Recolonization of Raoul Island by Kermadec red-crowned parakeets *Cyanoramphus novaezelandiae cyanurus* after eradication of invasive predators, Kermadec Islands archipelago, New Zealand

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SUMMARY

The Kermadec red-crowned parakeet *Cyanoramphus novaezelandiae* was driven to extinction on Raoul Island over 150 years ago by introduced cats *Felis catus* and rats (*Rattus norvegicus* and *R. exulans*). These predators were eradicated from the island (2,938 ha) between 2002-04 during the world's largest multi-species eradication project. In 2008 we documented a unique recolonisation event when parakeets were observed to have returned to Raoul, presumably from a nearby island group, The Herald Islets (51 ha). We captured and aged 100 parakeets, of which 44% were born in 2008, and breeding was observed on Raoul Island. This represents the first evidence of nesting of this species on Raoul Island since 1836. Our findings highlight the global conservation potential for island avifaunas by prioritising eradication areas through consideration of proximity of remnant populations to target management locations, instead of the classical translocation approach alone. The natural recolonization of parakeets on Raoul Island from a satellite source population is to our knowledge, a first for parrot conservation and the first documented population expansion and island recolonization of a parrot species after removal of invasive predators.

BACKGROUND

The introduction of alien predators during waves of human settlement on oceanic islands around the world has caused numerous bird extinctions (Blackburn *et al*. 2004). New Zealand is an example of this phenomenon, with approximately 42 bird species becoming extinct primarily as a result of introduced mammalian predators (Wilson 2004). A prevalent conservation tool for restoring populations of endangered biota throughout New Zealand is the translocation of native species to habitats following mitigation of the original cause of the decline (Armstrong & McLean 2005, Veitch & Bell 1990). In New Zealand the cause of declines has repeatedly been identified as the presence of alien predators and browsers (O'Donnell 1996, Wilson *et al*. 1998, Moorhouse *et al*. 2003). In addition to planned translocations, the natural recolonization of native species to managed areas is intuitively perceived as a benefit of control programs (Hutton *et al*. 2007). Surprisingly, while numerous studies document

the frequently successful management practices for introduced fauna and animal conservation via translocations (van Heezik & Ostrowski 2001, Taylor *et al*. 2004) documented examples of recolonization by native species without direct human assistance are rare (Brunton *et al*. 2008). Here we report the recolonization and population expansion on Raoul Island by a vulnerable species (www.iucn.org 2007), the Kermadec red-crowned parakeet *Cyanoramphus novaezelandiae cyanurus* in the Kermadec Islands archipelago (New Zealand) four years after the eradication of invasive mammals.

Raoul Island (2,938 ha) is a remote volcanic island situated approximately 995 km N of mainland New Zealand's North Island and 900 km SSW of Tonga, in the South Pacific. Historically, Kermadec red-crowned parakeets were considered plentiful on Raoul Island and Macauley Island (306 ha), the two main islands of the Kermadec archipelago; but there has not been a confirmed record of resident parakeets on Raoul Island since 1836 (Veitch *et al*. 2004). Goats *Capra hircus*, domestic cats *Felis catus*, brown rats *Rattus norvegicus* and Pacific rats *R. exulans* introduced by humans most likely caused the extinction of the parakeets and seven other bird species on Raoul (Veitch *et al*. 2004). While cats prey directly on parakeets and rats prey upon their eggs (Merton 1968, Hicks & Greenwood 1989), goats dramatically modify vegetation structure through overgrazing on islands (Cambpell & Donlan 2005). Invasive species and large-scale habitat modification were also involved in the disappearance of the nominate red-crowned parakeet subspecies, *Cyanoramphus novaezelandiae*, throughout mainland New Zealand (Higgins 1999) and other *Cyanoramphus* taxa in the South Pacific (Taylor 1979, Hicks & Greenwood 1989).

ACTION

Goat removal: Goats were removed in 1986 after 12 years of intense hunting (Campbell & Donlan 2005, Clout & Russell 2006).

