BREEDING BIOLOGY OF RED-TAILED TROPICBIRDS *PHAETHON RUBRICAUDA* AND RESPONSE TO PREDATOR CONTROL ON O'AHU, HAWAI'I

ERIC A. VANDERWERF & LINDSAY C. YOUNG

Pacific Rim Conservation, P.O. Box 61827, Honolulu, HI 96822, USA (eric@pacificrimconservation.com)

Submitted 2 December 2013, accepted 11 March 2014

SUMMARY

VANDERWERF, E.A. & YOUNG, L.C. 2014. Breeding biology of Red-Tailed Tropicbirds *Phaethon rubricauda* and response to predator control on O'ahu, Hawai'i. *Marine Ornithology* 42: 73–76.

The Red-tailed Tropicbird *Phaethon rubricauda* is a widespread but uncommon seabird that nests in the tropical Pacific and Indian oceans. The majority of the global population nests in the predator-free Northwestern Hawaiian Islands. In the Southeastern Hawaiian Islands, the species is restricted by non-native predators to steep coastal cliffs and small islets. We studied the breeding biology of Red-tailed Tropicbirds on O'ahu from 2005 to 2013, while we also controlled predatory non-native mongooses *Herpestes auropunctatus* and rats *Rattus* spp. with traps and poison bait stations to protect nests. Egg-laying peaked in March, hatching peaked in April and fledging peaked in July. The mean ± standard error incubation period was 44.2 ± 0.4 d (n = 155) and the mean fledging period was 82.3 ± 0.6 d (n = 127). The number of tropicbird chicks fledged increased steadily each year from seven to 26 in response to predator control, and reproductive success increased as predator control methods improved. Our results demonstrate that, with management, seabird colonies can thrive on islands inhabited by people and predators. More management is needed on high islands like O'ahu to enhance seabird populations and to help mitigate the projected impacts to seabirds of sea level rise associated with climate change.

Keywords: breeding biology, Hawai'i, predator control, Red-tailed Tropicbird, seabirds

INTRODUCTION

The Red-tailed Tropicbird *Phaethon rubricauda* is a widespread seabird that nests primarily in tropical areas of the Pacific and Indian oceans (Schreiber & Schreiber 1993, US Fish and Wildlife Service [USFWS] 2005). Red-tailed Tropicbirds are common throughout the Northwestern Hawaiian Islands (Harrison 1990, USFWS 2005), but in the larger Southeastern Hawaiian Islands they have a much more restricted distribution, nesting on steep coastal cliffs and small islets in just a few locations, including Kilauea Point on Kaua'i, Mānana Islet off O'ahu, Mokupuku Islet off north Kohala on Hawai'i, the northern coast of Moloka'i and along the Ka Iwi coast of southeastern O'ahu. Tropicbirds, and other seabirds in the Southeastern Hawaiian Islands, are restricted to such locations by introduced predators, including feral cats *Felis catus*, small Indian mongooses *Herpestes auropunctatus* and rats (*Rattus* spp.; Harrison 1990, USFWS 2005, VanderWerf 2012). Because of the remote location of most colonies, there is limited information about tropicbird population size, trends, and many aspects of their breeding biology (Harrison 1990, Schreiber & Schreiber 1993).

We began monitoring a small nesting colony of Red-tailed Tropicbirds near Halona Point in southeastern O'ahu in 2005 and found that nest predation was prevalent. We began controlling predators in 2006. Here, we report on the breeding biology of Red-tailed Tropicbirds on O'ahu, trends in their abundance and reproductive success, and their response to predator control.

