LONG-TERM OUTCOMES OF A LAYSAN ALBATROSS *PHOEBASTRIA IMMUTABILIS* FOSTER EGG TRANSLOCATION PROGRAM

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Received 27 February 2024, accepted 27 April 2024

ABSTRACT

VANDERWERF, E.A., YOUNG, L.C, KOHLEY, C.R., BEHNKE, J., MCFARLAND, B., FINNEY, K., OSTERLUND, H., MURPHY, J., SEROTA, A., BARNFIELD, L., GREEN, Y., ROGERS, K.S. & GRANHOLM, C. 2024. Long-term outcomes of a Laysan Albatross *Phoebastria immutabilis* foster egg translocation program. *Marine Ornithology* 52: 247–251.

In the 1960s and 1970s, Laysan Albatrosses *Phoebastria immutabilis* colonized several sites in the Pacific from which they had been extirpated or had not been known to nest previously, including the US Navy's Pacific Missile Range Facility (PMRF) on Kaua'i, Hawai'i, USA, where they increased to become a bird aircraft strike hazard (BASH). To reduce their population at PMRF, albatross eggs were destroyed or removed as part of a BASH reduction program until 2005, when an alternate plan was devised by the Navy, US Fish and Wildlife Service, and US Department of Agriculture Wildlife Services, in which eggs from PMRF were placed in foster nests at other colonies on Kaua'i where the natural egg was infertile or had died. During 2009–2022, we placed 500 eggs from PMRF in foster nests on Kaua'i and the Hawaiian island of O'ahu. The egg viability rate in all colonies was 73% and varied among years. The hatching rate of foster eggs was 53%, fledging rate was 72%, and overall reproductive success was 38%, rates that were slightly lower than in natural eggs at the same sites. This project resulted in 189 fledged Laysan Albatross that otherwise would have died, and it helped solve a human-wildlife conflict. Several useful management techniques and egg translocation methods were developed during this project that can be used in similar projects with other seabirds.

Key words: assisted colonization, bird aircraft strike hazard, egg candling, egg fostering, Laysan Albatross, translocation

INTRODUCTION

Translocation has become an effective management strategy for seabirds, having been used in at least 101 projects involving 37 seabird species worldwide, most often to create new colonies or augment existing ones (Spatz *et al.* 2023). Translocation has been particularly effective for seabirds in the order Procellariiformes, which includes albatrosses, petrels, shearwaters, diving petrels, and storm petrels, because they have high natal-site fidelity and usually return to nest where they were raised (Spatz *et al.* 2023, VanderWerf *et al.* 2023). Most translocations of procellariiforms have involved chicks, which are raised by hand at the release site. However, eggs have been moved in some cases, placed in foster nests of the same or a similar species, and raised by foster parents (VanderWerf *et al.* 2019, Spatz *et al.* 2023). Egg fostering has proved to be an effective, inexpensive method of creating or augmenting seabird populations.

The Laysan Albatross *Phoebastria immutabilis* is a large procellariiform seabird with a distribution that spans much of the North Pacific (USFWS 2005, Arata *et al.* 2009). Over 99% of the global Laysan Albatross population nests on atolls in the Northwestern Hawaiian Islands, where inundation from rising sea levels and increasing storm surges associated with climate change has become a threat (Baker *et al.* 2006, Reynolds *et al.* 2015). The protection and creation of breeding colonies at higher-elevation locations that are also safe from predators are among the highest priority conservation actions for this species (USFWS 2005, Flint *et al.* 2011, Young *et al.* 2012, VanderWerf 2012).

