SEABIRDS IN THE STOMACH CONTENTS OF BLACK RATS *RATTUS RATTUS* ON HIGASHIJIMA, THE OGASAWARA (BONIN) ISLANDS, JAPAN

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Eradication programs for invasive rodents have accelerated since pioneering efforts by New Zealand biologists in the 1970s to conserve not only seabird populations but also island ecosystems (Howald *et al.* 2007, Rauzon 2007). In Japan, Black Rat *Rattus rattus* eradication programs have been carried out recently in the Ogasawara (Bonin) Islands (Hashimoto 2009, Makino 2009). The Ogasawara Islands are known to be a sanctuary for birds, including several indigenous or endangered species such as *Columba janthina nitens, Apalopteron familiare,* Tristram's Storm-Petrel *Oceanodroma tristrami,* Matsudaira's Storm-Petrel *O. matsudaira* and Bonin Petrel *Pterodroma hypoleuca* (Chiba 1992). However, they are threatened by invasive mammals such as Black Rats, Norway Rats *R. norvegicus* and feral cats *Felis catus* (Kawakami 2002, 2008). Based on historical documents, Yabe (2006, 2008) estimated that Black Rats were introduced into the Ogasawara Islands in the 1910s, and Norway Rats and House Mice *Mus musculus* arrived more than 140 years ago. Despite their short history, Black Rats have expanded their distribution to more than 70% of islands and islets (Horikoshi *et al.* 2009), but Norway Rats and House Mice are known only on two islands (Kawakami 2002, 2008).

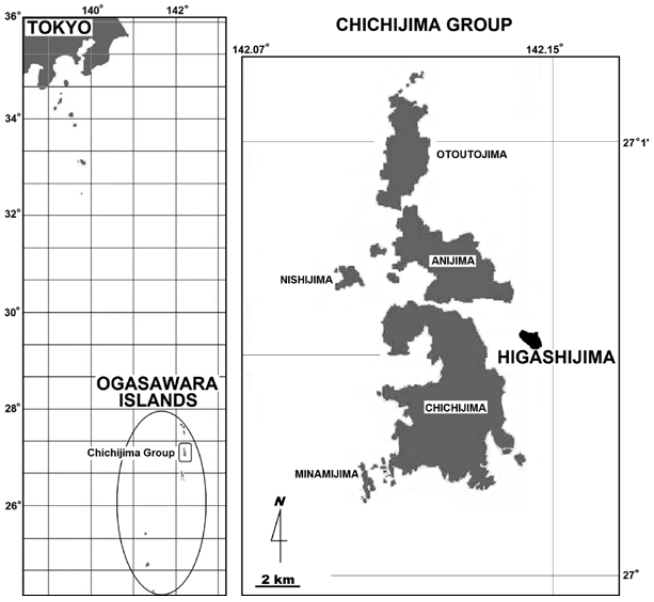

Fig. 1. Map of the Chichijima group, Ogasawara Islands. All islands in the group except Chichijima are uninhabited.

On Higashijima, Ogasawara Islands, rats are threatening the island species. Seabirds such as Bulwer's Petrels *Bulweria bulwerii* and Tristram's Storm-Petrels are threatened by Black Rats. Ten carcasses of Bulwer's Petrels were found for the first time on the island in July 2005 (K. Horikoshi pers. comm.). Pictures taken during the period between June and October 2006 with automatic cameras (and the amount of rat tooth marks on bones) suggested that Black Rats preyed on more than 1000 Bulwer's Petrels and their eggs, and that they also ate Tristram's Storm-Petrels (Horikoshi *et al.* 2009). Birds were deemed to have been killed by Black Rats not only because of tooth marks, but also because of other features that differed from features of deaths caused by accidents such as crashing or by predation by Common Buzzards *Buteo buteo* (K. Horikoshi, pers. comm.). Rosettes of an endemic plant, *Lobelia boninensis,* were also found to be heavily eaten by the rats in 2006 by an observer who had never seen such an event or an associated seabird disaster, despite regular visits in May or July (or both) since 1996 for research on the same plant (N. Kachi, pers. comm.). We therefore supposed this incident to indicate a shift in the diet of the rats continuing from 2005, and we wanted to learn the cause or the mechanism of the dietary shift.

Higashijima (27°05′N, 142°14′E) is a 28-ha uninhabited island situated in the subtropical climate zone (Fig. 1). It is covered with shrubland and grassland characterized by *Leucaena leucocephala, Pandanus boninensis, Vitex rotundifolia, Miscanthus boninensis, Paspalum orbiculare, Zoysia tenuifolia, Tridax procumbens* and other subtropical plants. No terrestrial mammals except Black Rats are known on the island.