STUDY AREA AND METHODS

Tropicbird monitoring

From 2005 to 2013, we searched for Red-tailed Tropicbird nests on the southeastern coast of O'ahu between Hanauma Bay and Halona Point. We monitored nests we found at approximately 7 d–10 d intervals from mid-January until September or October, when all nests had either failed or the chick had fledged. The interval between visits averaged 8.4 d (range = 6.7–10.6) among years. The terrain consisted of rocky cliffs and steep slopes 5 to 20 m tall and made of soft volcanic tuff that erodes relatively easily, producing a variety of overhung ledges, small caves, and rocky rubble in which the birds nest. We located nests by climbing up and down the slopes, and by watching for adult tropicbirds landing and exhibiting aerial courtship behavior. Nests from previous years were readily recognized by the accumulation of guano. To facilitate monitoring, we numbered each nest site using white automotive paint.

We assigned nest failures to one of 10 categories based on the following evidence: 1) *abandoned*—intact egg incubated less than the usual incubation period (42 d–46 d; Schreiber & Schreiber 1993); 2) *broken egg*—egg cracked or broken earlier than 42 d but damage not indicative of predation; 3) *failed to hatch*—intact egg incubated longer than 46 d but did not hatch; 4) *predation*—remains of an egg or chick with evidence of predation, such as tooth marks, blood, missing appendages, or torn to pieces; 5) *neglect/exposure*—carcass of a small, downy chick with no signs of predation; 6) *starvation*—carcass of a large feathered chick (less vulnerable to exposure) with no signs of predation; 7) *pathology*—abnormal physical characteristics such as tumors, swellings, etc.; 8) *entanglement*—chick trapped in vegetation or human refuse; 9) *human disturbance*—physical damage not apparently caused by predators; and 10) *unknown*—egg or chick simply gone with no evidence.

Following Schreiber & Schreiber (1993), we calculated hatching success as the proportion of eggs laid 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. As tropicbirds lay only a single egg (Schreiber & Schreiber 1993), reproductive success is equivalent to the proportion of successful nests. We also calculated daily nest survival using the Mayfield method (Mayfield 1961), in which the number of days survived was divided by the total number of exposure days. For statistical purposes we assumed that any change in status (laying, hatching, fledging or failure) occurred midway between visits: if, for example, a nest failed since the last visit 10 days earlier, we assumed that the failure occurred five days earlier. We used the estimated laying, hatching and fledging dates to determine the incubation and fledging periods, and added them to determine the total length of the reproductive cycle. This method should not affect the mean values, but may over- or underestimate incubation and fledging periods for individual nests, resulting in inflated variance. The mean incubation and fledging periods reported here, therefore, can be compared with those of other studies, but the range of values cannot. All values reported are mean ± standard error (SE) unless otherwise noted.

Predator control

We controlled predators with traps, poison bait or both; we used various techniques in different years. We used live traps to remove mongooses and feral cats for one to two weeks at the beginning of each season in 2006–2008, but discontinued the practice because the traps had to be checked frequently for humane reasons and were thus labor-intensive. Starting in 2010, we used two or three "DOC-250" kill traps made by the New Zealand Department of Conservation to humanely remove mongooses. The traps were baited with canned cat food and were housed in wooden boxes to prevent access by birds and other non-target animals. In 2012, we used six rat snap traps baited with peanut butter to remove rats from 22 January to 12 June. In 2013, we added three self-resetting pneumatic "A-12 Henry" kill traps (Goodnature Company, Wellington, New Zealand) baited with cat food to target mongooses. These traps are powered by compressed carbon dioxide canisters and can fire up to 12 times on a single canister. They are designed to humanely kill mongooses, but they are also capable of humanely killing smaller animals such as rats.

We also used poison bait to remove mongooses and rats, deploying three bait stations in 2008, four in 2009, five in 2011 and seven in 2012. We constructed the bait stations from lengths of 7.6 cm (3 inch) diameter ABS or PVC pipe, and secured them to large rocks with nylon line. We stocked each station with up to 454 g (16 ounces) of bait (Ramik mini-bars, HACCO Inc., Randolph, Wisconsin) containing 0.005% diphacinone, which is known to be effective for controlling mongooses and rats in Hawai'i (Smith *et al.* 2000, VanderWerf 2009, Young *et al.* 2013). Application of bait was conducted in compliance with US Environmental Protection Agency Registration 61282-26 and Special Local Need Registration HI-980005. Placement of bait stations was limited by the steep terrain and proximity to the ocean, but all stations were 25 m–75 m from at least one other station, as prescribed on the product label (Fig. 1). We checked the traps and bait stations with the same frequency as tropicbirds nests, at 7 d–10 d intervals. Because the interval between trap checks varied among and within years, we compared performance of different traps using the number of animals trapped per trap per visit instead of the number per trap night.

