PACIFIC SCIENCE Early View
A Quarterly Devoted to the
Biological and Physical Sciences of the Pacific Region

Response of Wedge-tailed Shearwaters *(Puffinus pacificus)* to Eradication of Black Rats *(Rattus rattus)* from Moku'auia Island after Reinvasion[1]

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Abstract

Moku'auia is a 5-ha island off northeastern O'ahu, Hawai'i that supports several thousand nesting Wedge-tailed Shearwaters *(Puffinus pacificus),* several species of migratory shorebirds, and is critical habitat for the federally endangered 'ohai plant *(Sesbania tomentosa)*. The island is separated from Malaekahana State Recreation Area on O'ahu by a channel 230 m wide and 1 m deep and receives numerous human visitors. Black rats *(Rattus rattus)* were first documented on Moku'auia in 1967 and were eradicated in the 1990s, but rats recolonized the island and were eradicated again in 2006. We re-eradicated black rats in November 2011 following another re-colonization, using snap traps and diphacinone in bait boxes spaced 25 m apart. Pre-eradication, 80% of tracking tunnels contained rat tracks. After 14 days, no more rats were trapped, bait take dropped to almost zero, and no rats have been detected since. Eradication of rats resulted in a doubling of Wedge-tailed Shearwater reproduction in 2006 and 2012 and is expected to enhance regeneration of native plants. Black rats may recolonize Moku'auia periodically in the future because of its proximity to O'ahu and the frequency of human visitation, but its small size and simple terrain make rats easy and inexpensive to eradicate, and the natural resources present warrant continued management.

[1] The Hawaii Division of Forestry and Wildlife funded this project. Manuscript accepted 13 December 2013.

Pacific Science, vol. 68, no. 8
May 14, 2014 (Early view)

Official Journal of the Pacific Science Association

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Introduction

Introduced mammalian predators are the most serious threat to many species, particularly on oceanic islands (Blackburn et al. 2004; Trevino et al. 2007, VanderWerf 2012), and rats are known to have severe negative effects on many species of seabirds (Jones et al. 2008). Predators have been eradicated from many islands (Nogales et al. 2004, Howald et al. 2007, Keitt et al. 2011), preventing the extinction of many species and leading to the recovery of others (Butchart et al. 2006, Smith et al. 2010). Islands selected for predator eradication typically have a low potential for re-invasion, such as those located far offshore or rarely visited by people, because the benefits to protected resources are likely to last longer (Ratcliffe et al. 2009, Capizzi et al. 2010, Phillips 2010). However, islands located close to shore and with a high potential for reinvasion still may have value and warrant predator eradication if they support valuable natural resources, particularly if more bio-secure alternatives are not available and the effort and expense required for eradication is small (Martins et al. 2006).

Mokuʻauia (also called Goat Island) is a 5-ha (12.4-ac) State Seabird Sanctuary located in Lāʻie Bay off the northeastern coast of Oʻahu, Hawaiʻi (Fig. 1). It is a low, flat island composed of raised limestone and sandy soil, with a maximum elevation of about 5 m. Mokuʻauia is located inside a fringing reef and is separated from Malaekahana State Recreation Area on O‘ahu by a channel 230 m wide and 1 m deep at low tide. The island is accessed frequently by people for recreational purposes who paddle or wade across the channel. Moku‘auia supports several thousand pairs of nesting Wedge-tailed Shearwaters (*Puffinus pacificus;* Smith et al. 2002) and several migratory shorebirds, including the Bristle-thighed Curlew *(Numenius tahitiensis)*. The island is designated as critical habitat for the federally endangered ‘ohai plant *(Sesbania tomentosa),* whose seed pods are attractive to rats, though the plant does not currently occur on the island (U.S. Fish and Wildlife Service 2012).

