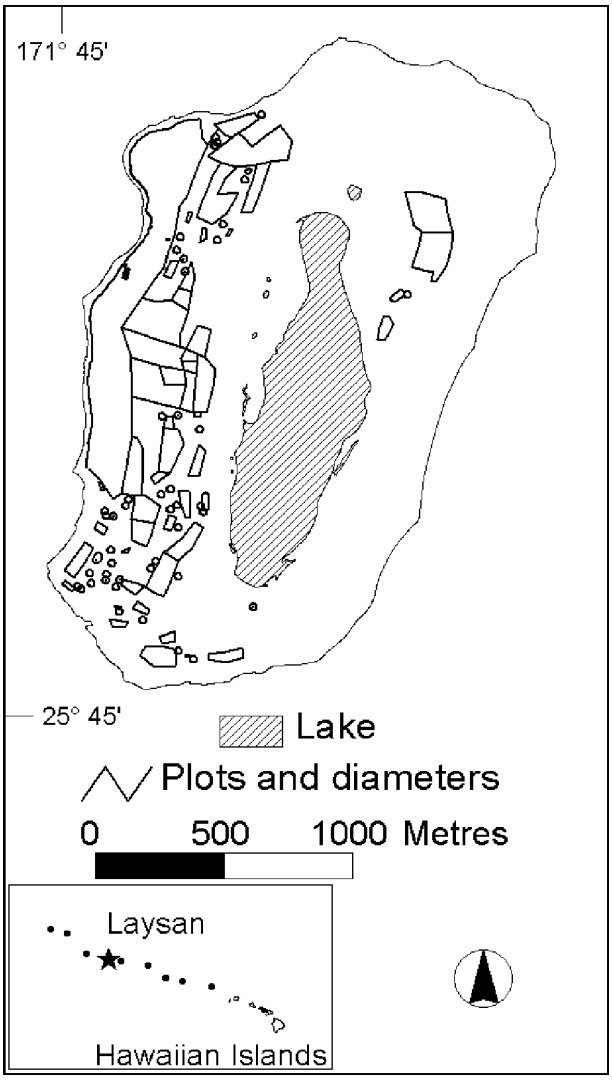

Fig. 1 Laysan Island, north-western Hawaiian Islands. Locations of plots and diameters in which *Cenchrus echinatus* was removed. The largest plot on the west side of the island was named the Blob.

METHODS

Control and Eradication

The staff tested several methods of killing *Cenchrus*, including heating plants with a propane torch, applying salt water, mechanical removal, and herbicide application. The most effective method for killing large mats and big plants with the least collateral damage to wildlife was to spray with 1% glyphosate (RODEO) mixed with a surfactant (LI700, Loveland Industries, Inc.) and a dye (Turf Mark, J. R. Simplot, Co.) to indicate areas already sprayed. We brought the large amounts of water needed to mix the herbicide by ship at each camp re-supply trip (three times per year) until 1994 when we installed a solar-powered reverse osmosis water maker. We applied herbicide using hand-pumped backpack sprayers. All sites at which any *Cenchrus* was found were assigned a permanent number, marked with posts made of 1.27 cm PVC pipe, and mapped. We marked patches of *Cenchrus* containing many plants along the entire perimeter and assigned a plot number. We marked the sites of solitary plants with a single pole and assigned a diameter number. These plots and diameters were placed in a rotation schedule in which they were revisited at intervals designed to allow detection of newly-sprouted *Cenchrus* before it could seed. The objective was to keep all plants in an area from setting seed and eventually deplete the seed bank and break the cycle of growth. Figure 1 shows all plots and diameters in which *Cenchrus* has been found and which are visited according to schedule. Greatest effort was first concentrated on plots located furthest to the north-east because the prevailing wind at Laysan is from that direction.

After initial spraying the technicians pulled subsequent regrowth by hand and removed it from the site in plastic bags. They brought the small amounts found to camp and burned them in a barrel. The main job in most plots after clearing of initial distribution of the weed becomes careful scrutiny of the entire area for any sign of *Cenchrus* sprouts. We initially set the interval between checks at two weeks but as life history data were collected we determined that *Cenchrus* did not go to seed for 8-19 weeks from initial sprouting. We changed the rotation schedule to increase visitation intervals to once every six weeks for three years after the last *Cenchrus* plant was found and then once per 16 weeks thereafter if no new plants were found in that time. Finally if a plot or diameter had no new plants found in five years, we changed the plot visitation rate to once per year. If a new plant appeared in a very large plot, a new interior diameter was established at the site to preclude having to increase the visitation rate for the entire plot. At every visit the staff recorded time spent in the plot, number of *Cenchrus* plants found and their stage of development, and number of seabird bur-

rows crushed. In 2001 as time constraints were eased from the assignment of more and more plots to the least frequently visited category we created one more category. "Hotspots" are plots or diameters in which *Cenchrus* has been found within the last two years and in two consecutive visits. We visit these sites every four weeks.

