Aspects of the biology of managed populations of two *Cyanoramphus* parakeet species in New Zealand: breeding biology, pathogen screening and translocation

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Red-fronted parakeet (above) and Malherbe's parakeet (below)

Photos by L. Ortiz-Catedral

I would like to dedicate this work to my parents Alfredo Ortiz Delgadillo and Emma Catedral Hernandez and to the memory of my aunt Eva Margarita Catedral Hernandez. She gave me my first book on birds. Such little gesture has opened up a world of wonders.

ABSTRACT

In this study, a visit to the remote Kermadec archipelago and the translocation of two parakeet species to novel sites opened up opportunities to document aspects of the biology of free-living and captive-bred parakeets. Four years after the eradication of cats and rats on Raoul Island by the Department of Conservation, the Kermadec red-fronted parakeet has naturally recolonised this site, potentially from the adjacent Herald Islets. Over a period of three weeks in March-April 2008, 100 parakeets were captured on Raoul Island and the first evidence of nesting of the species at this site since 1836 was recorded. These observations reinforce the view that eradication of introduced predators such as cats and rats is a requisite for the recovery and establishment of populations of New Zealand parakeets. These observations also suggest that strategic eradication of cats and rats can facilitate the natural dispersal of parakeets.

Taking into account the remarkable recolonisation of parakeets on Raoul Island and the existence of islands free of introduced mammalian predators and red-fronted parakeets in the Hauraki Gulf, a translocation of parakeets was envisaged. Between April and May 2008, 32 red-fronted parakeets were translocated from Little Barrier Island to Motuihe Island, in the first translocation of the species within the Hauraki Gulf in 32 years. Alongside such transfer, a total of 62 captive-bred Malherbe's parakeets were monitored on Maud Island, in the Marlborough Sounds. Because the translocations of red-fronted and Malherbe's parakeets were temporally close, a unique opportunity to study translocated free-living and captive-bred parakeets was identified. The focus of monitoring on both sites was the detection of successful

nesting attempts, a short-term measure of translocation success. On both sites (Motuihe and Maud Islands) evidence of successful nesting was found within a year of the release of the first flocks.

As part of the planning steps for the translocation of red-fronted parakeets, a survey was designed for four selected microorganisms of conservation concern for New Zealand parrots: *Campylobacter*, *Salmonella, Yersinia* and the beak and feather disease virus (BFDV). Only the latest was detected at a prevalence of 28% on Little Barrier Island. Subsequent isolation and sequencing of BFDV genomes revealed a previously undescribed genotype of this virus in New Zealand.

The discovery of a new BFDV genome in a wild population of endemic New Zealand parakeets highlights need of future research. BFDV is known to affect the immune system and survival of infected individuals in other species and is likely to hamper conservation efforts for threatened parrot species. The challenges to study BFDV in New Zealand, a global hotspot of parrot diversity, are outlined and high priority lines of research are identified and discussed.

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Although the research presented here is the result of the coordinated effort of numerous individuals, any mistakes or misinterpretations remain the sole responsibility of the author.

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CHAPTER ONE

General Introduction

Biodiversity loss and species extinctions

Current estimates of biodiversity loss as a result of human activities reveal extinction rates at least hundreds of times higher than the background estimated from geological records (Pimm and Brooks 1999; Dirzo and Raven 2003). Biodiversity loss has an effect on ecosystem functioning (Lyons, Brigham et al. 2005; Worm, Barbier et al. 2006) and ultimately on society and human well being as society relies on the services that ecosystems provide (Diaz, Fargione et al. 2006). Consequently, conservation biologists face the moral as well as technical challenge of identifying tools that can reduce or halt the loss of biological diversity. One component of biodiversity loss is the extinction of species (Dirzo and Raven 2003). The most recent estimates by the International Union for the Conservation of Nature (IUCN) indicate that approximately 36% of the nearly 50, 000 organisms evaluated in the 2010 IUCN Red List are threatened with extinction (www.iucn.org). The task to develop projects aimed at preventing the extinction of species is clearly overwhelming.

The chief drivers of species extinction include anthropogenic large-scale habitat destruction or modification and introduced species competing and/or preying upon indigenous wildlife, particularly on island ecosystems (Spray and McGlothin 2003; Blackburn, Cassey et al. 2004). Other factors contributing to the extinction of species or higher taxonomic groups include poaching for trade (Wright, Toft et al. 2001; Pain, Martins et al. 2006) and diseases (Thorne and Williams 1988; Daszak, Cunningham et al. 2000; Smith, Sax et al. 2005).

Psittaciformes: a highly threatened group of birds

Among birds, one of the most threatened lineages is the order Psittaciformes (Parrots and cockatoos) (Collar and Juniper 1991; Beissinger and Snyder 1992; Bennett and Owens 1997), with about 30% of all known species falling into various categories of conservation threat (Collar, Crosby et al. 1994; Pain, Martins et al. 2006). Since the 70's and 80's a number of calls to develop conservation strategies for Psittaciformes have taken place (Gochfeld 1974; Snyder, Wiley et al. 1987; Evans 1988; Forshaw 1989; Hicks and Greenwood 1989). Two major syntheses about the threats and conservation alternatives for psittaciformes have occurred: one targeting species from the Americas (Beissinger and Snyder 1992) and the most recent, addressing all threatened species globally (Snyder, McGowan et al. 2000). In both documents, understanding the multiple ecological and anthropogenic factors affecting psittacine biology is identified as the key to develop specific conservation management projects.

Studies on the biology of psittacines and the multitude of threats affecting natural populations have resulted in the implementation of strategies aimed at improving the breeding performance of individuals in remaining populations (White and Vilella 2004; White, Abreu-González et al. 2005; White, Collazo et al. 2005; White, Collazo et al. 2005; White, Brown et al. 2006), increasing population sizes (Clout, Elliot et al. 2002; Vaughan, Nemeth et al. 2003), and expanding the number of individuals and populations via translocation (Wiley, Snyder et al. 1992; Snyder, Koenig et al. 1994).

In recent years, studies on the biology of psittaciformes with conservation relevance have targeted aspects of their reproductive ecology, including nesting requirements (Heinsohn and Legge 2003; Murphy and Legge 2007; Ortiz-Catedral

and Brunton 2009) and mating systems (Ekstrom, Burke et al. 2007; Heinsohn, Ebert et al. 2007). However, the diversity of ecological and anthropogenic factors limiting productivity of natural and managed populations of parrots is far from fully understood.

Predation is a significant limiting factor to reproductive success among Psittaciformes worldwide (Renton 1998; Gonzalez 2003; Murphy, Legge et al. 2003). The range of nest predators impacting breeding productivity of parrots includes reptiles (Koenig 2001) birds (Pizo 2008), and mammals (Renton and Salinas-Melgoza 2004) incuding humans (Wright, Toft et al. 2001; Pain, Martins et al. 2006). In addition to native nest predators, several parrots have suffered from additional pressure of exotic nest predators, such as rats (*Rattus spp*), introduced by humans. The devastation caused by introduced predators into island ecosystems has reduced population sizes or caused the extinction of native psittacines on many insular sites, including Norfolk Island (Hill 2002), Macquarie Island (Taylor 1979) Puerto Rico (Snyder, Wiley et al. 1987), and mainland and offshore New Zealand islands (Higgins 1999).

Introduced mammals and threatened parrots in New Zealand

The detrimental role of introduced nest predators on the productivity of New Zealand forest-dwelling parrots and other birds has been widely documented (Beggs and Wilson 1991; Lloyd and Powlesland 1994; O'Donnell 1996; Wilson, Karl et al. 1998). Currently, intensive management to control or eliminate introduced predators through trapping, poisoning, and shooting is at the centre of the New Zealand conservation efforts (Towns and Broome 2003; Russell and Clout 2006). The mammal species that are the target of these control or eradication campaigns include

domestic cats (*Felis catus*), ship rats (*Rattus rattus*), Norway rats (*R. norvegicus*), kiore (*R.exulans*), and brushtail possums (*Trichosorus vulpecula*) (Graham and Veitch 2002; Towns 2002; Towns and Broome 2003; Greene, Scofield et al. 2004; Russell and Clout 2006). Other managed introduced mammalian species increasingly being trapped or eradicated include goats (*Capra hircus*) (Campbell and Donlan 2005) and house mice (*Mus musculus*) (Veitch and Bell 1990; Veitch 2002). While positive effects of predator control on the expansion of parrot populations have been reported (Moorhouse et al. 2003; Ortiz-Catedral et al. 2009), little is known about the other factors that might affect parrot productivity.

All New Zealand parrots are classified under categories of threat by the IUCN, ranging from 'vulnerable' such as red-fronted parakeets (*Cyanoramphus novaezelandiae*) and Antipodes Islands Parakeet (*C. unicolor*) to 'critically endangered' such as Malherbe's parakeet (*C. malherbi*) and Kakapo (*Strigops habroptilus*) (www.iucn.org). Currently, a number of New Zealand parrot species persist throughout their historical ranges, albeit in lower numbers or fewer populations owing to the combined pressure of introduced mammalian predators, shooting and habitat modification (Higgins 1999). Examples include red-fronted parakeet, yellow-crowned parakeets (*C. auriceps*), Forbe's parakeet (C. forbesi), kaka (*Nestor meridionalis*) and kea (*N. notabilis*) (Heather and Robertson 1996). A common approach often used in the protection of parrot species (and other fauna) in New Zealand is the translocation of a founder population to habitats were introduced mammals have been eradicated or undergo regular trapping/poisoning (Lloyd and Powlesland 1994; Berry 1998; Greene, Powlesland et al. 2004; Gaze and Cash 2008; Ortiz-Catedral and Brunton 2010).

Translocations in New Zealand

A translocation can be described as the deliberate release of organisms within or outside their historical range with the aim of establishing additional populations (Griffith, Scott et al. 1989; Armstrong and McLean 1995; Seddon, Armstrong et al. 2007; Armstrong and Seddon 2008). In New Zealand, translocations have been largely successful. Perhaps the most well known examples of translocations involve threatened birds such as kakapo (*Strigops habroptilus*) (Elliot, Merton et al. 2001), black robin (*Petroica traversi*) (Flack 1977) and South Island saddleback (*Philesturnus carunculatus carunculatus*) (Taylor, Jamieson et al. 2005) to island refuges. Such conservation efforts have resulted in population growth of these taxa (Hutching 2004) and have laid the foundation to incorporate translocation as a complement to conservation projects for an ever increasing number of species in New Zealand (McHalick 1999).

Historically, translocations in New Zealand were developed as an emergency action to rescue relict populations of endemic species such as kakapo and saddleback (Lovegrove 1996; Hutching 2004; Powlesland, Merton et al. 2006). Recently however the potential use of translocations for non-native species as part of ecosystem restoration projects has been highlighted in New Zealand and overseas. For instance, Parker et al. (2010) discuss the potential ecological benefits of translocating the Australian quail (*Coturnix ypsilophora*) as an ecological replacement for the extinct New Zealand quail (*Coturnix novaezelandiae*) to locations around the country (Parker, Seabrook-Davidson et al. 2010). Similarly, the potential translocation of red-crowned parakeets from New Zealand as surrogates to the extinct Lord Howe Island parakeet (Australia) has been discussed (Hutton, Parkes et al. 2007). Besides

ecological benefits, the multiple additional positive outcomes of carefully planned translocations have been outlined, for instance advocacy and community involvement (Galbraith and Hayson 1995; Parker 2008).