Surveys of Wedge-tailed Shearwaters on Moku’auia in 1964 documented 350 ± 25 nesting pairs (Fitch 1968). Black rats *(Rattus rattus)* were first documented on Moku’auia in 1967 (Fitch 1968) and were first eradicated in the early 1990s (D. Smith unpubl. data). By 1995, when annual monitoring of Wedge-tailed Shearwaters was begun by the Hawaii Division of Forestry and Wildlife (DOFAW), more than 3,000 shearwater chicks were produced annually on the island (Fig. 2). Following a decline in shearwater productivity in 2004 and 2005, black rats were detected on the island in February 2006 and eradicated by DOFAW in March 2006. Shearwater monitoring showed that reproduction declined again in 2007 and remained low for several years, suggesting that rats had re-invaded the island. Here we report on the re-eradication of rats from Moku‘auia, including the effort and cost involved, and we discuss the value of islands like Moku‘auia that are not bio-secure yet still provide opportunities for protection of natural resources.

Materials and Methods

In November 2011 we installed a 25-m grid on the island using a laser range-finder and 30-cm lengths of PVC pipe (Fig. 1). We placed ink cards baited with peanut butter into tracking tunnels spaced at 50-m intervals (n = 20 tunnels) to monitor relative rodent abundance and distribution pre-eradication and periodically afterwards to help confirm whether any rats remained on the island. We ran tracking tunnels for one night.

To remove rats we used a combination of snap traps and rodenticide bait containing 0.005% diphacinone (Ramik mini-bars ®, HACCO Inc., Randolph, Wisconsin, USA). We placed bait in tamper-resistant Protecta ® plastic bait stations (Bell Laboratories, Madison, Wisconsin, USA) to shield it from rain and prevent access by non-target species. We spaced stations 25-m apart (n = 55 stations) and we filled each station with 16 one-ounce bait blocks, the closest spacing and maximum amount of bait allowed by the product label. Application of diphacinone bait was conducted in compliance with U.S. Environmental Protection Agency registration number 61282-26 and special local need registration HI-980005 under restricted use pesticide applicator certifications provided to Eric VanderWerf (#A14950) and Michael Lohr (#A15247) by the Hawai‘i Department of Agriculture. We placed rat snap traps (Victor Professional, Woodstream Corp., Lititz, Pennsylvania, USA) at alternating bait station (n = 18 traps) to increase the rate of rat removal and to allow identification of rodent species present. We tied snap traps to plants above the ground to prevent injuries to shearwaters and other birds. We deployed snap traps and filled bait stations on 14 November 2011.

We made 10 visits to the island involving 203 hours of work to monitor and eradicate rats from October 2011 to January 2012. The total cost of materials was $1,268, including $420 for 140 lbs of bait, $660 for 55 bait stations, $50 for 20 snap traps, $60 for materials to build wooden tracking tunnels, $60 for 60 inked tracking cards, and $18 for peanut butter to bait snap traps. The rat eradication in March 2006 also employed a 25 m grid, consisting of 25 bait stations, 17 snap traps, and 18 live traps. A total of 133 hours of work were required in 2006.

We monitored shearwater reproduction using standard methods employed by DOFAW since 1995 (Smith et al. 2002), in which the number of chicks is counted in late October (just prior to fledging) in eight, permanent, 4-m radius circular plots distributed uniformly across the island (Fig. 1). The total number of shearwater chicks produced on the island was estimated by extrapolating the average density of chicks in the plots to the area of the island used by shearwaters. We compared the number of shearwater chicks fledged in years with vs. without rats using a Mann-Whitney U-test.

Results

Pre-eradication monitoring recorded high rat activity over much of the island, with rats detected in 80% of the tracking tunnels on 14 November 2011. Many ink cards were almost entirely covered in rat tracks and in many cases the card under the peanut butter had been chewed away.