We overlaid a 100 metre grid on a map of the entire island and systematically searched all sections as often as possible (usually once every two years) to locate new or undiscovered patches of *Cenchrus* as well as to maintain surveillance for other previously-undetected weeds.

The extremely high density of wildlife (hundreds of thousands of breeding seabirds) present year-round at Laysan Island necessitated special measures and considerations to reduce impacts. Spraying herbicide instead of pulling minimised the time the staff spent in any particular part of the colony and protected burrow structure. We chose glyphosate because of its relatively low vertebrate toxicity. We restricted the height of the PVC pole markers to reduce the collision hazard for flying seabirds. Early in the evaluation of methods for killing *Cenchrus echinatus* we rejected the idea of pursuing a biological control agent due to possible presence of an indigenous congener, *Cenchrus agriminioides laysanensis.* We believe that this variety is now extinct but did not choose to take the risk of introducing a biological control agent that might harm any survivors. When plots and diameters moved into the once-per-year rotation schedule we visited them during November and December when the fewest burrow-nesting seabirds were present and vulnerable to burrow collapse.

Maintaining a year-round camp increased the number of people visiting and the importation of equipment and food. This raised the probability of introducing new plants, insects, and pathogens to Laysan Island. A strict quarantine protocol has been in effect for the duration of the project: this includes the requirement that all soft gear (clothing, shoes, tents, packaging, etc.) that is brought to Laysan be brand new. All goods are packed in plastic containers. No corrugated cardboard is permitted. All items except for electronic and optical gear must be frozen for 48 hours prior to being landed at Laysan.

Monitoring

Throughout the operation we monitored the plant community and the resident bird community to assess the extent and effects of the *Cenchrus* infestation, to refine control techniques, to measure success in control efforts, and to measure the effects of control efforts on other species of plants and animals. We also measured standard weather variables (rainfall, temperature, wind velocity, cloud cover) to assess their relationship to *Cenchrus* growth.

Plant Community

In 1989 the staff established five vegetation transects to monitor the spread of the largest of the *Cenchrus* distributions (the Blob). These transects were lines ranging between 150 and 300 m long and placed to be perpendicular to the boundary between the interior of the Blob and the *Cenchrus*-free areas adjacent to them. Twice per year we recorded plant species or substrate at each metre mark on tape extended between the two ends.

We studied *Cenchrus* life history by marking individual sprouts as they emerged and continuing to monitor their development. We checked plants once per week to record the age when seeds appeared and when seeds were mature.

Effects on seabird populations

We studied the effects of *Cenchrus* and *Cenchrus* control actions on avian populations by establishing twelve 10m x 10m plots on the west side of the island. Eight plots were located adjacent to each other in the heart of the main *Cenchrus* distribution. Four were located at a site of similar aspect and distance from the ocean but outside the area infested by *Cenchrus.* In the infested area we cleared four of the plots of *Cenchrus* and maintained them *Cenchrus*-free using the techniques standard to the rest of the island. The other four plots were allowed to remain infested. We measured percentage cover of *Eragrostis,* percentage cover of *Cenchrus,* percentage cover of other plant species, numbers of clumps of *Eragrostis*, numbers of all active and empty nest sites for all bird species and the contents of those nests, and numbers of all birds in the plots not associated with nests. This study continued from June 1991 to April 1995.

RESULTS

There are currently 90 plots of varying sizes and 161 circles (called "diameters") with a 15 metre radius. Of these, 24 plots and 136 diameters have moved to the once-per-year rotation because no *Cenchrus* has been found for more than five years. Forty-nine plots and 19 diameters have been moved to visits once per tour (~16 weeks) because *Cenchrus* has not been found there in at least three years. The remaining 17 plots and six diameters remain on a six-week rotation schedule. In the period from October 2000 to March 2001 two full time technicians found only 13 *Cenchrus* plants, five of those that had seeds. From March 2001 to July 2001 they found no *Cenchrus* plants.