At present, translocations in New Zealand take place as part of management plans developed for critically endangered species such as takahe (*Porphyrio hochstetteri*) (Jamieson and Wilson 2003) or as part of ecological restoration projects led by community groups aiming to restore pre-European bird communities on managed islands (Rimmer 2004; Parker and Laurence 2008) or fenced mainland sites (Ritchie 2002). During translocations, individuals are sourced from remnant populations, for instance rifleman *Acanthisitta chloris* from Codfish Island to Ulva Island (Leech, Craig et al. 2007); translocated populations, such as the transfer of saddleback from Tiritiri Matangi Island to Motuihe Island (Parker and Laurence 2008) or captive populations, for example blue ducks (*Hymenolaimus malacorhynchos*) released at Egmont National Park (Oehler, Boodo et al. 2001), Brown teal (*Anas chlorotis*) released at Tawharanui Regional Park (Rickett 2010) and Kaka released in a number of locations across New Zealand (Pullar 1996; Greene, Powlesland et al. 2004).

Translocations are an ever-improving field. Multiple translocations of some species such as New Zealand robins (*Petroica longipes*) and hihi (*Notiomystis cincta*) have made it possible to develop models to estimate the effects of harvest rates (Dimond and Armstrong 2007) and follow-up translocations (Armstrong and Ewen 2001), and to refine translocation techniques, release methods (Castro, Minot et al. 1995) and population surveying (Armstrong and Ewen 2001). Although these studies are valuable as they provide elements for planning future translocations of these

species, the findings can only be extended to a limited suite of taxa that share some biological traits with the species studied. This means that the multiple aspects of a translocation i.e. capture, aviary holding, transfer, post-release monitoring etc. would need to be adjusted for different species, rather than applying the same techniques across a range of taxa.

Captive breeding for conservation translocations of parrots

Captive breeding and translocation is a common conservation approach used for threatened and endangered parrots worldwide. Well known examples include Norfolk Island green parakeet (*Cyanoramphus cooki*) (Hicks and Greenwood 1989; Hill 2002), Puerto Rican parrot (*Amazona vittata*) (Snyder, Wiley et al. 1987), Yellow-shouldered Amazon (*Amazona barbadensis*) (Sanz and Grajal 1998), Orange-bellied parrot (*Neophema chrysogaster*) (Holdsworth 2006) and Mauritius parakeet (*Psittacula echo*) (Malham, Kovac et al. 2008).

For New Zealand parrots, no less than 23 translocations have occurred between 1966 and 2010 (Higgins 1999; McHalick 1999; Gaze and Cash 2008; Adams and Cash 2010; Ortiz-Catedral, Adams et al. 2010; Ortiz-Catedral and Brunton 2010; Ortiz-Catedral, Kearvell et al. 2010). Of these, approximately 12 used captive populations as a source. Most of these translocations are considered successful but two translocations, of captive-bred Antipodes parakeets (*Cyanoramphus unicolor*) to Stephens Island failed, and the species is no longer found at the release location. However, the reasons for failure are unknown. An example of a successful translocation of captive-bred parrots in New Zealand is the red-fronted parakeets released on Tiritiri Matangi Island (Higgins 1999). This is a vulnerable species endemic to New Zealand currently inhabiting mainly offshore islands free of introduced mammalian predators (Higgins 1999). In addition to remaining natural and

translocated wild populations, it is also bred in captivity by individuals and zoos under specific permits issued by the New Zealand Department of Conservation. Since the 1970s, there has been a growing interest in the potential for extensive captive propagation of red-crowned parakeets and their subsequent release into the wild (Dawe 1979; MacMillan 1990).

Red-fronted parakeets and yellow-crowned parakeets (*Cyanoramphus auriceps*) are often listed as desirable species in management plans for restoring areas, and translocation is cited as a means to establish a population of the species at island and mainland sites (Miskelly 1998; McQueen 2004; Hawley 2005). Despite their popularity both in captivity and in a translocation context, both species remain poorly studied and there is uncertainty about the main determinants of translocation success for New Zealand parakeets in general. It has been speculated that dispersal from release sites or lack of suitable habitat are important determinants of success in parakeet translocations (Dawe 1979; Gaze and Cash 2008). However, confirmed reports of parakeet dispersal from a release site are on the whole very uncommon (Ortiz-Catedral 2010) (see also Appendix 6), making it difficult to objectively assess the role of dispersal in determining the outcome of parakeet translocations. Furthermore, there are examples of thriving parakeet populations in habitats substantially different from the source of the founding flocks: yellow-crowned parakeets have been transferred from Te Kakaho (Chetwoode Islands), an island with substantial cover of coastal broadleaf forest to Mana Island, with extensive grasslands (Adams and Cash 2010). In spite of the habitat differences, the population of yellow-crowned parakeets on Mana is large (Adams and Cash 2010).

It has also been suggested that the genetic makeup of founder flocks of parakeets might have an effect on the long-term persistence of translocated

populations established with small founder flocks. For instance, red-fronted parakeets on Tiritiri Matangi Island showed reduced hatching success over two breeding seasons (Ortiz-Catedral and Brunton 2008) which could be the result of inbreeding depression resulting from the small size of the founder flock (34 individuals) released between 1974 an 1977 (Dawe 1979). Although populations of New Zealand birds can be established with as few as 15 individuals (Taylor, Jamieson et al. 2005), it has been shown that bottlenecks of fewer than 150 individuals can cause increased hatching failure (Briskie and Mackintosh 2004). Bottlenecks in translocated populations can also compromise immunocompetence (Hale and Briskie 2007) making individuals more susceptible to pathogen infections (Tompkins, Mitchell et al. 2006). Thus, although small founder flocks can be used to establish new populations in the short-term, their long-term persistence might require surplus transfers to compensate the detrimental effects of genetic isolation (Westemeier, Brawn et al. 1998).

Moreover, the captive environment can have detrimental effects on individuals and affect the outcome of translocations. Behavioural changes that reduce reproductive success have been reported in Puerto Rican parrots (Wilson, Wilson et al. 1997). Also, inadequate social interaction of ex-pet captive Scarlet macaws (*Ara macao*) with wild birds after release makes them unsuitable for translocation (Brightsmith, Hilburn et al. 2005). The effect of captivity on the outcome of parrot translocations in New Zealand and overseas however remains largely unstudied.

Lastly, it has also been suggested that pathogens might have an effect on the viability of translocated parakeet populations. For example, the observed reduced hatching success reported in red-fronted parakeets inhabiting Tiritiri Matangi Island could be the result of a microorganism affecting incubating females because reduced health is often associated with limited reproductive success (Ortiz-Catedral 2006). In

addition, a number of exotic avian diseases have been identified by DOC as potential threats not only to remnant populations but also to translocated populations of New Zealand parrots (Jackson, Morris et al. 2000).

Pathogens in the context of parrot translocations in New Zealand

The relevance of pathogens in the context of translocations is being increasingly acknowledged in New Zealand and worldwide (Ballou 1993; Cunningham 1996; Parker, Brunton et al. 2006; Boyce, Weisenberger et al. 2011). The movement of individuals between populations changes the density and composition of faunal communities. For instance, restoring island habitats in New Zealand undergo sequential translocations of different animal species following eradications of mammals (Rimmer 2004; Parker and Laurence 2008). Such an approach has the potential of bringing novel pathogens into contact with species already present at the release site. Likewise, the individuals being translocated might come into contact with microorganisms at the release site that are not present at the source location.

The information about the range of pathogens affecting New Zealand parrots is limited, while research about the effects of pathogens on the outcome of parrot translocations in New Zealand is practically non-existent. Some studies have documented the results of pathogen surveillance during translocations of New Zealand parrots or in translocated populations of parrots. For example Adams and Cash (2010) screened 27 yellow-crowned parakeets being transferred from Te Kakaho to Mana Island for *Chlamydia*, *Salmonella*, *Yersinia*, *Campylobacter* and *Coccidia* as well as Beak and Feather Disease Virus (BFDV). None of the individuals

tested positive for any of these pathogens. Also, 45 yellow-crowned parakeets being transferred from Long Island to Motuara Island were screened for avian malaria, with 16% yielding positive results (Tompkins, Massey et al. 2008). However, the effect of avian malaria on the establishment of the new population on Motuara Island was not evaluated. Furthermore, 39 Kakapo on Codfish Island were screened for *Salmonella* and *Campylobacter* due to concerns that the critically endangered parrot could be exposed to *Salmonella enterica* because of the presence of House sparrows (*Passer domesticus*) at this location. All individuals tested negative for both bacteria (Brangenberg, McInnes et al. 2003).

Besides native parrots, a couple of studies have reported the occurrence of BFDV in exotic Australian species in captivity (Ritchie, Anderson et al. 2003) or in feral populations (Ha, Anderson et al. 2007) in New Zealand. Although the risk of disease transmission is often cited as a reason not to release captive-bred parrots this area remains largely unstudied in New Zealand and overseas (Wiley, Snyder et al. 1992; Jackson, Morris et al. 2000) and thus warrant further research.

Immunocompetence and translocations

The ability of an individual to control microbial infections is known as immunocompetence and has three functional components: innate, humoral and cell-mediated immunity (Norris and Evans 2000; Salvante 2006). A simple and reliable test to measure the strength of immunocompetence of an individual is the PHA test (Ewenson, Zann et al. 2003; Tella, Lemus et al. 2008), which reflects T-cell-mediated immunocompetence. Although this is only one of three components of the immune response, the PHA has widespread applicability due to its simplicity: it consists of

subcutaneous injection of phytohaemagglutinin and subsequent measuring of the swelling response at the point of injection (Smits, Bortolotti et al. 1999).

The strength of immunocompetence may play a significant role in the survival of a translocated individual. When released at a new location, an individual might encounter a different array or density of pathogens and its ability to mount an effective immune response would determine its chances of survival at a new site. Also, previous exposure to a pathogen might be an important determinant of survival (Boyce, Weisenberger et al. 2011). The strength of the immunocompetence response has been linked to genetic diversity (Reid, Arcese et al. 2003; Charpentier, Williams et al. 2008), which has lead to an increasing incorporation of immunological studies into conservation science (Tompkins, Mitchell et al. 2006; Hale and Briskie 2007). Conservation translocations often consist of founder groups of varying sizes (Swinnerton, Groombridge et al. 2004; Taylor, Jamieson et al. 2005), resulting in bottlenecks of different severity across a range of taxa. Thus, contrasting the immunocompetence of translocated individuals from sources varying in degree of genetic diversity can provide elements to refine translocation protocols when different sources of individuals are available, for instance captive and wild populations.

