RED-FOOTED BOOBY *SULA SULA* BREEDING SUCCESS AT ULUPA'U CRATER, MARINE CORPS BASE HAWAII

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Military activity has occurred at or near Ulupa'u Crater on O'ahu, Hawaii, since 1918. Following a period of intense military activity and a subsequent lull, Red-footed Boobies *Sula sula* had colonized Ulupa'u Crater by 1946. Two years later, the colony was well established (Hatch 1948, Richardson & Fisher 1950). Minimum counts of the number of boobies at the colony have been conducted annually since 1948 during the Audubon Christmas Bird Count. The number of boobies counted has fluctuated over time, from a low of 125 birds in 1997 to a high of 2 380 in 1969. The count in 2008 was a minimum of 337 birds. There are few nest counts for this colony, and there are no estimates of breeding success.

Ulupa'u Crater has been used as a weapons range by the Marine Corps since 1952. Although errant shots have caused occasional booby mortality (Pettit 1980), the major threat to this colony is fire (US Fish and Wildlife Service 1984). Fire has resulted in direct mortality as well as loss of nesting trees and shrubs (Rauzon & Drigot 1999). To mitigate the potential danger posed by fire, the Marine Corps has developed a network of firebreaks, fire hydrants and water cannons. In addition, artificial nesting platforms have been installed to relocate and supplement existing nesting habitat (Rauzon & Drigot 1999).

Introduced predators may threaten nesting boobies as well; there are several predatory species at Ulupa'u Crater, but there is no quantitative data how these species affect breeding success of Red-footed Boobies at Ulupa'u. The small Indian mongoose *Herpestes javanicus* is known to prey on booby chicks at Ulupa'u Crater (Ord 1964, Harrison 1990). However, this mongoose rarely climbs (Hays & Conant 2007); as Red-footed Boobies nest in shrubs and trees, they are provided some protection. Feral cats *Felis domesticus* and black rats *Rattus rattus* are also found at Ulupa'u, and both climb well and should be considered potential threats to chicks and possibly adult Red-footed Boobies (US Fish and Wildlife Service 1984). Breeding success can be used to assess the impact of introduced predators on nesting seabirds (Cooper *et. al.* 1995, Thibault 1995, Smith *et al.* 2002, Pascal *et. al.* 2008). If terrestrial predators affect breeding success of Red-footed Boobies at Ulupa'u Crater, we hypothesized that nest height would influence predation, with lower nests being more vulnerable.

The purpose of this note is to provide baseline breeding success data for the Red-footed Booby colony at Ulupa'u Crater, and to examine the relationship between nest height and breeding success in an effort to understand the threat from introduced predators at this colony.

Ulupa'u Crater is a partially eroded volcanic crater located on Mokapu Peninsula on the windward side of the island of O'ahu. The booby colony is approximately 12.5 ha in area, from 35 m to 95 m in elevation, and located on south-facing slopes of the crater. Similar to much of lowland Hawaii, Ulupa'u Crater is dominated by invasive plant species, including kiawe trees *Prosopis pallida,* koa haole shrubs and trees *Leucaena leucocephala,* guinea grass *Urochloa maxima* and buffelgrass *Pennisetum ciliare.*

Because of the danger from unexploded ordnance, we restricted our sample to nests adjacent to the road. Fifty booby nests were chosen at every five paces (~5 m) on alternating sides of the road on 7 April 2009. Nest locations were recorded with a Garmin GPS map 76CS. Geographic information was analyzed using ArcInfo 9.3 (ESRI 2009).

Nests were visited every three weeks until all nests in the sample had fledged young (successful) or failed. A 2.4 m ladder was used for visual verification of nest status. The status of nests was recorded as empty, egg, naked chick, downy chick or feathered chick (>50% feathered). If a nest was empty, it was considered successful if the chick was >50% feathered during the previous monitoring session. Breeding success was defined as the mean number of fledged birds per breeding attempt (Thibault 1995). To examine whether nest heights were greater for successful nests than nest failures, a one-tailed Mann-Whitney U test was used (significance level $P = 0.05$); sample mean ± standard error are reported.

A total of 50 nests were sampled, but three were omitted from analyses because no eggs were laid. Nest monitoring concluded on 21 August 2009. Thirty-eight of the 47 eggs hatched (81%), and 28 of 38 chicks fledged (74%), for an overall breeding success rate of 60%. Fledging in the sampled nests occurred between 16 July 2009 and 21 August 2009, but a small number of downy chicks were observed after that date range in nests not included in the study.

Heights of successul nests (200 ± 11 cm) were not different from heights of failed nests (190 ± 15 cm; Mann-Whitney U, $P = 0.27$). Nest heights in the sample ranged from 76 cm to 330 cm.

Examination of the spatial arrangement of successful and failed nests revealed that breeding success was not uniformly distributed throughout the population (Fig. 1). The breeding success for nests in the upper-elevation portion of the colony (right side Fig. 1,) was 85% ($n = 27$). By contrast, none of ten nests sampled in the southwest portion of the nesting colony (bottom left Fig. 1) were successful.