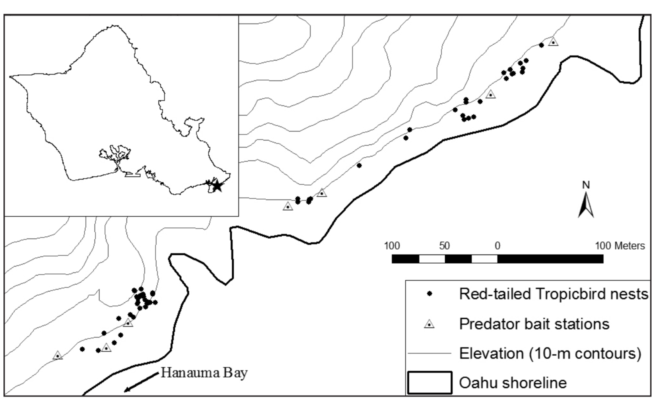

Fig. 1. Location of Red-tailed Tropicbird nests and predator bait stations between Hanauma Bay and Halona Point, O'ahu.

RESULTS

Tropicbird monitoring

The number of Red-tailed Tropicbirds nesting in southeastern O'ahu and their reproductive output increased steadily during the study period (Fig. 2). All measures of reproduction increased, including the number of eggs laid ($F_{1,6}$ = 46.09, P < 0.001), the number of eggs hatched ($F_{1,6}$ = 35.97, P = 0.001) and the number of chicks fledged ($F_{1,7}$ = 31.00, P = 0.001). The numbers of eggs laid and hatched in 2005 were unknown because we started monitoring in June after the nesting season had begun.

Eggs were laid from January to August, with a peak in March. Eggs hatched from March to August, with a peak in April. Chicks fledged from May to October, with a peak in July (Fig. 3). The mean incubation period was 44.2 d ± 0.4 d (n = 155) and the mean

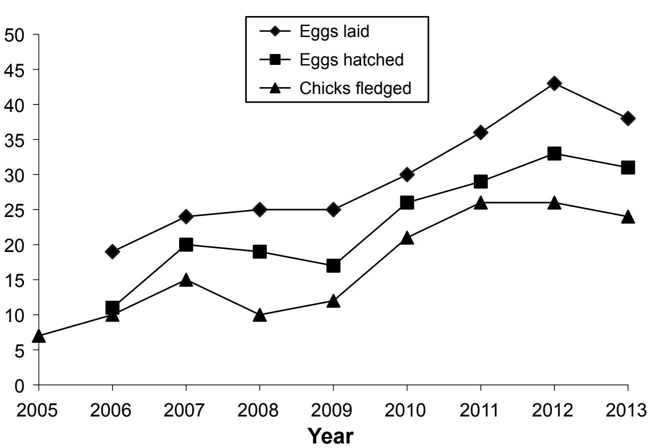

Fig. 2. Red-tailed Tropicbird reproduction on O'ahu, 2005 to 2013.

fledging period was 82.3 d ± 0.6 d (n = 127), resulting in a mean nesting cycle of 126.5 d ± 0.5 d.

Hatching success during the period 2006 to 2013 averaged 76% ± 3%; fledging success, 77% ± 4%; and overall reproductive success, 59% ± 4%. The average daily nest survival rate was 0.980 ± 0.002. All four of these success measures tended to be lower during the first four years of the study than during the last four years (Mann-Whitney U test, $P = 0.06$); the three lowest values occurred in the first four years.