Aims of the study and research questions

In its original form, this study was designed to:

1. Determine the relationship between naturally occurring pathogens to survival and dispersal following translocation of captive-bred and wild-sourced red-fronted parakeets.

2. Determine the relationship between T-cell mediated immune response (assessed using the PHA test) to survival and dispersal following translocation of captive-bred and wild-sourced red-fronted parakeets.

Thus, this study aimed at presenting the first attempt to simultaneously contrast the effects of source (captive *vs* wild), immunocompetence (using the PHA test) and pathogen load in a translocation context for a New Zealand bird species. Below I briefly present the general approach taken to answer the above questions.

Study sites: release locations

Three sites undergoing ecological restoration were selected to release mixed flocks of captive-bred and wild-sourced red-fronted parakeets: Motuihe Isand, Rakino Island and Tawharanui Regional Park. These sites occur within the Auckland region and the islands lack introduced mammalian predators. Tawharanui Regional Park has a predator-proof fence that serves as a barrier to incursions of mammalian predators and a network of traps within the area is used to intercept intrusive individuals. Therefore, I sought to compare the success of three translocations of red-fronted parakeets on two islands (Motuihe and Rakino Island) and one peninsula (Tawharanui Regional Park) determining survival, dispersal and habitat use following translocation as well as immune response using the PHA test measured prior to release at the experimental sites. The Community Trusts associated with Motuihe Island and Tawharanui Regional Park provided financial support to aspects of the project.

Source of captive-bred and wild Red-parakeets

A number of aviculturists keeping red-fronted parakeets in the Auckland region were identified and approached about the project. Three aviculturists agreed to provide parakeets ranging from ages 1 to 2 years. It was agreed that prior to any releases and just before the PHA-related handling, a thorough disease screening targeting selected bacterial and viral pathogens would take place. The selection of bacterial and viral microorganisms to screen for was decided after consultation with members of DOC and New Zealand Wildlife Center for Conservation Medicine, Auckland Zoo. The microorganisms selected included: *Campylobacter*, *Salmonella*, *Yersinia* and BFDV.

The wild population selected as a source of parakeets was Little Barrier Island. The species is common at this site, it is located within the Auckland region and it has all the facilities to undertake the capture of parakeets and subsequent PHA challenge. Parakeets caught on Little Barrier Island would be subject to the same pathogen screening as the captive-bred parakeets and all tests would be completed at the same commercial lab.

For the bacterial pathogens, cloacal swabs would be collected and kept at 4ºC until analysis. For the BFDV 70 µl of blood collected by venipuncture of the brachial vein would be placed in plastic tubes containing 0.5 ml of lysis buffer. Also, two to four contour feathers would be plucked using tweezers and placed in paper envelopes until testing at the Equine and Parentage Genetic Services, Massey University. All parakeets used in this project would be banded with a single metal "D" band and up to three colour plastic bands following guidelines by DOC.

Measuring immunocompetence in Red-fronted parakeets

Five captive-bred and five wild-sourced individuals would be injected subcutaneously in the patagium with a solution of 0.5 mg of phytohaemagglutinin dissolved into 0.1 mL phosphate-buffered saline solution, according to the methodology described in Tompkins et al. (2006). A control group of five captive-bred and five wild-caught parakeets would be injected subcutaneously in the patagium with 0.1 ml phosphate-buffered saline solution only. Swelling at the point of injection would be measured every 6 hours during a 24-hour period. In between measurements, parakeets would be kept in pet-carry cardboard boxes padded with Kanuka (*Kunzea ericoides*) and provided food and water *ad libitum*.

Post-translocation dispersal and survival

Ten parakeets per site used for the PHA challenge would have a 2g single-stage transmitter (Holohil Systems, Canada) attached to their tails. Also, ten other parakeets not used as part of the PHA challenge would be mounted an identical transmitter in the same way. After release, the parakeets would be located by homing of strength signal using a hand-held antenna. When located, the location of parakeets would be recorded using a hand-held GPS unit. Monitoring following translocation would last for three months, the approximate duration of the battery life of the transmitters used.

Changes to the original PhD project and methodology.

In implementing the original thesis plan a number of difficulties and new opportunities arose and, in consultation with my doctoral committee, the research questions of this thesis were modified. Below I present a summary of the sequence of events and key obstructions to the original project and the new directions undertaken.

1. *Failure to obtain a high-impact research permit from the New Zealand Department of Conservation (DOC) to use captive-bred red-fronted parakeets for experimental releases.*

I presented my PhD project to DOC in early August 2006 just after the start of my PhD studies. Extensive consultation with staff from the Auckland Conservancy, Auckland Region Area Offices as well as DOC Wellington Head Office took place between August and December 2006. In early January 2007 I was informed that a project involving captive-bred red-fronted parakeets would not be approved owing to concerns about: a) the genetic makeup of the captive-bred parakeets (i.e. potential hybrids of avicultural interest rather than the "wild type" of the species) and b) potential pathogens from aviary birds that could spread to natural populations. However, DOC staff provided valuable feedback into the project including the suggestion of determining the extent of hybridization among captive stock of red-fronted parakeets in the Auckland region. The work done on Chatham Island parakeets, Forbe's parakeets and their hybrids (Chan, Ballantyne et al. 2005; Chan, Ballantyne et al. 2006; Chan, Ballantyne et al. 2006) provided useful molecular markers that could be used in other New Zealand parrots. I approached the team at Victoria University of Wellington (VUW) responsible for the work on Chatham and Forbe's parakeets to determine the feasibility of this approach for captive stock of red-fronted parakeets. VUM staff indicated that this molecular work was both risky and expensive and funding was limited this approached was abandoned and a new DOC permit application was submitted and obtained for the red-fronted parakeets to compare the role

of pathogen load and strength of immune response in survival and dispersal following translocation among wild-caught individuals.

To compensate for the projects change in design, a proxy to captive-bred red-fronted parakeets and DOC's captive-breeding program for the critically endangered Malherbe's parakeet were judged to be an excellent and available proxy. Furthermore, a new translocation of captive-bred Malherbe's parakeets to Maud Island was taking place in February 2007, and I was able to incorporate this project into my PhD research. The one restriction was a limitation imposed by the DOC Recovery Group for the Malherbe's parakeet on the handling of the translocated individuals (i.e. capture, sampling etc.) as this species is critically endangered. Thus, this aspect of my PhD was restricted to field observations on the newly released parrots on Maud Island and PHA response could not be included. Nonetheless field-based research on such an unstudied species enabled me to providing information to refine translocation practices of parakeets in New Zealand. I aimed to document the breeding biology of captive-bred parakeets and conduct observations about their foraging behaviour following their release to the island. The DOC Nelson Area Office immediately provided permits I started fieldwork on Maud in March 2007. The Maud Island research provided the first ever documentation of breeding (including the entire nesting cycle) in the wild by captive-bred Malherbe's parakeets.

2. *Delays in permitting process (paucity of information on red-fronted parakeet translocations) and logistical and technical difficulties.*

   The permitting process for the translocations of red-fronted parakeets proposed by my study was substantially drawn-out (15 months) for a number

of reasons. Capturing and transferring 110 red-fronted parakeets to three sites around Auckland city (see Appendix 1) was considered risky by DOC. In particular, previous translocations of red-fronted, and yellow-crowned parakeets experienced high mortality during handling or aviary holding (cause unknown but assumed to be 'stress') and DOC were concerned this pattern would occur for my proposed project. No translocation of parakeets on this scale had ever taken place, and besides the capture and standard handling, a number of the caught parakeets would be handled further in order to assess their immune response. Given the limited information about translocations of this species (and in fact its general biology) and uncertainty about the technical challenges the project might convey, extensive consultation and revision was necessary prior to granting access to a source population.

Furthermore, the source population I proposed: Little Barrier Island had not been used as a source for translocations of fauna since 1995. Accessing Little Barrier Island and removing 110 red-fronted parakeets required consultation with the *iwi* Ngati Manuhiri and Ngati Wai alongside technical and scientific consultation. Staff from DOC, the then Auckland Regional Council (ARC), New Zealand Center for Conservation Medicine, Auckland Zoo (NZCCM), Ngati Manuhiri and Ngati Wai Trusts reviewed the proposal. The total time from submission for consultation to granting of the permit lasted fifteen months. Five months were necessary for the *iwi* consultation alone. Such extended consultation period was never anticipated. Demonstrating that I could coordinate a large-scale capture of parakeets without significant mortality was difficult despite having significant experience at successfully handling red-fronted parakeets as part of my MSc

(see Appendices 8 and 9). Finally, the successful results of a trip to Raoul Island (see next paragraph) aided the permitting process.

The opportunity arose to include red-crowned parakeets from Raoul Island into the PhD: specifically to determine baseline pathogens in another free-living population of the species (see Chapter 5). The March 2008 field trip to Raoul Island was coordinated by staff from DOC, Mark Hauber (co-supervisor) and research student Stefanie M. H. Ismar (both from Auckland University). Red-fronted parakeets were nowadays common on Raoul Island and capturing and processing health data on these parrots provided an important reference for the pathogen load analysis planned for Little Barrier Island. I took the leading role in this data collection, analysis and writing (see also section about *"Chapter outline and preparation of peer-reviewed papers"*) and this research formed part of my PhD thesis. The fieldtrip to Raoul Island was a success and I captured and sampled 100 parakeets without parrot mortality (see Chapter 2).

Nevertheless, during this extended permitting process period I conducted both the Maud and Raoul Island research, and gathered and published all the available information about recent translocations of red-fronted parakeets (including my previous research) and try to identify the factors that contributed more significantly to the success or failure of previous translocations (Appendices 8 and 9).

3. *Evidence of psittacine beak and feather disease (PBDF) on Little Barrier Island and mortality of parakeets during aviary holding.*

Permission to assess the strength of the immune response of a subgroup of parakeets was given on the condition that prior to injecting PHA to a group of parakeets I would inject a placebo to a single individual and demonstrate it did not suffer weight loss or death. During the first two days of capture on Little Barrier Island (May 2008), a number of parakeets were seen with feather abnormalities that appeared to conform to PBFD, a disease of parrots and allies caused by the Beak and Feather Disease Virus (BFDV) and was later confirmed by testing at New Zealand Wildlife Health Centre, Massey University (see Chapter 6). At the time, the disease was known to occur in aviary birds in the Auckland Region (Ha, Anderson et al. 2007) but no reports from native parrots existed. These observations represented an exciting but unanticipated development for my PhD research given its focus on the role of the natural load of pathogens in parakeets and its relationship to survival and dispersal following translocation. However, the most extreme cases of feather loss I observed on Little Barrier Island were so severe that the individuals could barely fly and for animal welfare and ethical reasons birds with severe feather abnormalities (see picture in Chapter 6) could not be included in any translocations and they sampled and then released back in site. Sample collection for *Salmonella*, *Yersinia* and *Campylobacter* was underway as part of the project (see Chapter 5) and a batch of 10 samples, including abnormal feathers was sent to the Equine Parentage and Genetic Services Centre, Massey Universtity in Palmerston North on May 9th. The Auckland Conservancy and DOC Head Office were notified immediately of the abnormal plumage of parakeets and the samples being sent for testing.

