BREEDING PERFORMANCE OF LAYSAN ALBATROSSES *PHOEBASTRIA IMMUTABILIS* IN A FOSTER PARENT PROGRAM

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SUMMARY

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Laysan Albatrosses *Phoebastria immutabilis* are large seabirds that breed primarily in the Northwestern Hawaiian Islands. In the 1960s, they began colonizing new sites across the Pacific, including the US Navy's Pacific Missile Range Facility (PMRF) on Kaua'i. Albatross were first recorded at PMRF in 1967, were breeding by 1977 and by 2012 had a colony of 84 nesting pairs. In 1988, a bird-aircraft strike hazard reduction program was begun in which adults were hazed and eggs were destroyed. In 2005, a foster parent program was initiated in which inviable eggs from Laysan Albatross pairs on Kaua'i's North Shore were replaced with viable eggs from PMRF. From 2009 to 2012, we placed 105 eggs from PMRF in foster nests. Hatching success of foster eggs (39%) was low because most foster eggs (71%) were placed with female-female pairs, which are known to have low hatching success compared with male-female pairs (32% vs. 63%). Fledging success of foster nests (93%) was high, but overall reproductive success of foster nests (36%) was lower than average for this species because of the low hatching rate. This project contributed to the conservation of Laysan Albatrosses by producing 37 additional young for the Kaua'i population and provided valuable insights into incubation, breeding performance and fostering methods. Additional foster pairs should be sought, and sites on other islands should be identified where excess eggs from PMRF could be used to create new colonies by hand-rearing chicks.

Key words: bird air strike hazard, egg candling, egg fostering, Laysan Albatross, translocation

INTRODUCTION

Laysan Albatrosses *Phoebastria immutabilis* are large, long-lived, tube-nosed seabirds with a wingspan just under 2 m, a pelagic distribution that spans most of the North Pacific, and a breeding distribution that is 99% contained within the Northwestern Hawaiian Islands (Awkerman *et al.* 2009). They begin returning to their natal colony at 2–5 years and begin breeding at 7–9 years; when not breeding, they spend their time at sea. Once birds have bred at a site, they usually return to the same site each year (Awkerman *et al.* 2009).

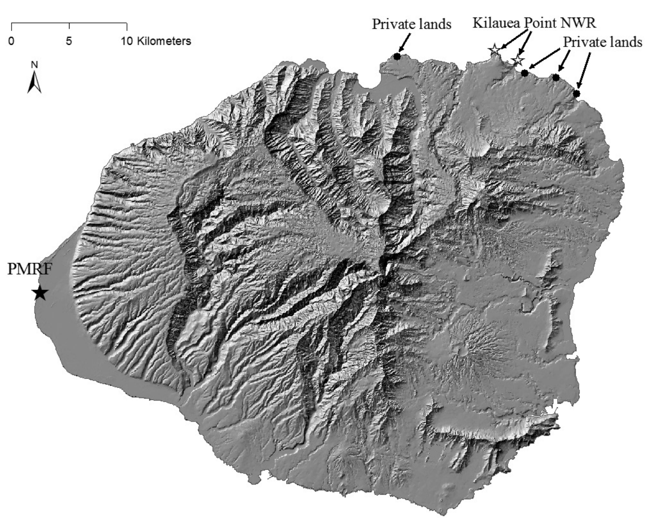

Fig. 1. Map of Laysan Albatross colonies on Kaua'i; Kīlauea Point NWR and "private lands" are referred to in the text as North Shore Kaua'i. PMRF: Pacific Missile Range Facility; NWR: National Wildlife Refuge.

In the 1960s and 1970s, Laysan Albatrosses began colonizing new islands and re-colonizing islands where they had been extirpated, despite their high natal philopatry. New breeding locations included Guadalupe, Clarión and San Benedicto Islands in the Eastern Pacific near Mexico (Gallo-Reynoso and Figueroa-Carranza 1996). Re-colonizations included Mukojima, Japan (Kurata 1978), O'ahu (Young et al. 2009) and Kaua'i in the southeastern Hawaiian Islands (Zeillemaker & Ralph 1977). On Kaua'i, the first historical records were of two birds at Makahuena Point near Kōloa in March 1945 and March 1946 (Pyle and Pyle 2009). Reports were scarce until 1967/68, when 4–10 birds were reported at the Pacific Missile Range Facility (PMRF) in southwestern Kaua'i (Fig. 1, Pyle and Pyle 2009).