Despite their high natal philopatry (Fisher 1971), Laysan Albatrosses began colonizing new islands in the 1960s and 1970s and recolonizing others where they had been extirpated (Young *et al.* 2009, 2024). Having nested on Kaua'i, Hawai'i, USA, pre-historically (Olson & James 1982), they began to visit again in 1945 but were rare until 1967/68, after which 4–10 birds were reported annually at the US Navy's Pacific Missile Range Facility (PMRF) in southwestern Kaua'i (Byrd & Telfer 1979, 1980; Pyle & Pyle 2017). Nests with eggs were first documented at PMRF in 1977/78 and annually thereafter (Zeillemaker & Ralph 1977).

Reproductive success of Laysan Albatrosses at PMRF during those years was low because of dog attacks, human disturbance, and inexperience of the young adults (Byrd & Telfer 1980, Moriarty *et al.* 1986).

In 1984, biologists from the US Fish and Wildlife Service (USFWS) moved eight chicks from PMRF to Kīlauea Point National Wildlife Refuge (KPNWR) on the northern coast of the island where they were hand-reared, but none of them survived to fledge (Moriarty *et al.* 1986). By 1988, the number of albatrosses at PMRF had reached a level considered to be a bird-aircraft strike hazard (BASH) due to their large size and diurnal flight patterns that crossed the path of aircraft during takeoff and landing. In response, the US Navy began a BASH reduction program to discourage them from nesting or landing around the airfield (Anders *et al.* 2009). Adult albatrosses at PMRF were moved to KPNWR, where a few pairs were already breeding (Moriarty *et al.* 1986), in the hope that they would remain there, but most returned to PMRF quickly (Anders *et al.* 2009). From 1988 to 2004, all albatross eggs laid at PMRF were legally destroyed or donated for research purposes as part of the BASH reduction program.

Rather than continuing to destroy eggs, the Navy, USFWS, and US Department of Agriculture Wildlife Services devised a program in 2005 to place fertile eggs from PMRF with foster parents in colonies on the northern coast of Kaua‘i whose natural egg was infertile. This egg fostering project has become known as the “albatross egg swap,” and it has been beneficial to the Laysan Albatross by augmenting the population on Kaua‘i and to the agencies involved by reducing the BASH risk at PMRF. The USFWS led this project until 2008, and in 2009 the non-profit organization Pacific Rim Conservation (PRC) were invited to continue the project. The results from 2009 to 2012 were reported by Young *et al.* (2014), and PRC continued to conduct the egg swap through 2022. In 2023, with the encouragement of PRC, biologists from the US Navy successfully conducted the egg swap independently along with volunteers who monitor albatrosses at colonies where eggs were placed. This change in project leadership is an appropriate time to update the status and efficacy of the egg swap program using 14 years of data from 2009–2022, and to summarize the useful management techniques learned during this project.

METHODS

Egg viability

We candled Laysan Albatross eggs at PMRF and foster sites to determine their viability (Ernst *et al.* 2004). We candled eggs either at night or using a black fabric hood to cover the observer and egg. When retrieving eggs from potential foster nests for candling, we placed a shield between the parent bird and observer to prevent the bird from accidentally striking its own egg. We candled eggs quickly (usually < 1 min) and returned them to the incubator (in the case of PMRF eggs) or to the incubating parent, which typically remained on the empty nest during the procedure. In most cases, we were able to determine whether an egg was infertile, fertile, or was fertile but the embryo had died. In a few cases the egg was badly decayed, and we knew only that it was not viable.

All albatross eggs at PMRF are collected by USDA Wildlife Services shortly after they are laid and placed in an incubator. We candled eggs during 12–20 December each year, which represented the end of the laying period. The age of the eggs at candling was variable because Laysan Albatross in Hawai‘i lay eggs over a roughly one-month period starting in mid-November (Arata *et al.* 2009). We did not attempt to determine the viability of eggs less than seven days old because they often show no visible signs of development at that age. We used chi-squared tests to compare the viability of eggs among sites. At foster sites, we did not candle eggs that had already been abandoned, but at PMRF we candled all eggs, including abandoned eggs. Therefore, the proportion of inviable eggs at the foster sites may have been higher than we report because female-female pairs are more likely to abandon eggs soon after laying, and many eggs from female-female pairs are inviable (Young & VanderWerf 2014).