The leading causes of failure were predation, 18%; failure to hatch, 17%; and neglect/exposure, 16%; although the cause of failure was unknown in the largest proportion of nests, 28% (Table 1). In cases where the egg failed to hatch, parents incubated the egg for an average of 72.2 d ± 5.0 d before giving up—one pair incubated for 121 days. Mongooses were the most frequent nest predator, as revealed by tracks in soil and large chew marks on eggs and chicks. Several large chicks depredated by mongooses had all or part of the head removed or chewed open, leaving the rest of the body intact. We observed one case of failure caused by pathology, in which a medium-sized dead chick had a large, fibrous growth on one side of the bill that probably prevented it from eating. In one case a large chick died after becoming entangled in thorny branches of a Kiawe *Prosopis pallida* tree. We observed one case of failure by human disturbance, in which a chick was flattened into the soil, as if trampled by people or crushed by a heavy object, but showed no signs of predation.

Predator control

We removed an average of 2.0 mongooses and 0.33 feral cats per year using live traps in 2006–2008, with an average capture rate of 0.14 mongooses and 0.02 feral cats per trap-check. In 2010–2013, we removed an average of 5.0 mongooses per year using DOC250 kill traps, with an average capture rate of 0.15 mongooses per trap-check. In 2012, we removed one black rat, one house mouse, and two unidentified rodents using rat snap traps, for an average capture rate of 0.03 rodents per trap-check. All four rodent captures occurred during the first two checks in January; no rodents were caught in snap traps from February onwards. In 2013, we observed the remains of one mongoose, one rat, and one mouse beneath the automated pneumatic traps, but the number of animals killed by these traps was likely higher because remains were scavenged. An average of 18.1 kg ± 2.9 kg of bait were taken from stations from 2008 to 2013, and the average daily take was 17.6 g ± 1.4 g per station.

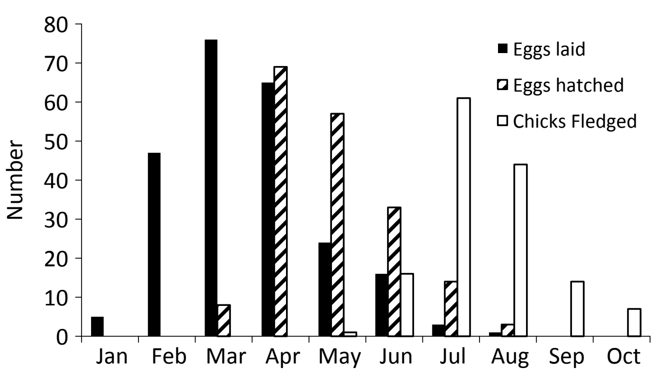

Fig. 3. Total numbers of Red-tailed Tropicbird eggs laid, eggs hatched, and chicks fledged on O'ahu, 2006-2013.

DISCUSSION

Red-tailed Tropicbird reproductive rates were low before predator control began and increased during the study as predator control methods improved. The increase in the number of breeding pairs at this colony is likely due to increased local recruitment resulting from predator control, and possibly also to immigrants attracted to the growing colony; in 2008 we found an adult that had been banded as a chick on Johnston Island in 2001, although it was not attending an egg. There is little information about trends in tropicbird numbers at other colonies in the Hawaiian Islands, but there is no evidence that the increase we observed is associated with a regional pattern.

The increase in reproductive success in the latter half of the study probably was caused by improved predator control methods and a decrease in predation; 12 predation events occurred during the first four years of the study, but only five occurred during the last four years. Adding kill traps for mongoose in 2010 resulted in improved nest protection with less labor, and the combination of kill traps and bait stations prevented most predation. The reproductive success rate that we observed on O'ahu (59%) was higher than rates measured on Kure and Midway Atolls (17%–42%) during periods when rats were present, higher than on predator-free Aldabra Atoll (4%–44%), and similar to or lower than on predator-free Johnston Atoll (56%–85%; Fleet 1974, Diamond 1975, Schreiber & Schreiber 1993).