Birds appeared annually at PMRF after 1967, and the first eggs were first documented in 1977/78, with an estimated 25–30 adults present (Byrd & Telfer 1979, 1980). In the years following, eggs were laid each year with at least 20 adult Laysan Albatrosses in attendance

(Pyle & Pyle 2009). Throughout this period, reproductive success of Laysan Albatrosses was low or non-existent because of dog attacks, human disturbance and inexperience of the young adults (Byrd & Telfer 1980, Telfer 1984, Moriarty *et al.* 1986).

In 1984, in response to the threat of predation by dogs and concern about the growing number of Laysan Albatross chicks hatching at PMRF, US Fish and Wildlife Service (USFWS) biologists moved eight newly hatched chicks from PMRF to Kīlauea Point National Wildlife Refuge (KPNWR, Fig. 1), where they were hand-reared (Moriarty *et al.* 1986). Unfortunately, the chicks did not survive to fledge. By 1988, Laysan Albatrosses were considered to be a bird-aircraft strike hazard (BASH) because of their large size and flight pattern, and the US Navy began to discourage albatrosses from nesting and/or landing around the airfield at PMRF (Anders *et al.* 2009). Laysan Albatross adults at PMRF were captured and driven around the island to KPNWR, where a few birds were already breeding (Moriarty *et al.* 1986), and released in hopes of discouraging them from returning to PMRF. Despite this, the PMRF population continued to grow. Small numbers of chicks fledged each year and new birds began breeding. By 2012, approximately 84 albatross pairs were attempting to breed each year at PMRF in addition to the 226 nesting pairs at KPNWR (and vicinity, i.e. on neighbouring private properties, hereafter referred to as North Shore Kaua'i, Fig. 1). With the exception of the eight chicks translocated in 1984, from 1988–2005, all eggs laid at PMRF were legally destroyed or donated for research purposes to discourage albatrosses from nesting in the area as part of the BASH reduction program.

In 2005, the Navy, the USFWS, and the US Department of Agriculture Wildlife Services devised a program to place fertile eggs from PMRF, which would have been destroyed, with foster pairs whose egg was infertile at North Shore Kaua'i. This fostering program has been referred to as the "albatross egg swap," which simultaneously augmented the albatross population at the North Shore and reduced aircraft strike hazards at PMRF by eliminating the possibility of new chicks hatching and imprinting on the site. The USFWS conducted this program until 2008, after which L.C.Y. and E.A.V. were invited to continue the project.

The purpose of this paper is to evaluate the egg swap program efficacy from 2009 to 2012, and provide recommendations for improving this foster program, and possibly others, if it is continued.

METHODS

Laysan Albatross reproductive biology

Laysan Albatrosses return to the breeding colony in early November and lay a single egg in late November or early December (Awkerman *et al.* 2009). Eggs are incubated for ~65 days and hatch in late January and early February. Chicks fledge in late June and July. In colonies with female-biased sex ratios, such as on Kaua'i and O'ahu, females may pair with another female when they cannot find a male mate. These female-female pairs have significantly lower reproductive success than male-female pairs as a result of poor hatching rates (Young *et al.* 2008, Young & VanderWerf 2014).

Foster egg collection and incubation

Most eggs at PMRF were taken from nests as they were discovered (typically within 1–2 days of laying), then placed in an ostrich egg incubator set at 35.6°C that allowed humidity control and regular egg turning. Eggs were maintained in the incubator for up to 23 days until foster parents were located. To determine whether the incubator was having a detrimental impact on egg viability, a sample of eggs (9–20/year; 47 total) were left to be incubated by the original parents in an area of the base away from the runway where they were regarded as less of a hazard to aircraft. On the day of the egg swap, the naturally incubated eggs were collected, candled, and if viable, transported to the North Shore to be placed in foster nests on the same day.