By May 13th we had captured 43 red-fronted parakeets that were kept in two aviaries awaiting transfer to Motuihe Island. Of these, eleven had been subjected to a PHA test following the success of the saline solution test (no weight loss over 24hours) of a single parakeet (see Appendix 7). The same day I found five dead parakeets in one of the aviaries. None of the dead individuals had been handled as part of the PHA test indicating that extended handling was not the likely cause of death. As part of the conditions of my research permit by DOC, the dead parakeets were sent for necropsy to the New Zealand Wildlife Health Centre, Massey University. The same day I received the test results for BFDV, confirming the presence of the virus in 5 individuals.

Prior to the discovery that the deaths were due to heavy metal poisoning from the new cages, a conservation approach was taken and stress of capture/handling/captivity was suspected and the remaining live birds were transferred and the PHA tests haltered. This followed urgent discussions with the rangers, my supervisor and staff from DOC to reach a consensus. Unfortunately, on May 14th, a further 10 parakeets were found dead and immediately all remaining live birds were captured and placed in transfer boxes and sent to Motuihe Island (see Chapter 3). Although the PHA test was suspended I did measure the immunocompetence of 11 parakeets (Appendix 7). The results of the necropsy on 15 parakeets revealed heavy metal poisoning in 13 individuals, all of which came from a single aviary. Two individuals had head traumas, possibly the result of hitting the aviary walls while flying to seek refuge.

The finding of heavy metal poisoning in parakeets was very controversial at the time. Legally, the results of the necropsies are the intellectual property of the Wildlife Health Centre, Massey University that carried out the analysis (under agreement with DOC) despite the material beiing collected as part of my project and the analyses funded by my PhD funds. Unfortunately an agreement on the use of these could not be reached to date (see Chapter 8). However, the mortalities of parakeets in the aviaries were not the result of mishandling but the holding cage design and materials and of direct relevance to improving translocation practices of parakeets in New Zealand.

Despite incomplete PHA trials, I had collected samples to test for bacterial pathogens (see Chapter 5) and I had evidence of beak and feather disease virus (BFDV) in a wild population (see Chapter 6). Further, I had evidence of lack of immune response on a parakeet infected with BFDV (see Appendix 7). These data provided the basis for a collaboration with staff from the University of Canterbury to molecularly characterize the strain of BFDV found on Little Barrier Island parakeets (Chapter 7).

4. *Loss of study site*

Although the translocation to Motuihe Isand and Tawharanui Regional Park proceeded, the translocation to Rakino Island was complicated by the absence of a community support group and private land ownership. I presented the project during a visit to Rakino Island and regular correspondence with landowners and DOC. By February 2008 we had the consent of 91 of the 92

landowners on Rakino Island but the view of the one dissenting landowner halted the translocation after 2 years of planning.

The last chance was to conduct the PHA test on a flock of parakeets destined to Tawharanui Regional Park and a fieldtrip to harvest parakeets on Little Barrier Island was hampered by bad weather. Nonetheless, I found funds to complete the lab work required to molecularly characterise the strain of BFDV found on Little Barrier Island and lab work started in May 2009 to compensate for the lost opportunity to measure immunocompetence in parakeets.

Given both constraints and opportunities outlined above, I re-structured my thesis as follows:

a) Document the natural re-colonisation of red-fronted parakeets on Raoul Island (chapter two)

b) Conduct a translocation of red-fronted parakeets from Little Barrier Island (a remnant population) to Motuihe Island (a restoring site) (chapter three)

c) Identify and characterise nesting sites and breeding behaviour of translocated captive-bred Malherbe's parakeets (chapter four)

d) Conduct a survey for selected bacterial and viral pathogens of conservation concern for New Zealand parrots (chapters five to seven)

Valuable management approaches have resulted from flexible research approaches that tackle unanticipated issues as they appear in the course of a given

parrot conservation project (Snyder, Wiley et al. 1987; Juniper 2002). As difficulties and opportunities arose in the course of my own project, I kept such perspective in mind. To make the most of the data resulting from a multifaceted project ranging from natural history data, reproductive biology and preliminary research about pathogens among native New Zealand parrots, I re-structured my thesis as described above. The common thread between such seemingly disparate themes was the need to provide basic management recommendations for the improvement of parakeet conservation in particular and New Zealand parrots in general (see Chapter 8).

Chapter outline and preparation of peer-reviewed papers

My PhD was submitted as a thesis based on publications, in accordance with the terms outlined in the Handbook for Doctoral Study, Massey University. Except for the introduction and general discussion chapters, the thesis is presented as a series of published peer-reviewed papers. As explained in previous section, the original project experienced multiple challenges leading to changes in research approach. To effectively tackle the number of issues and opportunities arising during my research I reached out for multiple collaborations with individuals from a number of institutions around New Zealand and overseas. The collaborations that have resulted have been lead by me and resulted in multiple co-authored publications. My leading role in all cases consisted included preparation of the permits for data collection (see Appendix 1), obtaining funds for data analysis, taking the leading role in data analysis and interpretation, manuscript preparation and dealing with all comments, suggestions and criticisms brought up by editorial panels of the six papers that conform this thesis plus

two book chapters (Appendices 2 and 3) and four other peer-reviewed papers included as Appendices 4 to 7. Detailed contributions for each chapter follow.

Chapter two has been published in the peer-reviewed journal *Conservation Evidence*. This paper introduces a key concept for the management of New Zealand red-fronted parakeets: the potential of recolonisation following the eradication of introduced predators. In addition to my supervisors, this paper was published with two other co-authors: Stefanie M. H. Ismar (The University of Auckland) and Karen Baird (Department of Conservation). Both co-authors assisted with field data collection in the remote Kermadec Archipelago. Their previous work on that area made it possible to visit Raoul Island and helped put the paper in the context of island conservation. The same input was provided for the preparation of chapter five. For this paper I was responsible for data collection on Raoul Island. I coordinated the capture and sampling of parakeets in the field with the assistance of a team of 2-4 volunteers. The idea for this paper was my own and accordingly I prepared the manuscript, circulated it to co-authors and coordinated and decided on the in the inclusion of comments and suggestions for the final draft. I then dealt with all the editorial requirements and corrected the page proofs.

Chapter three has also been published in the journal *Conservation Evidence*, co-authored with my supervisors. This paper is linked to chapter two as it describes the successful translocation of red-fronted parakeets to an area free of introduced mammalian predators and their subsequent un-assisted dispersal to a nearby site. The fieldwork associated with this paper made it possible to develop three other chapters. For this paper, I was responsible for the organisation of the required fieldtrips, parakeet capture and data collection. I was also responsible of data analysis and

manuscript preparation. As with the previous and following chapters, I dealt with the editorial comments from submission to publication of the work.

Chapter four has been published in the peer reviewed *Australian Journal of Zoology*. This chapter documents the breeding biology of captive-bred Malherbe's parakeets and discusses a common feature found among translocated populations of New Zealand parakeets: the diversity of nesting sites used by breeding pairs. This paper was co-authored with Jonathan Kearvell (Department of Conservation) who provided perspective and assistance with data collection in the field. John also provided numerous unpublished observations of mainland Malherbe's parakeets; necessary for preparing a comprehensive discussion on this critically endangered species. I was responsible for permit preparation, organisation of fieldtrips to Maud Island, data collection (i.e. observations of parakeets) database keeping and data analysis as well as preparation of the manuscript and the subsequent addressing of comments by the editorial panel and review of page proofs.

Chapter five has been published in the peer reviewed *New Zealand Journal of Zoology*. During the translocations described in chapter three, samples were collected for analysis of naturally occurring pathogens among parakeets. To maximise the scope of this paper, another co-author was invited to collaborate: John Ewen (Zoological Society of London). John had previously screened parakeets for bacterial parasites and his experience was important to delineate the relevance of negative findings in the context of parakeet management and translocation of birds in New Zealand. I was responsible of data collection on Little Barrier Island, Raoul Island and Tiritiri Matangi Island. I was also in charge of literature review and data analysis as

well as preparation of the manuscript. I also dealt with editorial comments and reviewing page proofs.

Chapter six has been published in the journal *Emu: Austral Ornithology.* In this paper, the first evidence of beak and feather disease virus (BFDV) occurring in a wild parakeet population in New Zealand is presented. This paper was co-authored with Kate McInnes (DOC). Kate assisted with data collection in the field and funding for analyses in chapter six and chapter seven. Once more, I was responsible for data collection and interpretation of the test results. I was also in charge of preparing the manuscript for publication and dealt with editorial comments and reviewer's criticisms.

Chapter seven has been published in the journal *Archives of Virology*. This paper describes BFDV genomes found in parakeets sampled during the research described in chapters three and six. This paper is co-authored with seven colleagues. In addition to my supervisors and Kate McInnes, co-author from chapter six, this paper benefited from the input of Melanie Massaro and Arvind Varsani from the University of Canterbury, Brigitta Kurenbach from Genøk Centre for Biosafety and Darren P. Martin from the University of Cape Town. These co-authors assisted with the processing of a large number of samples in the lab and the associated electrophoresis analyses. Also, they assisted with the analysis of results.

Finally, chapter eight identifies and discusses lines of research necessary for an integrated approach to the conservation of New Zealand native parakeets with special emphasis on management of BFDV. For this paper, I was responsible for data collection and lab work at the University of Canterbury and preparation of the manuscript. Given the authority of Arvind Varsani in the field of virus research, we

agreed on having him as the author for correspondence. Both Arvind and I dealt with the editorial comments from submission until the publication of the paper.

Chapter structure

Chapters two to seven are reprints of published papers in peer-reviewed journals. The journal page number appears either in the bottom center of the page, upper left hand side, or upper right hand side. The page numbers referred to in the table of contents is displayed in the lower right hand side throughout the thesis. The material in all chapters has been prepared following the journal guidelines and as a result section headings and the use of common names differs between chapters. For instance, in all but chapters two and three there is a "methods" section. In chapters two and three this section equals to "action" in accordance to the manuscript guidelines from this journal. Despite these differences, every chapter consists in general of an abstract, introduction, methods, results and discussion.

The internationally accepted "red-fronted parakeet" (www.birdlife.org) has been used for chapters one, three, six, seven and eight. However, in chapters two and five the common name used within New Zealand "red-crowned parakeet" has been preferred following advice from journal editors and colleagues as the material was published in a more "local" journal. In chapters one, four, seven and eight the internationally accepted "Malherbe's parakeet" (www.birdlife.org) has been used. Also the species is also known as "orange-fronted parakeet" or "orange-fronted kakariki" the internationally accepted name was used following advice from the journal editor.

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CHAPTER TWO

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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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.