By tracking individual *Cenchrus* plants the staff measured time required from sprouting to production of mature seeds. During the winter months (October-March) the first mature seeds appeared between eight and 19 weeks after marking (mean 12.3 weeks, n = 37). During a summer trial we observed comparable results with plants taking between eight and 12 weeks to produce mature seeds (mean 9.6 weeks, n = 6) (Marks 1995).

Cenchrus echinatus had a deleterious effect on wildlife by displacing the dominant plant *Eragrostis variabilis*. Figure 2 illustrates *Eragrostis* density in a transect through an area without *Cenchrus* and changes in percentage cover

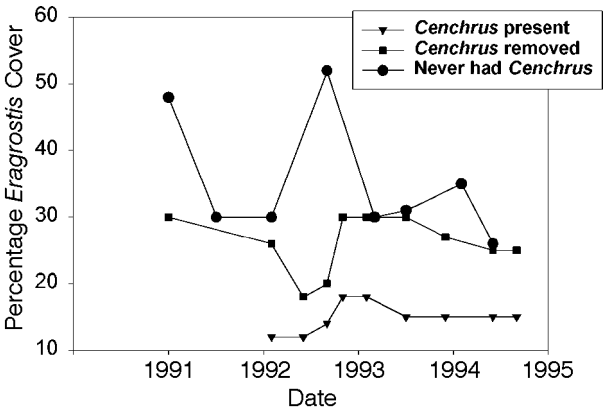

Fig. 2 Difference in *Eragrostis variabilis* cover between areas with and without *Cenchrus echinatus* present. Transect A was an area that never had *Cenchrus*. *Cenchrus* was removed and kept out in Plot B and left intact in Plot CB.

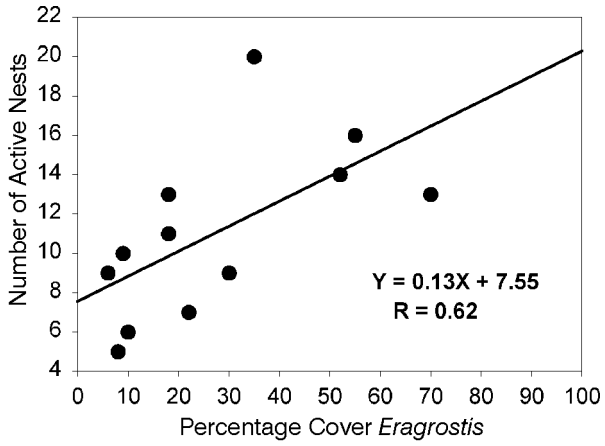

Fig. 3 Relationship between percentage cover of *Eragrostis variabilis* and number of active seabird nests in 12 plots (10 x 10 m) in July 1993. Y = 0.13X + 7.55, R = 0.62

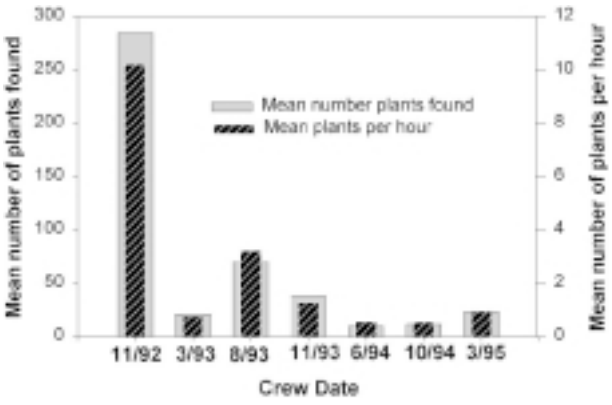

Fig. 4 Average Number of *Cenchrus echinatus* plants found per hour and average total plants found in seven different plots on Laysan Island between November 1992 and March 1995.

of *Eragrostis* over a four-year period in two adjacent plots (B and CB). *Cenchrus* was removed and excluded in plot B and left intact in CB. Figure 3 illustrates the positive relationship between seabird nest density and percentage cover of *Eragrostis variabilis*.