Determining egg viability

We used the technique of back-lighting eggs termed "candling" to determine the viability of Laysan Albatross eggs. Candling involves shining a bright light through the shell to illuminate the interior of an egg to visualize the blood vessels of the yolk sac and chorioallantoic membranes (Ernst *et al.* 2004). Since candling must be done in the dark, we either candled eggs at night or used a black hood or blankets to cover the observer. When retrieving eggs from potential foster nests for candling, we placed a shield (e.g., a clipboard or plastic garbage can lid) between the bird and observer to prevent the adult from accidentally striking its own egg. Eggs were candled quickly (typically in <1 min) and returned to the incubator in the case of PMRF eggs, or to the incubating adult, which typically remained on the empty nest during the procedure.

We candled eggs from 10–20 December each year, approximately 20–30 days after the initiation of egg laying and 0–10 days before the completion of egg laying. The age of eggs at candling thus ranged from freshly laid to more than 20 days for both PMRF and foster nests. We used chi-squared tests to compare the viability of PMRF eggs with eggs at the foster sites, and to compare the viability of eggs at PMRF that were incubated naturally with those that were placed in the incubator. However, we did not candle eggs at foster sites that had already been abandoned, so the proportion of inviable eggs at the foster sites may have been higher than we report because inviable eggs were more likely to have been abandoned.

Selection of foster nests

From 2009 to 2012, we located and numbered all Laysan Albatross nests at KPNWR and on nearby private properties that had granted us access (Fig. 1). All attended nests in which the egg was determined to be inviable by candling were selected as foster nests. Up to five private properties were included from 2009 to 2011, after they were deemed to have taken sufficient precautionary measures to prevent disturbance and predation to nesting albatrosses (such as fencing, predator control, etc.). In 2012, the Hawai'i Department of Land and Natural Resources did not permit placement of eggs on private properties until a management plan addressing habitat management, predator control, and other issues was completed. This had not happened before the commencement of the breeding season in that year. As a result, in 2012, eggs were candled on two of the private properties to collect data on egg viability, but no foster eggs were placed on those properties.

Reproductive outcomes

We monitored the reproductive outcome of all foster nests in which we placed an egg. We monitored nests weekly until the chick fledged. Monitoring consisted of recording the band number of the foster parents and noting the contents of the nest (egg, chick, dead chick, etc.) and determining the ultimate outcome of the nest.

We calculated hatching success as the proportion of eggs that hatched, fledging success as the proportion of chicks hatched that left the nest (fledged), and overall reproductive success as the proportion of eggs that resulted in a fledged chick. Because sufficient average reproductive measures did not exist for all the foster colonies, we used one-sample binomial tests of proportion to compare the hatching success, fledging success and overall reproductive success of foster eggs to average values reported in the literature (Arata *et al.* 2009, Young *et al.* 2009). We used a chi-squared test to compare hatching success between PMRF eggs that were placed in the incubator and PMRF eggs that were naturally incubated. We also used chi-squared tests to compare hatching and fledging success in female-female with success in male-female foster pairs.

RESULTS

Egg viability

Viability of PMRF eggs (0.63 ± 0.03) was lower than viability of eggs at foster sites (0.76 ± 0.02; chi-squared = 14.50, df = 1, $P < 0.001$). However, it should be noted that at PMRF we candled all eggs because eggs were collected before adults would have had a chance to abandon them, whereas at the foster sites we excluded eggs that already had been abandoned. At PMRF, viability did not differ between eggs placed in the incubator (0.63 ± 0.04) and those that were naturally incubated until being placed in a foster nest (0.64 ± 0.07; chi-squared = 0.006, df = 1, $P = 0.94$).

EGG PLACEMENT

We placed a total of 105 eggs in foster nests from 2009 to 2012. The number of foster eggs increased each year except 2012 (Fig. 2), when placement of eggs was not permitted on private properties. Of nests in which the sex of both parents was known through genetic sampling conducted at the time of banding (N = 59), 71% of eggs were placed with female-female pairs, even though female-female pairs comprised only 31% of the pairs on Kaua'i (Young *et al.* 2008). This was not done deliberately, but occurred because the egg in female-female pairs is more likely to be infertile or improperly incubated (Young *et al.* 2008). Many pairs received foster eggs in more than one year of the four-year study, including 33 pairs (32%) that received an egg in two years and two pairs (2%) that received an egg in three years. Of the pairs receiving two or more foster eggs in which the sex of both parents was known (N = 27 pairs), 89% were female-female pairs and 11% were male-female pairs. In every year, there were more viable foster eggs available than foster nests able to receive them, and multiple viable eggs from PMRF were still destroyed each year.