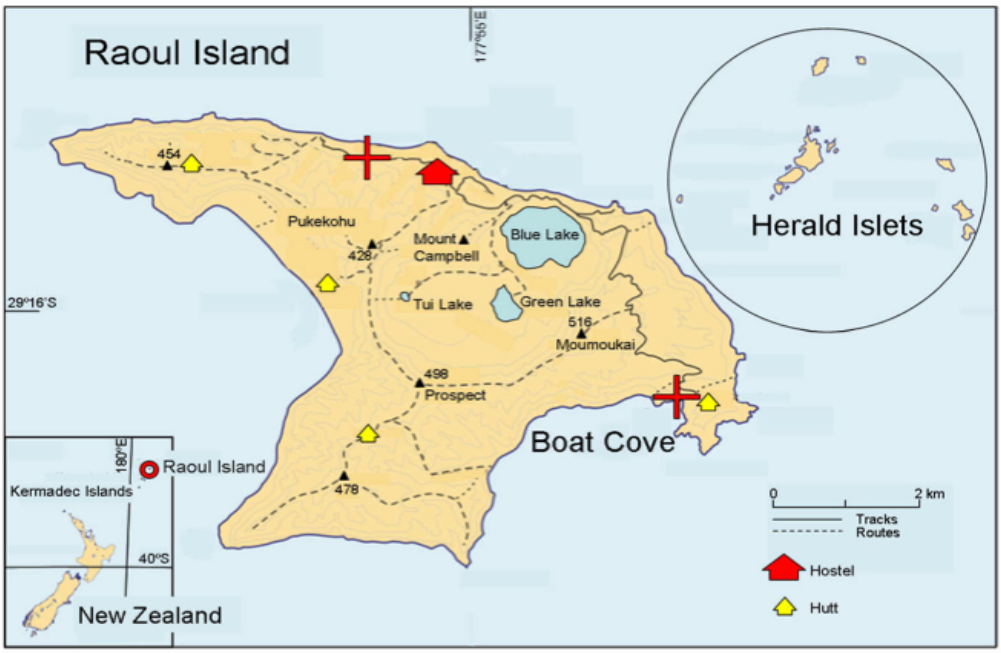

Figure 1. Raoul Island: a remnant population of Kermadec red-crowned parakeets persisted on the neighbouring Herald Islets before the eradication of cats and rats on Raoul Island. The two sampling locations during the study are marked by the red crosses.

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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CHAPTER THREE

Success of translocations of red-fronted parakeets *Cyanoramphus novaezelandiae novaezelandiae* from Little Barrier Island (Hauturu) to Motuihe Island, Auckland, New Zealand

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Success of translocations of red-fronted parakeets *Cyanoramphus novaezelandiae novaezelandiae* from Little Barrier Island (Hauturu) to Motuihe Island, Auckland, New Zealand

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SUMMARY

The red-fronted parakeet *Cyanoramphus novaezelandiae* is a vulnerable New Zealand endemic with a fragmented distribution, mostly inhabiting offshore islands free of introduced mammalian predators. Four populations have been established since the 1970s using captive-bred or wild-sourced individuals translocated to islands undergoing ecological restoration. To establish a new population in the Hauraki Gulf, North Island, a total of 31 parakeets were transferred from Little Barrier Island (Hauturu) to Motuihe Island in May 2008 and a further 18 in March 2009. Overall 55% and 42% of individuals from the first translocation were confirmed alive at 30 and 60 days post-release, respectively. Evidence of nesting and unassisted dispersal to a neighbouring island was observed within a year of release. These are outcomes are promising and indicate that translocation from a remnant wild population to an island free of introduced predators is a useful conservation tool to expand the geographic range of red-fronted parakeets.

BACKGROUND

The avifauna of New Zealand is presently considered to be the world's most extinction-prone (Sekercioglu *et al*. 2004). Currently, 77 of approximately 280 extant native species are considered threatened of which approximately 30% are listed as Critically Endangered (Miskelly *et al*. 2008). Many successful conservation programmes in New Zealand have involved the eradication of introduced mammalian predators such as feral cats *Felis catus*, Pacific rat (or kiore) *Rattus exulans*, ship (black) rat *R. rattus* and brown (Norway) rats *R. norvegicus*, and subsequent translocation to establish additional populations of threatened native species (Armstrong & McLean 1995, Veitch & Bell 1990). Here we report the recent translocation of red-fronted parakeets *Cyanoramphus novaezelandiae novaezelandiae* from a remnant natural population on Little Barrier Island (or Hauturu) to an island free of mammalian predators and undergoing ecological restoration, Motuihe Island.

Little Barrier Island (c. 3,000 ha; 36°12'S, 175°04'E) lies in the Hauraki Gulf approximately 80 km north of Auckland City (North Island), and is New Zealand's oldest wildlife reserve, established in 1894 (Cometti 1986). The island is covered mostly by regenerating coastal and kauri *Agathis australis* forests (Hamilton 1961). Little Barrier Island holds a great diversity of native New Zealand birds including threatened species such as hihi *Notiomystis cincta*, kokako *Callaeas cinerea* and North Island brown kiwi *Apteryx mantelli* (Robertson *et al*. 2007).

Motuihe Island (180 ha), located 15 km east of Auckland City, is currently the focus of a community-led restoration project in partnership with the New Zealand Department of Conservation (DOC). This restoration

involved eradication of four introduced mammal species: brown rat, house mouse *Mus musculus*, feral cat and European rabbit *Oryctolagus cuniculus* (Hawley 2005, Veitch 2002). Also invasive exotic weeds such as barberry *Berberis glaucophylla* and banana passionfruit *Passiflora tripartita* are the target of ongoing vegetation management (Hawley 2005). Revegetation using native plant species has been a major component of the project. The reintroduction of native avifauna is yet another aspect of the restoration of Motuihe and 17 species have been identified as suitable for translocation (Hawley 2005). The first bird species to be translocated to Motuihe was North Island saddleback *Philesturnus rufusater* in 2005 (Parker & Laurence 2008).

The red-fronted parakeet, listed as 'Vulnerable' (www.iucn.org, www.birdlife.org), was identified as a potential species to be translocated to Motuihe Island because of its generalist dietary and nesting requirements, and because of previous successful transfers to other sites (McHalick 1999). Red-fronted parakeets have been successfully translocated to at least four offshore islands subject to rehabilitation since the 1970s (Dawe 1979, Higgins 1999). Historically, the species was widespread throughout New Zealand but it is at present confined to offshore islands (Juniper & Parr 1998, Robertson *et al*. 2007). Red-fronted parakeets make use of diverse nesting sites in regenerating vegetation, grasslands and forest remnants (Ortiz-Catedral & Brunton 2009). Thus, the species is considered suitable for translocation to sites with fragmented native vegetation communities, which is often the case on offshore and mainland islands subject to restoration efforts throughout New Zealand (Saunders & Norton 2001). Invasive species and large-scale habitat modification were also involved in the disappearance of the nominate subspecies *C. n. novaezelandiae* throughout New Zealand (Higgins 1999) and other *Cyanoramphus* taxa in the South Pacific (Taylor 1979, Hicks & Greenwood 1989).

ACTION

In 2006, an initiative to translocate red-fronted parakeets from Little Barrier Island to Motuihe Island was prepared by the Motuihe Island Trust, DOC and the authors. This initiative was consulted and approved by representatives of the local Maori *Iwi* community *Ngati Manuhiri* and *Ngati Wai*. Motuihe was considered an appropriate site for release as it is free of introduced mammals and has suitable habitat for parakeets, including fragments of remnant coastal forest, re-vegetated patches and grassland. The translocation of parakeets to Motuihe was also considered to be beneficial as it was hypothesised by the authors that it would facilitate natural dispersal of parakeets to neighbouring islands undergoing ecological restoration such as Rangitoto, Motutapu and Rakino. The Motuihe Trust raised NZD $ 28,482 to cover the costs associated with capture, pathogen screening, radio transmitters and transport of the parakeets.

Capture of parakeets: We captured parakeets on Little Barrier Island using mist-netting techniques based on previous sampling of the species in New Zealand (Ortiz-Catedral *et al*. 2009a). The capture aimed to reach a target number of 50 individuals (25 males, 25 females). This number was decided after consultation with DOC, *iwi* and the Motuihe Island Trust. Mist-netting took place from 6 to 16 May 2008, approximately two months after the end of the breeding season of the species (Ortiz-Catedral 2006). Parakeets were captured between 06:00-11:00 h and 15:00-18:00 h. Every parakeet was ringed with a single numbered steel ring and one to three coloured plastic bands (according to DOC regulations), and feather, blood and cloacal swab samples were collected for analysis of naturally occurring pathogens (Ortiz-Catedral *et al*. 2009b, Ortiz-Catedral *et al*. 2009c). Sex was determined by measuring the culmen (Sagar 1988). After processing, parakeets were transferred to an aviary built on site, and held in captivity for up to 6 days while additional parakeets were captured.

The aviary measured approximately 3 x 5 x 2 m high. Its interior was densely covered with branches of kanuka *Kunzea ericoides* and fronds of nikau *Rophalostylis sapida* and ponga *Cyathea dealbata*. Also, curtains made of plastic mosquito net (50 cm width x 50-80 cm length) were hung from the ceiling approximately 80 cm apart to provide a soft barrier to prevent flying parakeets from hitting the aviary walls. Clean water and a mix of suitable food (freshly chopped apple *Malus domestica*, green peas *Pisum sativum*, corn *Zea mays*, grapes *Vitis* sp. and millet *Sorghum* sp. sprays) were provided *ad libitum*.

When at least 15 parakeets were captured, the birds were transferred to individual pet-carry boxes (measuring approximately 25 x 35 x 20 cm) lined with kanuka branches. Water, millet

and a piece of raw corn were also provided. The boxes were loaded onto a helicopter and flown from Little Barrier to Motuihe (approximately 30 min). On arrival, members of the Motuihe Trust, Ngati Wai and members of the public transferred the boxes to an area of remnant forest where the birds were released.

In March 2009, another field trip to Little Barrier Island was organised to attempt to capture additional parakeets to reach our planned target of 50 individuals. From 3-9 March we captured 19 parakeets (9 males, 10 females) using the same techniques as the previous year; these were transferred in a single helicopter trip to Motuihe. On arrival, one of the females appeared very weak and unable to fly, and it was flown back and released on Little Barrier Island.

Monitoring: On the morning of the transfer, a 2 g single-stage transmitter (Holohil Systems Ltd., Ontario, Canada) was mounted on two central tail feathers of 12 individuals. After release, parakeets were radio-tracked once per week for three months, and once every two weeks for another four months. Once located, parakeets were observed from distances of 25-30 m and their unique band combination recorded. Parakeets were also searched for by walking along the tracks on the island, and also around the coastline at low tide. Searches for potential breeding pairs continued up to five months after release in and around gullies on the island known to contain potential nesting trees, such as pohutukawa *Metrosideros excelsa*, puriri *Vitex lucens* and ti kouka *Cordyline australis*. Identification of breeding pairs and inspection of nest cavities followed methods used in other parakeet populations throughout New Zealand (Ortiz-Catedral & Brunton 2009, Ortiz-Catedral *et al.* 2010).