Extirpation patterns and seed bank persistence remained consistent throughout the period in which plots were brought under the control regime. As an example the average number of *Cenchrus* plants found per hour and the average number of plants found in seven different plots over a two and a half year period are shown in Fig. 4. The numbers of plants found in a very large plot over a period of approximately three years from initial clearing (Fig. 5) may indicate that seed bank depletion is somewhat independent of environmental conditions such as temperature and rainfall. All areas of Laysan Island had extensive mixing and turnover of the soil through the digging actions of the burrow-nesting seabirds such as wedge-tailed shearwaters (*Puffinus pacificus*) and Bonin petrel (*Pterodroma hypoleuca*). This accelerated the rate at which seeds were exposed to conditions that triggered germination. A very efficient ally in the depletion of the seed bank was the Laysan finch (*Telespiza cantans*). These granivorous birds actively searched the soil for seeds and destroyed them as they consumed them. Decline in the rate of finding new plants in a previously-cleared plot from as high as 84.7 plants per hour in Autumn 1994 to 0.043 plants per hour in Autumn 1999 is evidence that the seed bank is being depleted.

The monetary cost of eradicating *Cenchrus echinatus* at Laysan was high due to the extreme remoteness of the site. Prior to the initiation of the project we managed the refuge by visiting only once per year so the necessity of establishing a year-round camp significantly increased the annual expenditures for this site to an average of USD150,000 per annum. Although we did other biological and management tasks while at the field site we can attribute the entire budget to the eradication effort because we would not have maintained a permanent camp there if not for the *Cenchrus* project.

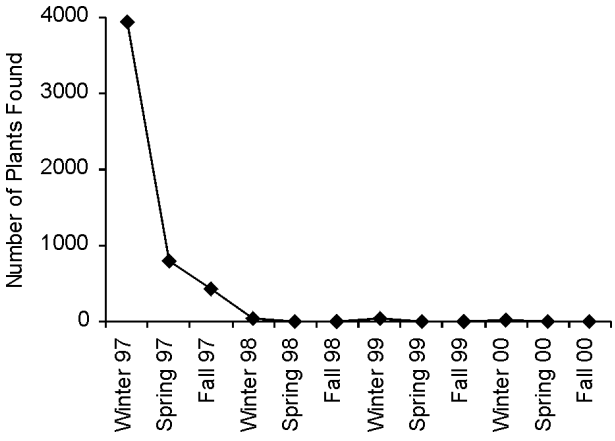

Fig. 5 Number of *Cenchrus echinatus* plants found in South Blob plot on each tour after initial clearing.

It is somewhat harder to quantify the impacts of an eradication program on wildlife. Hundreds of burrows of nesting seabirds were destroyed each year during operations. Some of these cave-ins killed the eggs or more rarely the chicks in the burrow. Small numbers of adult albatrosses and terns were also killed or injured in collisions with the radio antenna in camp or with the PVC plot poles. Grey-backed terns (*Sterna lunata*) and sooty terns (*Sterna fuscata*) flushed from their eggs by our activities lost eggs to ruddy turnstones (*Arenaria interpres*) and Laysan finches. Despite the adverse effects of our activities at Laysan on individual seabirds we do not believe that our work was detrimental to any population of birds at Laysan Island.

In the 10 years since we have had the quarantine protocols in effect, we have had only one possible introduction of a plant. A single seedling of what could only be tentatively identified as a member of the genus *Medicago* sprouted in 2000. It died before it flowered. Our ability to detect new terrestrial invertebrate introductions, and soil-borne pathogens is less well-developed due to less information about the invertebrate community at the outset of the project but we are not aware of any introductions that can be attributed to the *Cenchrus* eradication.

DISCUSSION

A year-round effort targeting the invasive grass *Cenchrus echinatus* at Laysan Island was successful at reducing the plant to almost undetectable levels. In balancing between active management and scientific documentation of the biology of *Cenchrus* and the effects of its removal, we put most resources into plant removal rather than into exhaustive monitoring of outcomes or analysis of data.

In 1993 refuge staff discovered a small, incipient invasion of *Cenchrus echinatus* at Rose Atoll, American Samoa. When found there were 10 robust clumps, most of which had gone to seed. These plants were pulled and the site visited again on subsequent trips. The seeds remaining in the soil had sprouted by the next visit in 1994. Biologists working with the Department of Land and Natural Resources of the American Samoa Government pulled all the plants again, burned the area, and covered it with a plastic tarpaulin. This action killed the remaining seeds in the seed bank and today Rose Atoll is *Cenchrus*-free. The Rose Atoll experience underscores the value of early intervention, especially at sites that you cannot occupy year-round.