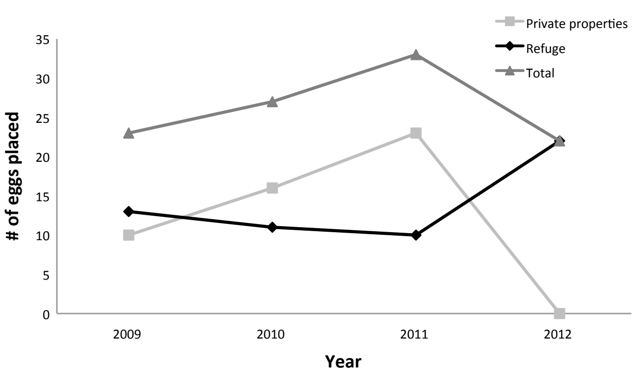

Fig. 2. Number of foster eggs placed on Kaua'i, by property type and by year.

Reproductive outcomes

The hatching success of foster eggs was 39% over all four years combined, which was lower than the average hatching success in a Laysan Albatross colony at Ka'ena Point on O'ahu (62%, binomial proportion test, $P < 0.001$; Young *et al.* 2009) and lower than the average hatching rate at Midway (64%, binomial proportion test, $P < 0.001$; Fisher 1975). The main cause of the low hatching success was that many eggs were placed with female-female pairs, which tended to have lower hatching success (32%) than male-female pairs (63%, chi-squared = 2.79, df = 1, $P = 0.09$). The hatching rate of foster eggs placed with male-female pairs (63%) was very similar to the average hatching rate at Ka'ena Point and at Midway. There was a suggestion that hatching success was lower in PMRF eggs that had been placed in the incubator (35%) than in PMRF eggs that were naturally incubated (45%), although all eggs selected for placement in foster nests appeared to have been viable when candled. Differences, however, were not significant (chi-squared = 1.06, df = 1, $P = 0.30$) because of the small sample size of naturally incubated eggs (N = 47).

Once the eggs had hatched, the fledging success of foster chicks (93%) was higher than the average fledging success in Laysan Albatrosses at Ka'ena Point (78%, binomial proportion test, $P = 0.02$; Young *et al.* 2009) but not significantly different from the average at Midway (86%, binomial proportion test, $P = 0.27$; Fisher 1975). There was no difference in fledging success between female-female foster pairs (88%, n = 14/16) and male-female foster pairs (100%, n = 10/10; chi-squared = 1.36, df = 1, $P = 0.23$).

Overall reproductive success of pairs with foster eggs was 36%, which was lower than the reproductive success at Ka'ena Point (48%, binomial proportion test, $P = 0.02$; Young *et al.* 2009) and at Midway (55%, binomial proportion test, $P < 0.01$; Fisher 1975). Surprisingly, reproductive success was higher on private lands (46%) than on the refuge (27%, binomial test of proportion, $P = 0.05$), despite both areas having similar proportions of female-female pairs. A total of 37 additional albatross chicks fledged as a result of this project, or an average of 9.3 per year.

DISCUSSION

This project produced 37 additional Laysan Albatross chicks for the Kaua'i population from eggs that otherwise would have been destroyed, and it also resulted in the development of a useful wildlife management tool. Although not all foster eggs hatched or resulted in a fledged offspring, all foster parents would have failed at reproduction because their biological egg was not viable. The main factor limiting the number of foster chicks raised was the number of foster parents available; the number of viable eggs removed from PMRF has exceeded the number of available foster nests each year. While reproductive success of foster eggs was limited by the low reproductive success of female-female pairs (Young & VanderWerf 2014), not using female-female pairs as foster parents would have resulted in even fewer eggs being placed due to the paucity of available male-female foster pairs.