Rat capture rate in snap traps and take of bait from stations were high at first, but declined rapidly (Fig. 3). The number of rats trapped fell to zero on 28 November, after 14 days. A total of 20 black rats were captured in snap traps, and 1,157 one-ounce bait blocks (72.3 lbs) were taken from stations during this period. Take of bait was very low thereafter and the condition of the remaining bait blocks suggested all subsequent take was by invertebrates, not rodents. There was no known mortality of non-target species from the snap traps or bait. Tracking tunnels detected no sign of rats on 1 December 2011, 18 January 2012, and 17 June 2012. The number of rats trapped in 2006 was higher (67) and the amount of diphacinone bait taken from stations was lower (52 lbs) than in 2011, presumably because more traps and fewer bait stations were used.

The number of Shearwater chicks produced on Moku'auia was higher in years when no rats were present (3,127 ± 150) than in years when rats were present (1,275 ± 102; Mann-Whitney U = 143, $p = 0.0006$). The number of chicks produced doubled in the year immediately after rat eradications in 2006 (n = 915 vs. 1,989 chicks) and 2012 (n = 1,326 vs. 2,614 chicks; Fig. 2).

Discussion

We eradicated black rats from Moku'auia in November 2011 in 2 weeks, following previous eradications in the early 1990s and 2006. The proximity of Moku'auia to O'ahu and the history of colonization by rats strongly suggest recolonizations will recur. Although this lack of bio-security contradicts standards often used for prioritizing island eradication efforts, the cost of eradicating rats from Moku'auia was relatively low and the island supports valuable natural resources. It provides a roosting and foraging site for the Bristle-thighed Curlew, a species of concern, and supports one of the largest breeding colonies of Wedge-tailed Shearwaters in the southeastern Hawaiian Islands (Harrison 1990). We anticipate that it will be feasible to monitor the island for the presence of rats and periodically eradicate them as needed in the future. The cost of any future re-eradications will be lower than in 2011 because the bait stations, snap traps, and tracking tunnels can be re-used and the monitoring grid is already in place. This site also presents an opportunity to test and compare different rat removal methods due to the small size of the island and ease of access.

The relative abundance of rats on the island pre-eradication was high (detected in 80% of tracking tunnels). At a comparable coastal site at Ka'ena Point on O'ahu, the pre-eradication tracking rate of black rats was 5% (Young et al. 2013). The large and rapid increases in Wedge-tailed Shearwater reproduction that occurred after each eradication demonstrate that this species is vulnerable to rats. Similar increases have been seen in Cory's Shearwater *(Calonectris diomedea)* and Audubon's Shearwater *(Puffinis iherminieri)* after rat eradications (Pascal et al. 2008, Igual et al. 2006). A small breeding colony of Wedge-tailed Shearwaters formerly occurred at Malaekahana State Recreation Area directly opposite Moku‘auia, but the abundance of predators in the park caused chronic nest failure and death of adults (Smith et al. 2002), and this colony no longer exists. Eradication of black rats from Mokoli‘i Island, which is located farther south on the eastern coast of O‘ahu, also resulted in a rapid increase in reproduction of Wedge-tailed Shearwaters (Smith et al. 2006), though in that case shearwater reproduction declined again, apparently because of an increase in number of yellow crazy ants *(Anoplolepis gracilipes)* following rat eradication (Plentovich et al. 2011). Yellow crazy ants have been documented to attack and kill birds and mammals (Haines et al. 1994, Matsui et al. 2009) and spray formic acid around the eyes of nesting seabirds, causing sufficient irritation to adults that they abandon their breeding attempt (Freare 1999).

It is possible that the low reproduction of shearwaters on Moku‘auia from 2007-2011 was caused by rats, ants, or both. Follow-up monitoring for rats did not detect their presence in January or February 2007 but no rat monitoring occurred for several years thereafter, and monitoring of yellow crazy ants began in May 2007 (J. Eijzenga unpubl. data). Plentovich et al. (2011) attributed the decline in shearwater reproduction to yellow crazy ants, but given that shearwater reproduction rebounded immediately following rat eradication in 2011 when the yellow crazy ants were still present, it is likely that rats were the primary driver of shearwater decline. Continued monitoring of shearwaters will help to determine the role that ants play.