Selection of foster nests

Laysan Albatross nest in several locations on the northern coast of Kaua‘i, including KPNWR and a variety of private lands ranging from small publicly accessible residential properties in Princeville to large residences and agricultural lands that are closed to the public. Laysan Albatross nest on the ground, often on top of steep bluffs and ridges, but also on the edges of golf courses and pastures. We located and numbered all Laysan Albatross nests each year at each site where the landowner had agreed to participate and, for private lands, those that had been approved by the Hawai‘i Division of Forestry and Wildlife (DOFAW). One to five private properties were included each year, after owners were deemed to have taken sufficient precautionary measures (such as fencing, predator control, etc.) to prevent disturbance and predation. We candled all eggs at each site and replaced infertile or dead eggs with fertile eggs from PMRF.

In 2014, we began translocating some eggs to the island of O‘ahu, in part because so few foster eggs could be placed on Kaua‘i and we did not want viable eggs to be destroyed. On O‘ahu, Laysan Albatross breed primarily at two locations: Ka‘ena Point Natural Area Reserve and Kuaokalā Game Management Area (Young *et al.* 2024). We monitored all nests in both colonies each year (VanderWerf & Young 2016), and we candled all eggs to determine which were infertile and could be replaced with an egg from PMRF. In some years, chicks that hatched from foster eggs on O‘ahu were moved to James Campbell National Wildlife Refuge (JCNWR) on the northeastern coast of the island as part of another project to create a new breeding colony at that location (VanderWerf *et al.* 2019).

Egg incubators and transport

At PMRF, eggs were usually collected one to three days after laying and were housed in a large commercial incubator (model 1500, GQF Manufacturing, Savannah, Georgia, USA) equipped with a thermostat to maintain the prescribed temperature (97.5°F or 36.4°C, VanderWerf *et al.* 2019), a water reservoir to maintain humidity, and racks that rotated the eggs automatically. During 2009–2020, we transported eggs in 20-gallon (75-L) plastic Rubbermaid coolers that had been modified by Avey Incubator (Hugo, Colorado, USA) to be used as parrot chick brooders. During 2021–2022, we transported eggs in 16-quart (15.1 L) plastic Stanley coolers that had been modified by the Darwin Chambers Company (St. Louis, Missouri, USA). Both types of incubators had a heater, a fan for distributing warm air, a thermostat that could be set to the desired temperature, and a plug compatible with a standard American wall outlet or a 12-volt outlet in a vehicle. The Avey incubators could accommodate 21 albatross eggs and the Darwin Chambers incubators could accommodate 9 eggs. For each incubator, we made custom foam padding inserts with spaces cut out to accommodate albatross eggs. In years when eggs were moved to O‘ahu, they were flown by the US Navy from PMRF to either Marine Corps Base Kaneohe Bay or to Barbers Point Naval Air Station and driven over land to their final destinations.

Reproductive outcomes

We monitored the status of all nests in which we placed a foster egg on an approximately weekly basis until either the chick fledged or the nest failed. We calculated hatching success as the proportion of eggs that hatched, fledging success as the proportion of hatched chicks that fledged, and overall reproductive success as the proportion of eggs that resulted in a fledged chick. We used chi-squared tests to compare hatching success, fledging success, and overall reproductive success between Kaua‘i and O‘ahu, among sites on Kaua‘i, and between foster eggs and natural eggs on O‘ahu.