Invasive predator removal: In the world's largest multi-species eradication project to date, the New Zealand Department of Conservation (DOC) successfully removed domestic cats, Norway and Pacific rats from Raoul Island via aerial drops of poisoned bait for rats between 2002 and 2004, with follow-up ground hunting with dogs and guns for cats (Clout & Russell 2006).

Prior to the removal of these invasive species on Raoul, the last strongholds for Kermadec red-crowned parakeets were the Herald Islets (approx. 50 breeding pairs) and Macauley (ca. 10,000 breeding pairs) 2-4 km E and 108 km S off the coast of Raoul Island respectively (Veitch *et al*. 2004, Greene *et al*. 2004).

Bird surveys: Commencing in the year 2000 (i.e. 2 years prior to initiation of the predator removal program), staff from DOC have carried out bird surveys roughly once a year on Raoul to assess bird responses to the removal of predators through estimation of bird densities. During these surveys no parakeets were detected prior to eradication of cats and rats. Upon completion of the combined cat and rat eradication campaign, rangers on Raoul reported infrequent sightings of one to three parakeets; however neither the presence of resident parakeets or their nesting on Raoul has been recorded for over 150 years. A survey of Raoul Island aiming to confirm the presence of resident breeding parakeets was thus undertaken.

Parakeet capture and observations: We visited Raoul Island between 27 March and 28 April 2008. Transportation to Raoul Island was provided by the Royal New Zealand Navy vessel Canterbury. Parakeets were captured using mist-nets placed along the airstrip on Raoul Island and gullies around Boat Cove on the north and southeast sides of the volcano respectively (Fig. 1). Every parakeet captured was banded (ringed) with numbered steel bands and four breast feathers were collected for PCR-based test determination of sex (Griffiths *et al*. 1998). Caught individuals were classified either as adults or sub-adults born on the same year of sampling considering plumage development, moult pattern and colouration of bare parts (Higgins 1999). Behavioural interactions were also recorded between parakeets encountered opportunistically when walking along tracks in search of additional mist-netting sites.