Although the predator control program was generally effective and resulted in high nest success, predation was still the leading known cause of nest failure, accounting for 18% of failures. In addition, some failures that we classified as unknown were likely caused by a predator carrying away the egg or chick. Garbage and food left by people appear to be attracting predators to the area, including Hanauma Bay Nature Reserve, which is managed by the City and County of Honolulu. Greater enforcement and education is needed to discourage littering.

TABLE 1
Causes of Red-tailed Tropicbird nest failures on O'ahu, 2006 to 2013

Cause	Number	%
Abandonment	3	3
Broken egg	9	9
Failed to hatch	16	17
Predation	17	18
Neglect/exposure	15	16
Starvation	6	6
Human disturbance	1	1
Entanglement	1	1
Pathology	1	1
Total	96	100

Fifty-two percent of nest failures occurred from natural causes, including abandonment, failure to hatch, starvation, neglect/exposure and disease (Table 1). Failure of eggs to hatch could have been caused by infertility, inconsistent incubation or damage to the embryo during development. We rarely observed unattended eggs, and if an unattended egg was subsequently observed being incubated, it usually failed to hatch. Schreiber & Schreiber (1993) reported that inexperienced breeders often fail to make the transition from incubation to brooding, causing chicks to die of neglect or heat exposure just after hatching. Because the colony on O'ahu is new and growing, it probably contains a high proportion of new breeders, which would explain the relatively high proportion of failures from neglect or exposure on O'ahu, 16%. Starvation of large chicks was uncommon (6%). Schreiber & Schreiber (1993) reported that starvation occurred primarily in years with strong El Niño Southern Oscillation oceanographic patterns, which resulted in fewer and smaller meals delivered to chicks (Schreiber 1994). Egg breakage could have occurred by the parents accidently stepping on the egg, or during aggressive interactions in competition for nest sites with other tropicbirds (Diamond 1975, Schreiber & Schreiber 1993). Two cases of egg breakage occurred in 2006 and 2007 at nests where there had been aggressive interactions between Red-tailed and Red-billed Tropicbirds (*Phaethon aethereus*; VanderWerf & Young 2007), and in 2008 we observed a Red-billed Tropicbird sitting on an egg that was later broken.

The nesting phenology of Red-tailed Tropicbirds on O'ahu was generally similar to that on Johnston Atoll (Schreiber & Schreiber 1993). Some of the eggs laid later in the season may have been the result of re-nesting attempts by pairs that failed earlier in the season, but because few of the adults were banded we could not confirm whether they were the same birds. In many cases, second eggs were laid in the same nest site used previously.

Red-tailed Tropicbirds have begun nesting at other locations on O'ahu since the Halona Point colony began increasing in size: Halona was likely the source of colonists at those new locations. We observed a pair of tropicbirds nesting at Koko Head, just 2 km from Halona, in 2012 and 2013; another pair attempted to nest at Black Point, 11 km away, in 2011 (C. Blackburn pers. comm.). We also have observed increasing numbers of Red-tailed Tropicbirds (up to seven simultaneously) displaying at Kaena Point, where a predator-proof fence was installed and all predators were eradicated in 2011 (Young *et al.* 2013).

The global population of Red-tailed Tropicbirds is relatively small (17 000–21 000 pairs), the majority of which nest in the Northwestern Hawaiian Islands (9 000–12 000 pairs), of which the largest concentrations are on Midway, Laysan and Kure Atolls (Harrison 1990, USFWS 2005). Rising sea levels associated with climate change pose a serious threat to seabirds nesting on those islands (Hatfield *et al.* 2012, Young *et al.* 2012). Protection of existing colonies and creation of safe nesting sites on high islands like O'ahu are important ways of mitigating the effect of climate change on seabirds (VanderWerf 2012, Young *et al.* 2012). Our results demonstrate that it is possible to create safe nesting sites in areas with predators and people. More such efforts are needed now, before the islands are further inundated and birds are displaced, so that social attraction by established breeding populations can help to naturally relocate displaced birds to sites that are safe.