CONSEQUENCES

Survival and establishment: A total of 32 parakeets (16 males, 16 females) were caught and transfered in three helicopter trips on 14 and 17 May 2008 (15, 13 and 4 parakeets/trip, respectively). One female died shortly after arrival on Motuihe. Post-mortem revealed head trauma and concurrent infection of beak and feather disease virus (BFDV) and avian malaria (*Plasmodium relictum*) (Ortiz-Catedral, unpubl.). Seventeen (55%) of the 31 remaining parakeets were observed alive and their band combinations recorded 30 days after release, including 10 of the parakeets with transmitters. One of the transmitters was located high on a tree and remained in exactly the same position for two months, suggesting it had fallen off the bird and lodged in vegetation. Another transmitter was lost within a week of release but it is unclear if the transmitter failed or if the parakeet flew away from the island. At 60 days after the release, 13 individuals were recorded alive (42%) including 10 with transmitters. It is likely that the survival was higher than recorded given the numerous sightings of parakeets whose band combinations could not be accurately recorded.

One nest was found five months after release (October 2008) in a cavity on a dead branch of a puriri tree. Eight months after release two family groups were recorded: one consisting of three unbanded juveniles and an adult, and another of two adults and a juvenile. Another, 18 individuals were released on Motuihe in March 2009, bringing the total number of translocated parakeets to 49 (25 males, 24 females). This second flock of parakeets was not monitored immediately after release due to limited funds.

Dispersal to other islands: Within a year of the first release, sightings of parakeets on adjacent island sites such as Rangitoto and Motutapu Islands were reported. On 29 November 2009, we visited Motutapu (less than 1 km away from Motuihe) and recorded a male released on Motuihe eight months earlier paired with an unbanded adult female and accompanied by three recently fledged juveniles. We also recorded a dead, unbanded adult on Motutapu, but it is unclear if it hatched at this site or if it originated from Motuihe. Conservation volunteers working on Motuihe and Motutapu Islands have reported sightings of banded and unbanded parakeets indicating survival of members of the founder flocks and locally hatched parakeets.

Costs: The overall cost per parakeet transferred from Little Barrier Island to Motuihe Island was $580 NZD (approximately € 298). The cost included screening for selected pathogens such as *Campylobacter*, *Salmonella*, *Yersinia*, *Plasmodium* and BFDV (see Ortiz-Catedral *et al.*, 2009a, 2009d for details). Also, the funds were used to cover the food and accommodation of teams of 14-16 volunteers involved in the capture, processing and care in the aviary of parakeets, as well as transportation to and from Little Barrier Island by boat and helicopter.

Discussion and conclusions: Our observations on Motuihe Island show that wild parakeets are able to survive and successfully pair after translocation to a restoring ecosystem free of introduced mammalian predators. It is still unclear what founder number is the minimum required to establish a new population via translocation. Previous translocations of the species have released between 30 and 80 individuals (McHallick 2005), thus our founder flock can be seen as intermediate in terms of numbers of released parakeets. The number of parakeets released on Motuihe appears to have been enough at least for the short-term establishment of an additional population of red-fronted parakeets, and successful breeding has been confirmed.

Experience from another translocated population indicates that the long-term persistence of parakeets on Motuihe is likely. On Tiritiri Matangi Island, 80 captive-bred parakeets were released between 1974 and 1976 (Dawe 1979; Higgins 1999). The Tiritiri Matangi population has persisted for 36 years without management intervention, and recent research indicates periodic breeding (Ortiz-Catedral & Brunton 2008) and local recruitment of juveniles into the breeding population (Ortiz-Catedral 2006). The translocation of wild red-fronted parakeets to Motuihe was an inexpensive exercise considering the benefits obtained, which include an additional population of a vulnerable species, natural dispersal to a nearby restoring site (Motutapu Island), and the opportunity to engage scientists and conservation volunteers in a translocation project with potential for education and scientific research.

The translocations of red-fronted parakeets may also serve as a model for management of closely related threatened parakeets, such as the Norfolk Island green parakeet *Cyanoramphus cookii*, a species with a current population of around 160 individuals (Hill 2002).

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CHAPTER FOUR

Breeding biology of the critically endangered Malherbe's parakeet on Maud Island, New Zealand, following the release of captive-bred individuals

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Breeding biology of the critically endangered Malherbe's parakeet on Maud Island, New Zealand, following the release of captive-bred individuals

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Abstract. We studied a population of the critically endangered Malherbe's parakeet (*Cyanoramphus malherbi*), following the release of 62 captive-bred individuals on Maud Island, New Zealand, to identify and characterise nesting sites in a novel island environment. Previous work on Malherbe's parakeets consisted of limited observations on remnant mainland populations. The age of breeding pairs on Maud Island was 7.2 ± 4.7 months and included both captive-bred individuals of the first release flock and individuals hatched on Maud Island within a year of the first release. Nests were found in hollows of mamaku (*Cyathea medullaris*), vacant nests of sacred kingfisher (*Todiramphus sanctus*), a hole in the ground and a hollow in a kohekohe (*Disoxylum spectabile*). Active nests were found in the austral spring, summer and autumn. Clutch size was 5 eggs. The fledging of three Malherbe's parakeets was confirmed for one nest 43 days after hatching. Observations of newly fledged individuals around the island indicate that at least seven successful nesting attempts occurred. Consistent with other studies in *Cyanoramphus* parakeets, our results suggest that availability of nesting sites on small islands may not be a limiting factor for the establishment of additional populations of Malherbe's parakeets via captive breeding and translocation. The formation of breeding pairs at an early age, the use of diverse nesting sites in regenerating vegetation, and the evidence of successful breeding shortly after release on an island represent encouraging prospects for the conservation of New Zealand's rarest parakeet.

Additional keywords: captive breeding, conservation, parrot, translocation.

Introduction

Phenotypic plasticity of colonisers of a novel environment can produce adaptive and maladaptive responses that contribute to the likelihood of successful establishment and persistence of new populations (Yeh and Price 2004). Translocations are artificially induced colonisations, and thus adaptive and maladaptive behaviours in founder groups can occur. Phenotypic plasticity might be low in species of conservation concern owing to reduced genetic diversity of remnant individuals (Frankham 1995). Reduced plasticity is particularly worrying among captive breeding programs for endangered species, since the offspring available for translocations are often produced by a limited number of breeding pairs. The Malherbe's parakeet (*Cyanoramphus malherbi*; also known as orange-fronted parakeet or orange-fronted kakariki) has recently been elevated to full species status on the basis of mitochondrial DNA analysis (Boon *et al.* 2000) and it is New Zealand's most threatened parakeet. It is listed as critically endangered, with ~200–300 individuals restricted to natural remnant populations in three valleys in the Canterbury region, plus two recently translocated populations on Chalky Island in Fiordland, and on Maud Island in the Marlborough Sounds (Grant and Kearvell 2001; Gaze and Cash 2008). Field observations suggest that habitat destruction and predation of nesting birds by introduced predators such as mustelids (*Mustela* spp.) and rats (*Rattus* spp.) have played a significant role in the decline of Malherbe's and other *Cyanoramphus* parakeets (O'Donnell 1996; Higgins 1999; Grant and Kearvell 2001).

Since 2005, the Department of Conservation (DOC), New Zealand, has coordinated the reproduction and translocation of Malherbe's parakeets bred at the Isaac Wildlife Trust, a captive-breeding facility in Christchurch, New Zealand (Grant and Kearvell 2001). Avian island translocations represent a very active area of conservation in New Zealand (McHalick 1999; Taylor *et al.* 2005) and various endemic species have significantly recovered after such management (Hooson and Jamieson 2003). Offshore predator-free islands are thus considered crucial for the recovery of Malherbe's parakeet via captive breeding and

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translocation. Nevertheless, the response of a critically endangered mainland parakeet species translocated to an island environment has not been formally evaluated. Gaining basic information about the breeding response of translocated Malherbe's parakeets can provide a useful proxy to determine whether or not captive breeding and release is a sound strategy likely to increase the species' population size and downgrade its extinction risk.

Prior to our research there has been only one study at a mainland site, documenting nesting sites of Malherbe's parakeets (Kearvell 2002) but information about the biology of Malherbe's parakeets is non-existent for island environments. Since the first release on Maud Island, we have monitored translocated Malherbe's parakeets with the aim of identifying the nesting sites of this species on an island and to document aspects of its breeding biology. Our research provides new data about the breeding biology of this rare and elusive species that can be used to refine current recovery actions towards species conservation, site choice for translocation and habitat management.

Methods

Study site and species

Between March 2007 and December 2008, DOC released onto Maud Island 62 parakeets of known sex and age bred at the Isaac Wildlife Trust, Christchurch. From March 2007 to January 2009 we visited Maud Island approximately every second month to study parakeets (18 visits in total). Each visit lasted one to two weeks. Maud Island (41°1′28″S, 173°53′19″E) is a 296-ha Scientific Reserve managed by DOC in the Marlborough Sounds of the South Island of New Zealand. The vegetation consists of regenerating manuka (*Leptospermum scoparium*) and kanuka (*Kunzea ericoides*) scrub (220 ha), remnant native broadleaf coastal forest (47 ha), introduced Radiata Pine (*Pinus radiata*) forest (17 ha) and grassland (12 ha) (Fig. 1).

Malherbe's parakeets are small (23 cm), and mostly green in colour, with a narrow band of orange feathers above the culmen, and a yellow crown (Forshaw 2006). As in other *Cyanoramphus* species, juveniles are identified by their colour of their culmen (pale pink to pale grey in juveniles, bluish-grey with a dark tip in adults) and legs (pale pink in juveniles, dark grey in adults) (Higgins 1999). Both sexes have an orange patch on either side of the rump. The frontal orange band and the rump patches are considered the diagnostic features of the species. Sexes are monochromatic to human eyes, but males are slightly larger than females. They resemble the yellow-crowned parakeet (*C. auriceps*), but the latter have red patches on the sides of the rump and a narrow red band above the culmen (Juniper and Parr 1998). Males of Malherbe's parakeets also have shorter bills (Young and Kearvell 2001).