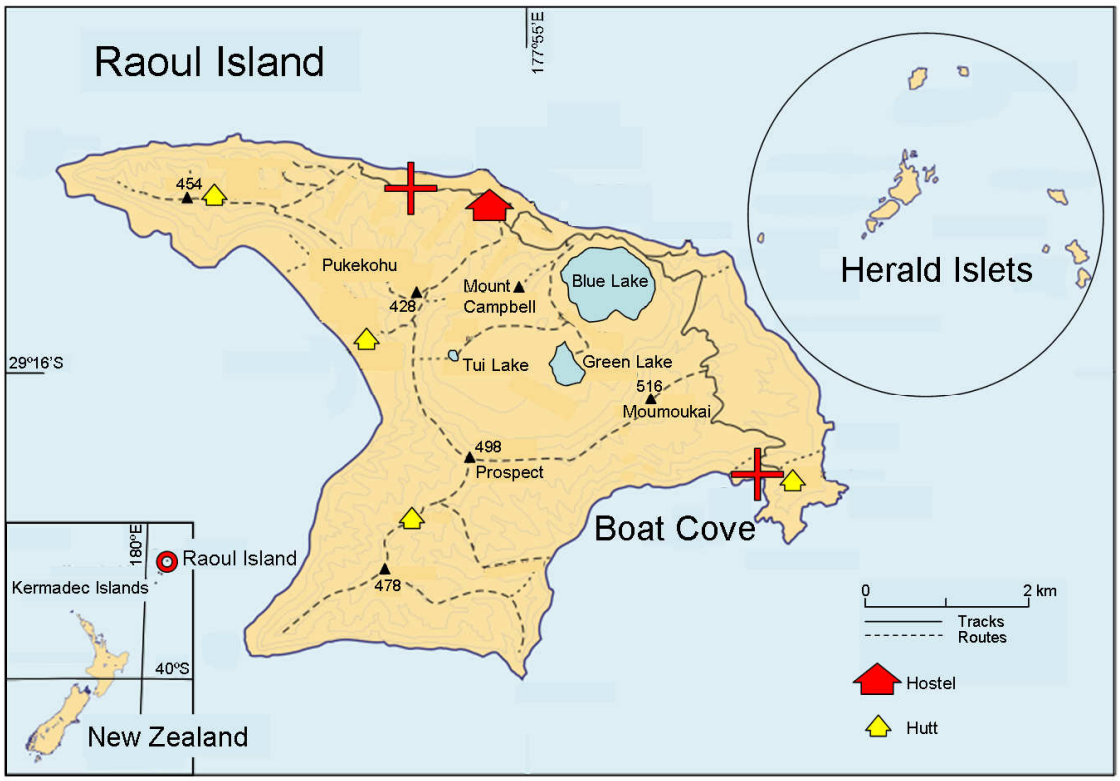

Figure 1. Raoul Island: a remnant population of Kermadec red-crowned parakeets persisted on the neighbouring Herald Islets before the eradication of cats and rats on Raoul Island. The two sampling locations during the study are marked by the red crosses.

CONSEQUENCES

During the more-or less annual bird surveys conducted by DOC staff undertaken since 2000, no parakeets were detected prior to cat and rat eradication (A.Warren pers. comm.).

In 2008 during the parakeet survey, 100 parakeets were caught during the 13-day mist-netting period. Of these, 59 were female and 41 were male, of which 56 were adults and 44 sub-adults hatched in 2008. Three independent feeding events involving an adult parakeet and one non-flying fledgling were recorded. We also observed one full pre-mating display followed by copulation and confirmed the presence of two nests located in fallen logs of Kermadec pohutukawa *Metrosideros kermadecensis* trees. We estimated these nests were at incubation stage given the typical whining calls of the nesting females, food-soliciting behavior towards attending males and the extended periods spent inside the nest cavities by the females; these behaviours are routinely used to estimate nesting stage of other *Cyanoramphus* parakeet populations in New Zealand (Ortiz-Catedral 2009). In October 2008, a parakeet nest containing three nestlings of about 50 days old was found on the northern side of Raoul Island in a burrow located approximately 5 m above the ground in a bankside (N.Goomes pers. comm.). These series of observations represent the first evidence of breeding of parakeets on Raoul Island since 1836 (Veitch *et al*. 2004).

Due to their proximity (<4 km distant), The Herald Islets are the most likely source population of the founder parakeets on Raoul Island, although historically the species complex has dispersed naturally throughout the entire south-west Pacific region (Hicks & Greenwood 1989), indicating that long distance dispersal over the sea (hundreds of kms) is possible. Red-crowned parakeets also exhibit life-history traits that can permit rapid recolonization of new sites, including low specificity for nesting site (Ortiz-Catedral & Brunton 2009), rapid sexual

maturation, and large clutch sizes (Higgins 1999).

Discussion: The natural recolonization of Raoul Island from a neighboring small remnant source population is a first for parrot conservation and it is, to our knowledge, the first documented population expansion and island recolonization of a parrot species after removal of invasive predators. Our findings indicate that proximity to remnant populations of native species of conservation concern, combined with knowledge of their dispersal capabilities, should be explicitly incorporated into management strategies based upon eradicating invasive species from islands. Such an approach could maximize conservation outcomes by increasing the likelihood of nearby species to recolonize naturally into managed areas after the removal of invasive predators and pests. Finally we note that rapid natural expansion to a large eradication site from a small nearby remnant population offers a unique opportunity to study the genetic effects of population bottlenecks on island species. The small Herald Islets population has been largely isolated from the Macauley island population and they represent different evolutionary units (Rawlence 2006). The rapid expansion of such a small population onto Raoul Island and potential reverse colonization from this large new population to the source population poses conservation concerns about probable genetic impoverishment on the remnant allelic diversity of The Herald Islets population. However, research has shown that contemporary bottlenecks cause little genetic erosion on genetically depauperated taxa that passed through large historical bottlenecks (Taylor & Jamieson 2007); a parallel situation to the collapse of parakeets on Raoul Island and subsequent expansion from a satellite population.

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