We set 60 cage traps baited with fish sausage in grassland and shrubland for three consecutive nights in mid-June 2008. A total of 44 Black Rats (28 males, 16 females) were caught in traps. Collected specimens were identified, sexed, measured externally and dissected, and their stomachs were preserved in 10% formalin. Stomach contents were spread on a meshed Petri dish and sorted under a stereoscopic microscope in the laboratory. Items in stomach contents were calculated in frequencies and volume percentages. The percentage volume of food items in each stomach's contents (excluding bait) was estimated, and the mean percentage volume of each food item was calculated across all stomachs examined. For the calculation of percentage volume, we excluded stomachs filled with excessively digested contents even though they contained a few feathers. The rats that had seabirds in their stomachs and those

in which no seabirds were found were defined as bird-eaters and non-bird-eaters respectively.

Bird feathers or mixtures of meat and feathers (Fig. 2) were found in 16 stomachs or 36.4% of 44 stomachs, but no traces of eggs were detected. The average volumes of 30 stomach samples were 27.5% seabirds, 1.6% insects, 49.5% seeds and fruits, 18.7% leaf and stalk tissues and 2.7% unknown plant materials. The other 14 stomach samples were inadequate for the volume calculation. The main food item of bird-eaters (n = 14) was 58.9% seabirds; that of non-bird-eaters (n = 16) was 75.0% seeds and fruits by volume. Feathers in the stomach contents were compared with those of local birds: *Zosterops japonicus, Cettia diphone diphone, Hypsipetes amaurotis squamiceps, Monticola solitarius, B. bulwerii, Puffinus pacificus* and *P. lherminieri,* which were listed around Higashijima in the season of our survey (Chiba *et al.* 2007, Horikoshi *et al.* 2009, K. Kawakami unpubl. data). On Higashijima, we found carcasses of adult Bulwer's Petrels with tooth marks that were probably made by rats; all feathers examined were contour feathers judged to be those of *B. bulwerii* (5 samples) or Procellariidae (11 samples).

Black Rats prefer seeds and fruits to animal materials, and their stomach contents are usually composed mostly of plant materials; Norway Rats are omnivorous and eat animal materials commonly (Yabe 1979). However, Black Rats change their food habits and eat unusual quantities of animal or other unfamiliar materials under severe conditions such as starvation. For example, the volume percentages of bark and insects in the stomachs of Black Rats were 8.9% and 44.1% respectively when the rats uncharacteristically stripped the bark of Tankan Orange *Citrus tankan* trees because of starvation (Yabe 1998). A failure of preferred foods or a seasonal decrease in food availability influences the incidence of predation on birds (Moors & Atkinson 1984, Atkinson 1985, Caut *et al.* 2008).We therefore surmise that Black Rats on Higashijima have experienced an event such as a failure of preferred foods and starvation since 2005. This development in Black Rats poses a threat to seabirds.

Body size was different between bird-eaters and non-bird-eaters. The average body mass of the bird-eaters (202.1 ± 26.4 g, n = 16) was significantly larger than that of the non-bird-eaters (144.6 ± 52.5 g, n = 28) at the 5% significance level (Mann–Whitney *U*-test, $Z = 4.0 > Z_{0.975} = 2.0$). The bird-eaters ranged from 167 g to 253 g in body mass, and they were larger than Bulwer's Petrels, which are 78 g to 130 g (del Hoyo *et al.* 1992). Body masses of the other procellarid birds, Wedge-tailed Shearwater *P. pacificus* and Audubon's Shearwater *P. lherminieri* are 300–570 g and 150–230 g respectively (del Hoyo *et al.* 1992). However, the victims in this case were probably Bulwer's Petrels, given our finding of chewed carcasses on the island. Horikoshi *et al.* (2009) found no carcasses of Wedge-tailed Shearwaters killed by rats on an island where both species bred. The carcasses we recovered were adults, because the period when we caught rats (mid-June) was the egg-laying or early nestling period for the birds (Kiyosu 1978) and only contour feathers were found in rat stomachs. The foregoing data suggest that smaller rats avoided eating even carcasses. The reason for the avoidance remains a puzzle for us.

Black Rats on Higashijima threaten extinction for Bulwer's Petrels, because of the birds' small body size and their burrow- and crevice-nesting behavior. Jones *et al.* (2008) point out that, compared with large, ground-nesting seabirds, small burrow- and crevice-nesting seabirds are especially vulnerable to invasive rats. Small procellariiform seabirds tend to be affected by invasive predators because of their size, a lack of effective anti-predator behavior and the habit of leaving nests unattended while making long-range feeding flights (Moors & Atkinson 1984). Rats also hasten the extinction of petrel populations by preying on adults. Kawakami (2008) suggests that, on the Ogasawara Islands, relatively small burrow-nesting species such as Audubon's Shearwater and Tristram's Storm-Petrel were locally extirpated by rats, while larger or open-nesting species such as Wedge-tailed Shearwaters survived. We conclude that Black Rats on the Ogasawara Islands are now a threat to the remaining birds, especially those smaller than the rats, particularly Bulwer's Petrels. However, seabirds and endemic plants on Higashijima remained unharmed until at least May 2009, following an eradication campaign for rats conducted in August 2008 (Hashimoto 2009, K. Horikoshi & T. Yasui pers. comm.).

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Fig. 2. Meat of seabirds in the stomach of a Black Rat *Rattus rattus.*

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