The cost per plant of continuing the *Cenchrus* work each year has become very high but the cost of discontinuing the programme too soon is also very high. The probability that the eradication of *Cenchrus* will be successful at Laysan Island is higher than might be predicted for other infestations of comparable size because of the extreme isolation of the site, the high degree of control the management agency has over access to the island, and the ability to maintain the effort throughout the long period of extremely low *Cenchrus* yield that inevitably occurs at the end of any eradication effort.

With the imminent extirpation of *Cenchrus* at Laysan, the staff have incorporated other restoration activities into their schedule including propagation and planting of indigenous species that either had become exceedingly rare at Laysan (*Mariscus pennatiformes, Chenopodium oahuense*) or were completely eliminated by rabbits prior to 1923 (*Pritchardia remota, Capparis sandwichiana, Santalum ellipticum*). The decision to control or attempt eradication of other non-indigenous species at Laysan will be made on an individual basis when our understanding of each species' role indicates that it has the potential to have the same profound effects observed during the *Cenchrus echinatus* invasion.

ACKNOWLEDGMENTS

Our gratitude goes to Ken Niethammer, and Darcy Hu for early work on establishing the need for the project. Our deepest appreciation is given to Refuge Manager, Ken McDermond for starting and maintaining the efforts throughout his tenure at the Pacific Remote Islands Wildlife Refuge Complex. We thank Jeff Marks for his clear synthesis and summary of the first five years of the project. We thank Chris Depkin for his contributions to the actual fieldwork and subsequent data analysis. We thank the following biologists, managers, and biological technicians for their hard labour, detailed documentation, and careful stewardship of Laysan Island during the *Cenchrus* project: Mark Rauzon, Steve Barclay, Craig Rowland, Dick Bauer, Robert Rydell, Pam Bruce, Donna Ball, Jennifer Gervais, Randall Hetzel, Kay Kepler, James Applegate, Cindy Newton, Anthony Chappelle, Rebecca Howard, Rick Schauffler, Willie Joe Rogers, Nathan Darnall, Timothy White, Vanessa Gauger, Josh Adams, Hannahrose Nevins, Monette Boswell, Brad Keitt, Amy Edmonds, Leslie Leroux, Leah de Forest, Gregory Spencer, Donna O'Daniel, Charles Monnett, Marc Webber, Drew Wettergreen, Rebecca Bernard, Brian Allen, Nathan Johnson, Amber Pairis, Michael Shultz, Peter Winch, Carolyn Mostello, Christina Sulzman, Heather Ziel, Vanessa Pepi, Elizabeth Mitchell, Catharine McMahon, Hadie Muller, Mari von Hoffman, Natalie Wilkie, Thomas Wilkie, Christopher Dodge, Jay Kelly, Matthew Patterson, Russell Bradley, David N. Johnson, Patty Scifres, Alex Wegmann, Rebecca Woodward, Brendon Courtot, Bart McDermott, Matthew Berry, Matthew Schultz, Kelly Kozar, Chris Eggleston, Holly Gellerman, Jennifer Hale, Marvin Friel, Eric Lund, Joseph Wiggins and David Carroll. We thank Lee Ann Woodward for her thoughtful contributions to the manuscript and Dick Veitch, Carol West, and Elizabeth Rippey for their helpful improvements to the paper.

REFERENCES

Ely, C. A and Clapp, R. B. 1973. The Natural History of Laysan Island, Northwestern Hawaiian Islands. *Atoll Research Bulletin 171*. Washington, D.C., Smithsonian Institution.

Marks, J. S. 1995. Laysan Island *Cenchrus* Control, 1991 to 1995: Project Review and Recommendations for the Future. Administrative Report, Hawaiian Islands National Wildlife Refuge. US Fish and Wildlife Service. Honolulu, Hawaii.

Morin, M. P. and Conant, S. 1990. Nest substrate variation between native and introduced populations of Laysan Finches. *Wilson Bulletin 102*: 591-604.

Moulton, D. W. and Weller, M. W. 1984. Biology and conservation of the Laysan Duck (*Anas laysanensis*). *Condor 86*: 105-117.

Newman, A. L. 1988. Mapping and monitoring vegetation change on Laysan Island. Unpublished MA Thesis, University of Hawaii, Honolulu.

Spennemann, D. H. R. 1998. Excessive harvesting of Central Pacific seabird populations at the turn of the 20th century. *Marine Ornithology 26*: 49-57.