It is possible that, by receiving a foster egg, foster pairs were forced to attempt a complete reproductive cycle when they normally would have left the colony and returned to sea to replenish their energy reserves. Laysan Albatrosses that successfully fledge a chick have slightly lower annual survival than those that fail in their breeding attempt (94.2% vs. 95.4% in females, 92.2% vs. 97.2% in males; VanderWerf & Young 2011). It is conceivable that, by providing a viable egg to birds whose natural egg would not have hatched, we inadvertently also reduced their survival. However, since only 36% of foster eggs resulted in a fledged chick and 71% of foster pairs consisted of two females, which only experience a 1% decrease in annual survival, the population level impacts of the potential reduction in adult survivorship are more than offset by the increase in the number of chicks fledged, even when survival from fledging to breeding (63%; Fisher 1975) is taken into account. This indicates that, of the average nine chicks produced each year, approximately six will survive to breed as adults—a meaningful number given the breeding population size of 226 pairs at KPNWR and vicinity.

There are several human-related factors that also could have played a role in the low hatching success. First, the transport of eggs from PMRF to the foster nests involved several hours in a vehicle at temperatures lower than ideal incubation temperature and on bumpy roads that could have inadvertently addled some eggs after we determined viability. Second, artificial incubation may have had a negative effect on hatching success. Although candling showed that viability did not differ between PMRF eggs placed in the incubator and those naturally incubated, the tendency toward lower hatching success of incubator eggs suggests that some changes may be warranted in the incubator conditions. The incubator used was designed for Ostrich *Struthio camelus* eggs, which are much larger than Laysan Albatross eggs, but that was the closest egg size available. It is possible that the incubator temperature, egg rotation frequency or pattern, and humidity were suboptimal for Laysan Albatross eggs and resulted in poor development of the embryo. New information is available about natural incubation temperature and egg rotation patterns that can be used to improve artificial incubation practices (Schaffer *et al*. 2014).

An alternative to artificial incubation is to allow nesting albatrosses at PMRF to incubate their eggs until they are removed for placement in foster nests. Preliminary data from the BASH reduction program at PMRF indicate that fewer birds are in the air, where they are a hazard to aircraft, when they are allowed to incubate (Anders *et al.* 2009). If all albatrosses at PMRF were allowed to naturally incubate their eggs until they were placed in foster nests, the Navy could eliminate costs associated with incubator maintenance, reduce the number of birds in the air (thus increasing aircraft safety), and possibly enhance the conservation value of the project through increased hatching success of eggs placed in foster nests.

Within-species fostering is an uncommon management tool because few cases exist where there is both an appropriate donor and recipient population of the same species. More typical scenarios have involved cross-fostering of chicks or eggs from a rare species by a closely related but more common species to attempt to create a new population. For example, an egg cross-fostering experiment was conducted on Kaua'i in the 1970s in which eggs of the threatened Newell's Shearwater *Puffinus auricularis newelli* were brought from their remote montane nesting sites and fostered by Wedge-tailed Shearwaters *P. pacificus* at KPNWR (Byrd *et al.* 1984). The chicks from this experiment successfully hatched, and some returned to breed, resulting in a small population of Newell's Shearwaters that continue to breed at KPNWR today (Ainley *et al.* 1997). Because the Laysan Albatross is not listed under the Endangered Species Act and currently is relatively abundant, there is less incentive to salvage and foster its eggs. This also likely explains the scarcity of within-species fostering programs, because the presence of a donor and a recipient population imply that the species is widespread and of lower management priority. Nonetheless, the Laysan Albatross is considered to be a species of concern by the USFWS and as "Near Threatened" by the International Union for the Conservation of Nature (IUCN), and it still warrants management assistance. Moreover, the effects of climate change, particularly rising sea level, are likely to have severe impacts on the low-lying atolls in the Northwestern Hawaiian Islands (Reynolds *et al*. 2012), where the vast majority of Laysan Albatrosses breed. Protection and augmentation of existing colonies on high islands such as Kaua'i and O'ahu, and creation of additional colonies, are needed to ensure the persistence of this and other seabird species (Young *et al*. 2012, VanderWerf 2013).

In future years, additional suitable foster parents should be located on Kaua'i, and suitable sites on other islands, such as James Campbell National Wildlife Refuge on O'ahu, should be identified where new Laysan Albatross colonies could be created by hand-rearing chicks from excess PMRF eggs (Deguchi *et al.* 2014).

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