RESULTS

Egg viability

Egg viability averaged 0.73 annually and did not differ between Kaua‘i (0.72, range 0.62–0.80) and O‘ahu (0.74, range 0.64–0.84; $\chi^2 = 2.17$, $df = 2$, $p = 0.14$). Egg viability differed among locations within Kaua‘i ($\chi^2 = 16.63$, $df = 2$, $p < 0.001$) and was lower at PMRF (0.67, range 0.64–0.80) than at both KPNWR (0.77, range 0.63–0.90) and the private properties (0.73, range 0.63–0.89). The egg viability rate varied among years, but the temporal pattern was not the same among sites and appeared to be random (Fig. 1). For example, egg viability was highest at PMRF in 2017 and highest on the private lands in 2016, but those years were average at the other locations.

Foster egg placement

We placed a total of 500 eggs from PMRF in foster nests during 2009–2022, including 255 on Kaua‘i and 245 on O‘ahu. The locations where eggs were placed varied substantially among years (Fig. 2). On Kaua‘i, we placed 68 eggs at KPNWR and 187 at private properties. We placed eggs at private properties every year except 2012 due to changes in permitting procedures, and we were permitted to place eggs at KPNWR only during 2009–2012 and in 2022. On O‘ahu, we initially placed all eggs in foster nests at Ka‘ena Point Natural Area Reserve. During 2014–2016, we moved chicks hatched from foster eggs from Ka‘ena Point to JCNWR at two to three weeks of age and raised them by hand. During 2017–2022, chicks hatched from foster eggs at Ka‘ena Point remained in place and were raised by the foster parents to supplement the existing population.

Reproductive success

Of the 500 foster eggs, 263 eggs hatched and 189 chicks fledged, for a hatching rate of 53% (263/500), a fledging rate of 72% (189/263), and an overall reproductive rate of 38% (189/500). The hatching, fledging, and reproductive success rates were slightly higher on Kaua‘i (54%, 77%, 42%, respectively) than on O‘ahu (51%, 66%, 34%, respectively), but the differences were not significant (respectively: $\chi^2 = 0.26, 4.29, 3.14$; $df = 1, 1, 1$; $p = 0.61, 0.06, 0.08$).

Within Kaua‘i, the hatching rate was higher on private lands (65%) than at KPNWR (24%; $\chi^2 = 34.94$, $df = 1$, $p < 0.001$), and this resulted in higher overall reproductive success on private lands (49%) than at KPNWR (22%; $\chi^2 = 15.08$, $df = 1$, $p < 0.001$). Part of the reason why success was lower at KPNWR was that in 2022, half of all albatross eggs at KPNWR were eaten by feral pigs, including 6 of 12 foster eggs. However, even if 2022 is excluded, reproductive success at KPNWR was lower (25%; $\chi^2 = 10.26$, $df = 1$, $p < 0.001$).

The hatching rate of foster eggs on O‘ahu was similar to that of natural eggs (58%; $\chi^2 = 0.058$, $df = 1$, $p = 0.81$), but fledging success was higher in natural eggs (75%) than in foster eggs ($\chi^2 = 5.53$, $df = 1$, $p = 0.019$).

DISCUSSION

A total of 189 Laysan Albatross that otherwise would have died fledged during 2009–2022 as a direct result of this project. This project also helped resolve a human-wildlife conflict by reducing the BASH at the US Navy’s PMRF (Anders *et al.* 2009). Many of the birds that fledged from JCNWR on O‘ahu have returned to that site as adults. Although they have not bred there yet as of 2024, they have helped to attract other adults that have bred, thereby helping to establish a new breeding colony at a secure, elevated location safe from sea-level rise and invasive alien predators (VanderWerf *et al.* 2019).