Focal breeding pairs

Every parakeet was given a unique numbered steel band and colour combination by DOC before release. Twenty individuals

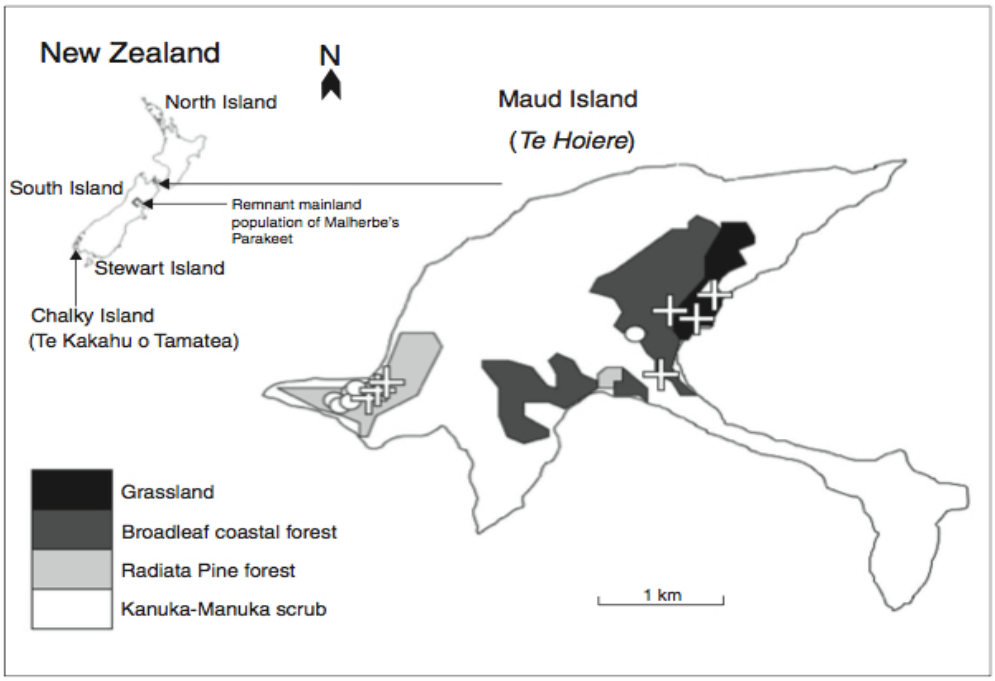

Fig. 1. Location map showing present populations of Malherbe's parakeet (arrows) and map of Maud Island showing vegetation types and location of active nests (white circles) and sighting locations of unbanded parakeets (white crosses).

also had a single-stage transmitter (Holohil Systems Ltd, Ontario, Canada) weighing 2 g (less than 5% of the bird's body mass) mounted on two central tail feathers. The transmitters were later dropped during moult. Individuals were radio-tracked at least once per week for the duration of the transmitter's battery life (~3 months). Their location was determined by homing the signal strength and registered on a GPS 60™ (Garmin International, Kansas). Once located, observations on parakeets were recorded from a distance of 25–30 m to minimise disturbance.

We considered as focal breeding pairs two individuals (male–female) seen together for at least two consecutive weeks. None of the released birds had bred before. Focal breeding pairs without transmitters were found opportunistically by walking the entire track network during each visit to Maud Island. Other endangered taxa, such as the Maud Island frog (*Leiopelma pakeka*), the takahe (*Porphyrio mantelli*) and, intermittently, the kakapo (*Strigops habroptilus*), inhabit forested patches of Maud Island. To avoid disturbing breeding habitat of these species, areas of remnant forest were avoided in accordance with DOC regulations. This resulted in biased search effort towards accessible areas of the island, but we considered this to be a reasonable compromise, given the critically endangered status of the species, the limited information available about its breeding behaviour and the ethical requirement to keep disturbance of a recently reintroduced population to a minimum.

Nest variables and nesting habitat

We classified nests as 'potential' or 'active'. Potential nests were cavities around which prospecting behaviours common to other *Cyanoramphus* species were noticed (see Greene 2003; Ortiz-Catedral and Brunton 2009*a*). Active nests were those where eggs or chicks were confirmed and the resident female presented a clear brood patch or courtship feeding was observed. These behaviours are also regularly used during the successful location and protection of wild Malherbe's parakeet nests on the New Zealand mainland.

Nests were not always accessible. Accessible nests were on stable terrain, allowing measuring of variables without compromising the structure of the nest, the fate of the nesting attempt and the safety of observers. Non-accessible nests were located either on fragile terrain, such as steep sandy banks or high in dead branches of trees. The only variables measured in non-accessible nests were aspect (in degrees using a compass) and tree species surrounding the nest. For all nests, the plant species within a radius of 5 m were also recorded. We searched for focal breeding pairs and nests year round.

For accessible nests (active and potential), we recorded the following variables: plant species and status (dead or alive); diameter at base of nest-bearing plant (DBP, cm); diameter at nest entrance of nest-bearing plant (DNE, cm); height of the nest-bearing plant (cm); length and width of nest entrance (cm); and depth to nest chamber (cm). We also recorded habitat variables within a 25-m^2 plot around the nest following Rayner *et al.* (2007): slope (in degrees using an inclinometer); aspect (holding a compass at the centre of the plot); plant species and status (dead or alive); plant height (m); diameter at breast height (DBH) of woody shrubs and trees with DBH >2 cm; and canopy and understorey cover under four predefined categories: (1) 0–25%, (2) 26–50%, (3) 51–75%, and (4) 76–100%. All nest and habitat measurements were taken after fledging of chicks or failure of the nesting attempt.

Accessible nests were inspected only after females left the nest to be fed by males, a common behaviour in other *Cyanoramphus* parakeets (Greene 2003; Ortiz-Catedral and Brunton 2009*a*). We checked the nests with an extendable mirror and a flashlight, or using a fibrescope (ProVision 636, Tactical Solutions Corp., Auckland). The onset of egg-laying date was estimated by back-dating clutches assuming a two-day interval between laid eggs, as in the red-fronted parakeet (*Cyanoramphus novaezelandiae*) (Ortiz-Catedral and Brunton 2009*a*). The age of nestlings was estimated by looking at their feather development and comparing it to known-age chicks of the red-fronted parakeet (Ortiz-Catedral 2006). Nests were inspected only three times during the nesting cycle to minimise the chances of nest desertion. Close to the expected fledging of chicks (40–50 days after hatching), we opened a lateral access hole to weigh and band the chicks. A removable cover was attached to protect the hole and prevent rain entering the nest cavity. This cover consisted of two layers of synthetic butyl rubber Butynol® (Ardex, New Zealand) wrapped around the nest-bearing plant. We frequently use this type of cover to monitor natural nests of the red-fronted parakeet on Tiritiri Matangi Island and have not recorded any nest-desertion or failure associated with this procedure in five years of research. After modification of the nest, we did not record discernible behavioural changes in breeding pairs of Malherbe's parakeets. Handling of chicks was restricted to a single event, and disposable latex gloves were worn by the handler.

We recorded behaviours of parakeets to determine the approximate stage of breeding. New Zealand parakeets display similar stereotypical behaviours during different stages of the breeding cycle (described in detail in Higgins 1999). We used these behaviours to locate nests or distinguish between incubating and brooding pairs in other parakeet populations and species. We observed nests from hides 5–25 m away, depending on the features of the terrain. The duration of observations was affected by weather conditions as most nests were located in steep unstable terrain and heavy rain or wind would make it unsafe for observers. Observation periods were variable, ranging from 1 to 7 h between 0600 and 1900 hours. We recorded the band combination of every individual observed at the nest or within the visual radius from the observation point (5–30 m) and determined the total duration of its visit to the nest area. We determined time spent inside and outside the nest by females and the frequency of visits by males during egg-laying. We distinguished feeding or non-feeding visits by males. During feeding visits, females emerged from the nest after arrival of calling males and food transfer was directly observed or the characteristic food-soliciting soft whines of females were heard. After food transfers, or when the female stopped whining, the pair allopreened, foraged together in nearby plants or females would fly straight back to the nest. This behaviour is similar to that of closely related species such as yellow-crowned parakeets and red-fronted parakeets (Higgins 1999). During non-feeding visits, females remained inside the nest or exited for brief periods (<1 min) to preen with males. For one breeding

pair, we also recorded the duration of feeding visits to chicks. The frequency of nesting behaviours was recorded as hourly rates. We classified breeding pairs as 'captive pairs' (both members of the pair were captive-bred and released on the island), 'mixed pairs' (one member was captive-bred, while the other was either unbanded, or a banded wild-bred parakeet from a known nest on the island) or 'wild pairs' (both members were unbanded and were hatched on the island). Prior to the release of Malherbe's parakeets on Maud Island, there was no resident population of the species at this site. For every focal pair observed we confirmed all the diagnostic features of Malherbe's parakeet. Thus, we are confident that our classification of unbanded Malherbe's parakeet as fledged on Maud Island is reasonable. Data are presented as means ± standard deviation, ranges and coefficients of variation.

Results

Nesting sites and nest site characteristics

We found eight nests, of which six were active and two were potential nests. Active nests were located in spring, summer and autumn, while prospecting behaviours were noted around potential nests in winter (Table 1). Active nests belonged to captive pairs found within two months after release ($n = 3$), two wild pairs and one mixed pair. The male of this latter pair was banded and fledged from the only successful nest found in 2007 (Table 1). Since all pair members of four of these nests were banded and of known hatch date, we estimated the average age of these breeding pairs when first sighted as 7.2 ± 4.7 months (Table 1).

Five of the active nests and the two potential nests were located in steep gullies on the west side of Maud Island along an ~500 × 100-m-long strip. The predominant vegetation along this strip consists of a plantation of Monterey/radiata pine (*Pinus radiata*) mixed with native trees and shrubs (Fig. 1). The other active nest was found on the east side of the island in a remnant of coastal forest dominated by nikau (*Rhopalostilis sapida*), kohekohe (*Disoxylum spectabile*), titoki (*Alectryon excelsus*), kawakawa (*Macropiper excelsum*) and mahoe (Fig. 1).

Five nests (three active and two potential) were accessible. However, measuring of nest variables was possible only in four nests located inside dead stems of mamaku (New Zealand black fern, *Cyathea medullaris*). The other nest (from a mixed pair) was located in a hole at ground level formed by the roots of a fallen tutu (*Coriaria arborea*) but it collapsed due to heavy rain before it could be measured. Nest variables of active and potential nests were comparable (Table 2). The three non-accessible nests were found in a dead branch of a kohekohe (one nest) and in vacant nesting holes excavated in soil banks by sacred kingfisher or kotare (*Todiramphus sanctus*) (two nests). The nesting habitat was variable in terms of composition and structure, with DBH showing the greatest coefficient of variation (Table 3). Only 13% of stems of measurable DBH were dead ($n = 16$; stems standing alive $n = 127$).

Copulation, egg laying, clutch size and hatching success

Copulation was observed during egg-laying in two instances involving two breeding pairs. Males perched in or next to the nest entrance and called softly for ~1 min until the female emerged, then both flew immediately to a branch 12–15 m away from the nest and 3–5 m above the ground. Females crouched with their tails slightly upwards and uttered a high-pitched begging call for ~1 min. Males jumped between branches forming a 20-cm-radius circle around crouching females and uttered soft calls continuously. When females stopped calling, males climbed on their backs and lowered their tails slightly. Copulation lasted 20–30 s. Males descended from the females' back and silently perched next to the females after copulation, or both flew to a different branch where preening occurred for a few seconds to 10 min. In both cases, females returned to the nest immediately after and males left the area calling. Copulations were observed on 27 April 2007 at 1250 hours and on 27 November 2008 at 1053 hours.