ACKNOWLEDGEMENTS

This project was funded by the Hawai'i Division of Forestry and Wildlife in 2012; in all other years we conducted the work as volunteers. For assistance with monitoring nests and controlling predators, we thank Mike Lohr, Andrew Titmus, David Smith, Matthew Burt and David Leonard. We thank David Smith and Jason Misaki of the Hawai'i Division of Forestry and Wildlife for providing live traps, and Darren Phelps of the New Zealand Department of Conservation for providing mongoose kill traps. Greg Spencer, Tony Gaston and David Ainley made helpful comments that improved the paper.

REFERENCES

DIAMOND, A.W. 1975. The biology of tropicbirds (*Phaethon* spp.) at Aldabra Atoll, Indian Ocean. *Auk* 92: 16–39.

HARRISON, C.S. 1990. Seabirds of Hawaii: natural history and conservation. Ithaca, NY: Cornell University Press.

HATFIELD, J.S., REYNOLDS, M.H., SEAVY, N.E. & KRAUSE, C.M. 2012. Population dynamics of Hawaiian seabird colonies vulnerable to sea-level rise. *Conservation Biology* 26: 667–678.

MAYFIELD, H.F. 1961. Nesting success calculated from exposure. *Wilson Bulletin* 73: 255–261.

SCHREIBER, E.A. 1994. El Niño-Southern Oscillation effects on provisioning and growth in red-tailed tropicbirds. *Colonial Waterbirds* 17: 105–119.

SCHREIBER, E.A. & SCHREIBER, R.W. 1993. Red-tailed Tropicbird (*Phaethon rubricauda*). In: The birds of North America, No. 43. Poole, A. & Gill, F. (Eds.). Philadelphia, PA: The Birds of North America, Inc.

SMITH, D.G., POLHEMUS, J.T. & VANDERWERF, E.A. 2000. Efficacy of fish-flavored diphacinone bait blocks for controlling small Indian mongoose (*Herpestes auropunctatus*) populations in Hawai'i. *'Elepaio* 60: 47–51.

SMITH, D.G., SHIINOKI, E.K. & VANDERWERF, E.A. 2006. Recovery of native species following rat eradication on Mokolii Island, Oahu, Hawai'i. *Pacific Science* 60: 299–303.

US FISH & WILDLIFE SERVICE. 2005. Regional seabird conservation plan, Pacific region. Portland, OR: US Fish and Wildlife Service, Migratory Birds and Habitat Programs, Pacific Region.

VANDERWERF, E.A. 2009. Importance of nest predation by alien rodents and avian poxvirus in conservation of Oahu elepaio. *Journal of Wildlife Management* 73: 737–746.

VANDERWERF, E.A. 2012. Hawaiian Bird Conservation Action Plan. Pacific Rim Conservation, Honolulu, HI. Available online at: http://www.pacificrimconservation.com/publications/; accessed 14 April 2014.

VANDERWERF, E.A. & YOUNG, L.C. 2007. The Red-billed Tropicbird *Phaethon aethereus* in Hawaii, with notes on interspecific behavior of tropicbirds. *Marine Ornithology* 35: 81–84.

YOUNG, L., SURYAN, R.M., DUFFY, D. & SYDEMAN, W.J. 2012. Climate change and seabirds of the California Current and Pacific Islands Ecosystems: Observed and Potential Impacts and Management Implications. Report to the US Fish and Wildlife Service, Region 1. Available online at: http://www.faralloninstitute.org/Publications/YoungEtal2012USFWSRep.pdf; accessed 14 April 2014.

YOUNG, L.C., VANDERWERF, E.A., LOHR, M.T., MILLER, C.J., TITMUS, A.J., PETERS, D. & WILSON, L. 2013. Multi-species predator eradication within a pest-proof fence at Ka'ena Point, Hawai'i. *Biological Invasions* 15: 2627–2638. doi:10.1007/s10530-013-0479-y