Ceasing the public feeding of feral cats at Malaekahana might help decrease the availability of this food for rats, which could decrease rat abundance in the area (Smith et al. 2002), thereby reducing the number of potential colonists that could reach Moku'auia.

Otherwise, improving biosecurity for Moku'auia will be difficult because of its proximity to O'ahu, frequent human visitation, and lack of funding for enforcement. Rapid detection of rat reinvasion, followed by re-eradication, is likely to be more practicable and cost-effective. We plan to run tracking tunnels just prior to the start of the shearwater breeding season each year and initiate an immediate response if rats are detected. We intend to use new types of traps or new rodenticides as they become available, using this island to test eradication techniques and compare their cost-effectiveness with previously-used methods, while continuing to protect native species.

Acknowledgments

Management of offshore island seabird sanctuaries, including the work on Moku‘auia, was funded by the Hawaii Division of Forestry and Wildlife. For assistance with field work we thank Raphael Bergstrom and Arthur Charfauros. Comments by two anonymous reviewers helped to improve the manuscript.

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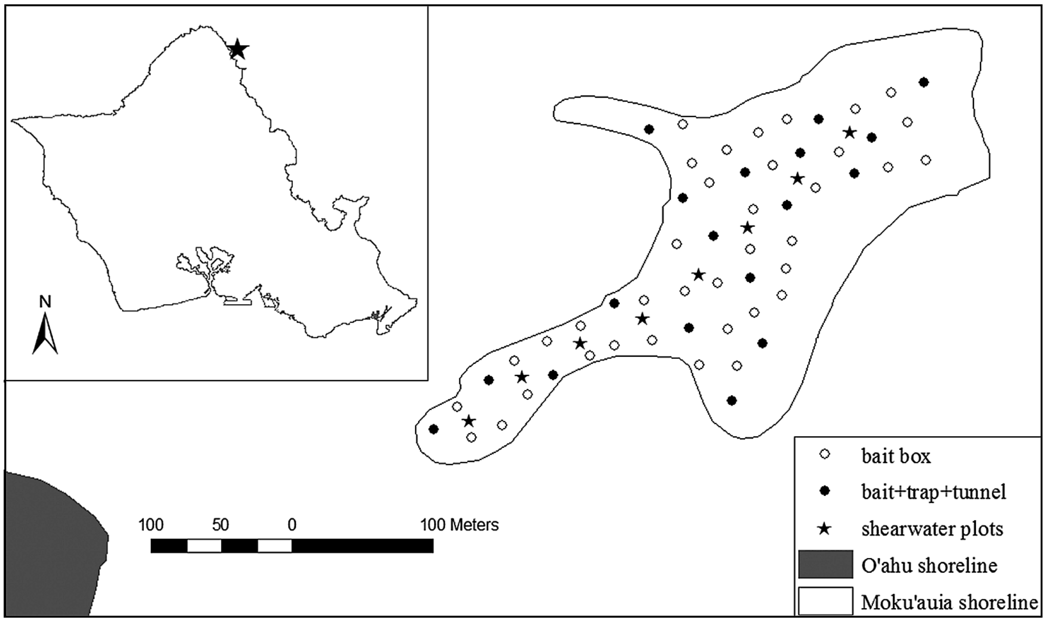

Figure 1. Locations of shearwater monitoring plots (n = 8) and bait stations (n = 55) and snap traps (n = 18) used to eradicate black rats from Moku‘auia in November 2011.