Breeding success of Red-footed Boobies and many other seabirds can vary substantially among years, particularly in association with El Niño–Southern Oscillation events (Schreiber *et al.* 1996), but the breeding success of Red-footed Boobies at Ulupa'u Crater appears typical for populations in Hawaii and the central Pacific. Hatching success at Ulupa'u (81%) was somewhat higher than at Johnston Atoll (60%–65% in 1994; Schreiber et al. 1996), Kure (67.9% in 1986; Woodward 1972), and French Frigate Shoals (45%–67% 1988–1993; US Fish and Wildlife Service unpubl. data), while fledging success at Ulupa'u (74%) appeared to be lower than at Johnston (92%–95%) and Kure (90%) and similar to that at French Frigate Shoals (66%–79%), resulting in similar overall breeding success. Harrison (1990) reported that Red-footed Booby breeding success in Hawaii was 66%–76%, and that Hawaiian populations have generally higher breeding success than other populations in the world. The timing of breeding observed during this study is also consistent with previous observations on O'ahu; on Moku Manu, an islet located 1 km from Ulupa'u, Richardson & Fisher (1950) observed eggs and young in different stages throughout the year, with a peak in number of eggs between March and May. Ashmole & Ashmole (1967) reported that the breeding season was fairly well defined, with most eggs laid from March to late May.

If terrestrial predators were affecting the breeding success of this population, we hypothesized that nest height would be greater for successful nests. No evidence of this was detected. Mongoose densities are high at Ulupa'u Crater; one month after nest monitoring, mongoose capture success was 92% (n = 25) at Ulupa'u Crater. In 1968, the Pacific Ocean Biological Survey Program estimated that 46–50 mongoose lived in the colony (R.B. Clapp, pers. comm.). Also, rats are ubiquitous on O'ahu. Despite the presence of mongoose and rats, Red-footed Booby breeding success at Ulupa'u was similar to that on predator-free islands. On the other hand, no cats were detected during three nocturnal spotlight-surveys conducted during the same timeframe as Red-footed Booby nest monitoring. Therefore, it is unknown whether feral cats affect the breeding success of this population.

What caused the low success of nests in the lower-elevation portion of the nesting colony? Boobies in this area of the colony nest exclusively in kiawe trees, as they are the only trees available. Because nest monitoring required visual verification of nest status, only nests located on the outer perimeter of trees were sampled. Kiawe trees are somewhat dome-shaped in this area; the outer branches are long and skinny, and sway easily in the wind. The nests located on outer branches may have failed when wind gusts destroyed them. We developed this hypothesis when we noticed that, despite poor breeding success for sampled nests in the lower-elevation area, adults and chicks were still present in the central portion of these trees (Fig. 2).

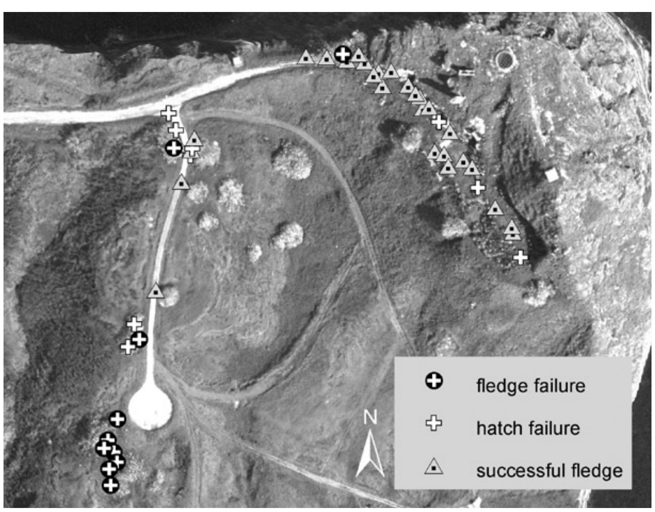

Fig. 1. Breeding success of sampled nest sites (n = 47) at Ulupa'u Crater, Marine Corps Base Hawaii, O'ahu.

Predators appeared to have little, if any, current impact on the breeding success of this population. This result is surprising considering the impact that introduced predators frequently have on oceanic island bird populations. However, the colony should be monitored for signs of feral cats because their potential effect on this population is unknown. Fire appears to be the most immediate threat to the viability of the nesting Red-footed Booby population at Ulupa'u Crater. Considering this, managers should continue efforts to reduce ignition and severity of fires related to range activities. The cause of low breeding success in low-elevation areas of this colony should be investigated further. In addition, data on long-term survival, nest site fidelity and breeding success of individuals over time may augment knowledge of the colony's population biology.

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Fig. 2. Example of high-density nesting of Red-footed Boobies in the central portion of kiawe trees at the lower-elevation area of the nesting colony. High winds are hypothesized to have destroyed nests on outer branches.

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