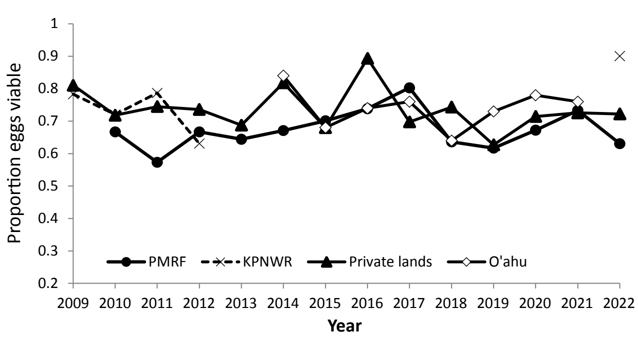

Fig. 1. Laysan Albatross *Phoebastria immutabilis* egg viability rate on Kaua‘i and O‘ahu in Hawai‘i, USA, during 2009–2022. PMRF = Pacific Missile Range Facility (US Navy) on Kaua‘i; KPNWR = Kīlauea Point National Wildlife Refuge on Kaua‘i; Private lands = private property on Kaua‘i.

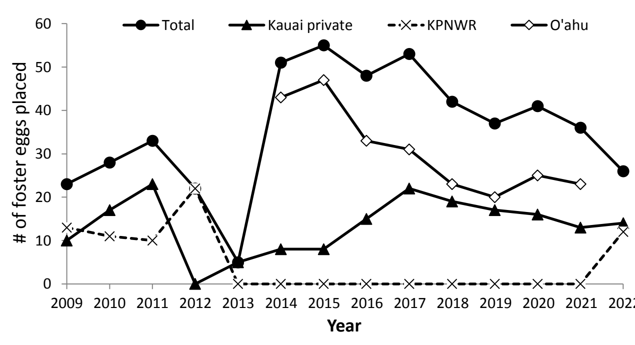

Fig. 2. Number of Laysan Albatross *Phoebastria immutabilis* eggs placed in foster nests at various locations in Hawai‘i, USA, during 2009–2022. Kaua‘i private = private property on Kaua‘i; KPNWR = Kīlauea Point National Wildlife Refuge on Kaua‘i.

The location of foster nests varied substantially over the years because of changes in permitting. In 2012, permission to place eggs on private lands was rescinded by DOFAW until the safety of each site was evaluated, the landowner completed an albatross management plan, and any issues were corrected. Permission was restored gradually to some private lands over the next several years. There have been occasional problems with predation by feral dogs and cats at some sites, even to the time of writing this paper. In 2013, KPNWR withdrew from the egg swap program, even though it was initiated in 2005 by a former KPNWR biologist. KPNWR agreed to participate again in 2022.

Egg viability varied among years but there was no clear temporal pattern to the variation across sites, suggesting that it was simply random. It should be noted that the number of inviable eggs included infertile eggs and eggs that were fertile but in which the embryo died during development. In some years, we were able to collect data on the number of dead fertile eggs, but this was not the case in all years or at all sites. Some eggs were broken each year or disappeared before we could candle them, and this may have contributed to the annual variation.

Compared to natural eggs in the same colonies, the foster eggs had a slightly lower chance of resulting in a fledged chick, which we believe was caused by two factors. First, many of the foster parents were pairs that consisted of two females. In female-female albatross pairs, both females may lay an egg, both of which often are infertile (Young & VanderWerf 2014), which made them candidates to receive a foster egg. The rate of nest abandonment is higher in female-female pairs than in male-female pairs because the male usually takes the first and longest incubation shift, allowing the female to go to sea to feed and replenish her energy after producing the egg. In female-female pairs, both parents need to feed and thus may leave the nest, resulting in lower hatching success (Young & VanderWerf 2014). Second, some of the foster parents were also young and inexperienced at nesting; such pairs also tended to abandon eggs more often, provide only intermittent incubation, or inconsistently provide food for the chick.

Bird eggs are fragile, and the developing embryo and associated blood vessels can be easily damaged by excessive jostling. The fact that the hatching rates on Kaua'i and O'ahu were similar indicates that additional travel, including an airplane flight and driving on a rough road to Ka'ena Point, did not affect the eggs. We were careful to minimize jostling of the eggs, and we walked the incubators over the roughest portions of the road. There were just a few cases in which an egg was determined to be viable on Kaua'i but had died or cracked by the time it reached O'ahu.