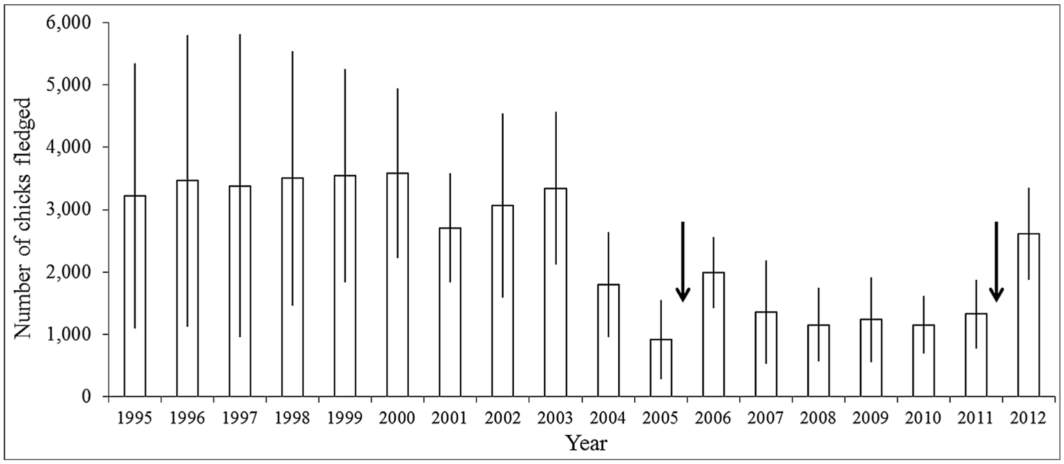

Figure 2. Reproduction of Wedge-tailed Shearwaters on Moku'auia State Seabird Sanctuary from 1995-2012 (mean ± 95% CI). Arrows indicate timing of rat eradications.

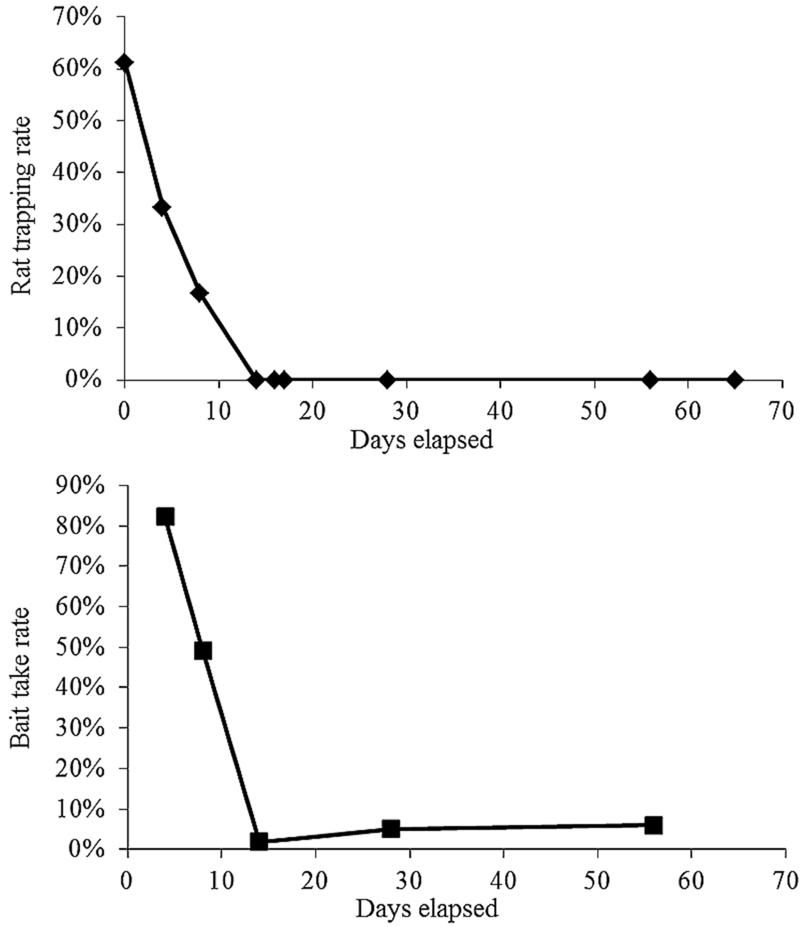

Figure 3. Rates of rat trapping and bait take on Moku‘auia during eradication efforts in November 2011.