Both the Darwin Chambers and Avey incubators were effective for safely moving albatross eggs, but those made by Darwin Chambers were preferable overall and had several advantages. The Darwin Chambers incubators were smaller and could not fit as many eggs, but they were more durable, had a more secure closing mechanism, and could be carried in one hand, which made it easier to walk with them over rough terrain. The Avey incubators needed to be carried with two hands because of their size, and the thermostat controls were less durable and harder to use. In both the Darwin Chambers and Avey incubators, the distribution of heat within the incubator was uneven. Airflow was restricted by the foam padding that we used, with eggs on the top layer being warmer than those on the bottom layer, but the temperature in all parts of the incubator was within acceptable limits for the few hours required to transport them to the foster location.

The egg transport methods described above, and several other techniques developed during this project, were valuable in subsequent projects with Black-footed Albatross *P. nigripes* translocations from Midway Atoll in the Northwestern Hawaiian Islands to O'ahu and from Midway Atoll to Guadalupe Island, Mexico. For example, we had more foster eggs than foster nests available on O'ahu in some years, and we had to give some foster parents two foster eggs or chicks in succession. It is well known that albatrosses cannot distinguish their egg from another egg and will readily incubate fake eggs or eggs from other species (Shaffer *et al.* 2014). We learned that we could remove an egg and replace it with a small chick or remove a chick for hand rearing and replace it with an egg. Without exception, the parents accepted the egg or chick and provided the appropriate form of parental care, i.e., incubation for eggs or brooding and feeding for chicks. Foster eggs and small chicks were never rejected by foster parents. The lack of egg recognition and plasticity of parental care allowed for a variety of management techniques. However, it is likely that this parental behavioral plasticity declines once the chick reaches the post-guard stage at about three weeks of age. At that stage, the chick can thermoregulate independently and no longer requires parental brooding, its greater nutritional needs require both parents to leave the nest to forage, and it may begin to wander from the nest site.

Egg fostering was conducted with another procellariiform seabird species at KPNWR in the 1980s, in which eggs of the threatened Newell's Shearwater *Puffinus newelli* were placed in Wedge-tailed Shearwater *Ardenna pacifica* nests (Byrd *et al.* 1984). This resulted in a few Newell's Shearwater pairs eventually breeding at KPNWR (Young *et al.* 2023). This technique could be applied with other vulnerable species in several locations protected by predator-exclusion fences to create additional colonies that are more secure from climate change and invasive predators (Young & VanderWerf 2023). Examples include placing Black-footed Albatross eggs in Laysan Albatross nests at KPNWR, Christmas Shearwater *P. nativitatis* eggs in Wedge-tailed Shearwater nests at KPNWR and JCNWR, and Newell's Shearwater eggs in Wedge-tailed Shearwater nests at JCNWR.

ACKNOWLEDGMENTS

We thank Brenda Zaun, former biologist at KPNWR, for initiating the egg-swap program and implementing it during 2005–2008. Funding for the involvement of PRC was provided by the US Navy. Permission to place eggs in foster nests on private lands was provided by the landowners (all of whom prefer to remain anonymous) and by DOFAW. Permission to place eggs in foster nests at Ka'ena Point was provided by the Hawai'i Natural Area Reserves System. Permission to move foster chicks to JCNWR was provided by the USFWS. For assistance with field work, we thank Dylan Blanchard, Daniela Casillas, Megan Dalton, Erika Dittmar, Allene Henderson, Marilou Knight, Stephen Rossiter, and Peter Silva. The manuscript was improved by comments from David Ainley and an anonymous reviewer.

AUTHOR CONTRIBUTIONS

EAV conducted field work, analyzed the data, and wrote the paper. LCY, JB, BM, and KF conducted field work, compiled data, and

reviewed the paper. CRK conducted field work. HO, JM, AS, LB, YG, KSR, and CG monitored outcomes.

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