Eggs were confirmed in three active nests. The resident females at the other three active nests had a visible brood patch, but the nest contents could not be observed. Egg-laying started synchronously on 25 April for two nests found in 2007, both with a clutch size of five. For the last nest found during our study, we estimated 20 January as the beginning of egg laying. Final clutch size could not be determined since the resident female was still laying eggs during our last field trip to Maud Island. She had a partial clutch of two at the time of our observations. Hatching success of the two 2007 clutches was 100%.

Table 1. Nests of Malherbe's parakeet (*Cyanoramphus malherbi*) on Maud Island (2007–09)
EL, egg laying; NP, nest prospecting; A, active; P, potential; C, captive pair; W, wild pair; M, mixed pair (see Methods for description)

Nest	Month	Stage	Notes	Pair	Age (months) (male/female)	Evidence
Kohekohe[A]	April 2007	EL	A	C	4.9/4.7	Brood patch[B]
Mamaku 1	April 2007	EL	A	C	4.7/4.7	Eggs seen
Mamaku 2	April 2007	EL	A	C	4.7/4.8	Eggs seen
Mamaku 3	June 2007	NP	P	C	6.8/6.9	Nest inspection[B]
Mamaku 4	June 2007	NP	P	C	7.8/7.9	Nest inspection[B]
Ground	March 2008	EL	A	M	13.2/16.2	Brood patch[B]
Kingfisher 1[A]	November 2008	EL	A	W	Unknown	Brood patch[B]
Kingfisher 2[A]	January 2009	EL	A	W	Unknown	Eggs seen

[A]Non-accessible nests.
[B]Females escorted by a male. Note: Pair from Mamaku 2 is the same prospecting pair in Mamaku 3 and 4.

Table 2. Active and potential nest cavities used by Malherbe's parakeets on Maud Island between 2007 and 2009

DNE, diameter of nest entrance; DBH, diameter at breast height; DBP, diameter at base of plant

Variable	Active nest		Potential nests	
	Mean ± s.d.	c.v.	Mean ± s.d.	c.v.
DBP (cm)	22.65 ± 0.07	0.01	17.45 ± 1.34	0.08
DBH (cm)	21	0	16.80 ± 2.97	0.18
DNE (cm)	20.5 ± 2.12	0.1	15.05 ± 4.88	0.32
Height (m)	1.845 ± 0.15	0.08	2.84 ± 0.90	0.32
Depth (cm)	100 ± 70.71	0.71	202.25 ± 25.10	0.12

Table 3. Characteristics of habitat surrounding nests of Malherbe's parakeets on Maud Island

Variable	Mean ± s.d.	Range	c.v.
No. of woody species	5.2 ± 1.92	3–8	0.37
No. of stems >2 cm DBH	25 ± 14.22	6–43	0.56
Height of stems (m)	3.85 ± 1.52	0.6–10.57	0.39
Understorey cover	2.4 ± 0.89	1–3	0.37
Canopy cover	3 ± 0.70	2–4	0.23
DBH (cm)	13.44 ± 13.88	2.1–73.2	1.03
Aspect (degrees)	322 ± 20.18	295–350	0.06
Slope (degrees)	43.8 ± 2.49	40–46	0.06

Male visits to nesting females, nesting cycle and outcome of nesting attempts

During egg-laying, males visited females 0.39 times h^{-1} for feeding visits and 0.43 ± 0.42 times h^{-1} for non-feeding visits (n = 25 observation periods, five focal nests). Females left the nest only when their partners arrived in the area (n = 34, six focal nests) except for two cases. Overall, females stayed outside the nest for 17. 52 ± 20.60 min (range 1–90 min, n = 36 six focal nest watches). Females spent 60.33 ± 37.67 min (range 10–132 min, n = 14 focal nests watches) inside the nest between visits by males. In one nest, feeding visits to chicks lasted 3 ± 1.15 min (range 2–4 min, n = 2 nest watches). Both parents fed the brood.

The nesting cycle lasted 65 days from egg laying to fledging and was recorded in only one nest inside a mamaku stem. The clutch in this nest (5 eggs) hatched after ~22 days of incubation. All nestlings within the brood had a similar size and degree of feather down development, indicating low hatching asynchrony. Three chicks (60%) fledged 43 days after hatching. One chick was found dead with an empty crop at the bottom of the nest and another hanging upside-down from one of the walls of the nest. One of its legs was stuck between the hard fibres of the mamaku stem. The remaining active nests either failed or had an unknown outcome. Failed nests included one inside a mamaku stem where the entire brood starved, one ground nest that collapsed after heavy rain and a nest inside a vacant sacred kingfisher nest where egg remains were found outside of the nest due to unknown reasons.

Recently fledged juveniles were awkward fliers and remained in the vicinity of the nest for about four weeks, often perching silently until parents returned to feed them. Eight weeks after fledging, two banded siblings were seen foraging with a banded non-parent individual ~700 m from their nest. Around 16 weeks after fledging, one banded juvenile was seen together with its parents, who were prospecting for a new nest. The parents chased this juvenile away and resumed prospecting behaviour. Another four recently fledged unbanded juveniles and six unbanded adults were seen in different locations around the island (Fig. 1). Given the limited mobility of fledglings within a month after fledging, it is likely that their nest of origin was in the vicinity of the sighting locations. It was difficult to determine whether these represent one or more broods. Conservatively assuming that the four fledglings were from two broods, the minimum number of successful nesting attempts is seven.

Discussion

The recent recognition of Malherbe's parakeet as a distinct species and its status as in severe decline has resulted in emergency conservation actions such as translocation of captive-bred offspring. These actions aim to expand the geographic range of the species and to increase its global population size in island refuges safe from alien nest predators (Grant and Kearvell 2001). Our study represents the first attempt to gain information about the breeding biology of this species at a novel island site. We found that Malherbe's parakeets successfully breed at an early age using diverse nesting sites and shortly after release to a new site. The use of diverse nesting sites suggests that these might not be limiting for establishment of new populations of Malherbe's parakeets. Unbanded individuals found throughout our study indicate successful breeding. However, as only one successful breeding attempt was directly observed, it is difficult to establish whether the outcome of nesting attempts is related to characteristics not measured during our study.

A high proportion of parrots studied in the wild so far are secondary cavity nesters and commonly reach sexual maturity after several years (Powlesland *et al.* 1992; Koenig 2001; Murphy *et al.* 2003). Both of these features predispose them to high extinction risk (Bennett and Owens 1997). Consequently, nest and nesting habitat management is an important part of the recovery programs of endangered species, such as the Norfolk Island green parakeet (*Cyanoramphus cookii*) (Hicks and Greenwood 1989; Hill 2002), the Mauritius parakeet (*Psittacula eques*) (Butchart *et al.* 2006; Tatayah *et al.* 2007) and the Puerto Rican parrot (*Amazona vittata*) (Snyder *et al.* 1987; White and Vilella 2004).

On Maud Island, Malherbe's parakeets used nesting sites not previously documented for this species such as cavities in dead stems of mamaku, a hole in the ground and vacant nesting holes excavated by sacred kingfishers. These nesting sites were surrounded by regenerating vegetation, indicating that remnant mature forested habitat is not a necessary requirement for successful nesting. Most importantly, successful hatching of two clutches occurred shortly after release onto a new site and breeding pairs were less than one year old. These observations indicate that captive-bred Malherbe's parakeets have high reproductive potential on an offshore island. Other island populations of *Cyanoramphus* have been established using captive-bred individuals, for instance red-fronted parakeets on

Tiritiri Matangi Island, near Auckland, New Zealand (Higgins 1999). In that population, parakeets used natural nests as well as nest-boxes, and there is no evidence that nest type affects nesting success (Ortiz-Catedral and Brunton 2009*a*). Our limited data on Malherbe's parakeets are insufficient to determine whether or not direct management of nesting sites (i.e. nest-box provisioning) is required on Maud Island to enhance breeding success of the species. There is evidence (direct and indirect) of successful breeding on Maud Island, but it is unclear whether reproductive success at this site is comparable to that of remnant populations on mainland New Zealand and its relationship to available nesting sites.

The use of captive-bred psittacines for reintroduction has been widely discussed due to the popularity of parrot species in aviculture and the high proportion of endangered species in the group (Wiley *et al.* 1992; Brightsmith *et al.* 2005). One common concern is the potential for behavioural maladaptation of captive-bred individuals that might lower the chance of success of their breeding attempts in the wild (Collazo *et al.* 2003). In general terms, pairs of Malherbe's parakeets on Maud Island exhibited behaviours common to other *Cyanoramphus* species. During egg laying and incubation, females in our study mostly left their nests while the male was present, a common feature of wild Malherbe's parakeets and red-fronted parakeets (Greene 2003). Although our observations on breeding pairs are limited and restricted to the nesting cycle, we did not notice maladaptive behaviours that might explain failed breeding attempts. Instead, failed nesting attempts resulted from heavy rain and brood failure, both causes also documented in wild (Greene 2003) and translocated (Ortiz-Catedral and Brunton 2008) populations of red-fronted parakeets.

Our observations of nesting innovations by Malherbe's parakeets can be considered good indicators of flexibility in nesting behaviour of a critically endangered species, which, together with other factors, can explain its establishment on Maud Island. Research on reintroduced birds has shown that species with greater foraging innovations show a higher probability of establishing at a new site (Sol *et al.* 2002). Further, sedentary and broad-diet parrot species show higher establishment success in novel environments (Cassey *et al.* 2004). For Malherbe's parakeets, we have preliminary evidence of consumption of novel dietary items such as fruits and leaves of introduced plant species on Maud Island (Ortiz-Catedral and Brunton 2009*b*) previously unknown from studies on the mainland (Kearvell *et al.* 2002). Thus, rather than finding discernible breeding maladaptations within a population established using captive-bred parakeets, we have evidence of behavioural flexibility that can be used in conservation planning to improve the recovery of the species.

Translocations of captive-bred individuals have resulted in two populations of Malherbe's parakeets, on Chalky and Maud Islands. Although our results indicate that remnant forest and specific nesting cavities are not a requisite for successful breeding of translocated pairs, the precarious state of Malherbe's parakeet is a call to strategic research. We recommend that future research focus on measuring reproductive parameters of translocated populations to predict the recovery potential of the species under current management, and to realistically evaluate the contribution of captive-breeding and translocation to islands to the conservation of New Zealand's rarest parakeet species.

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CHAPTER FIVE

No evidence of *Campylobacter*, *Salmonella* and *Yersinia* in free-living populations of the red-crowned parakeet (*Cyanoramphus novaezelandiae*)

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No evidence of *Campylobacter*, *Salmonella* and *Yersinia* in free-living populations of the red-crowned parakeet (*Cyanoramphus novaezelandiae*)

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Abstract Screening for pathogenic micro-organisms is an essential component of translocation-based conservation management. While there are some data on pathogens in New Zealand passerines, little is known about the distribution and prevalence of pathogens infecting New Zealand Psittaciformes. We conducted a survey for pathogens of the vulnerable New Zealand endemic red-crowned parakeet *Cyanoramphus novaezelandiae* in two wild populations (Little Barrier Island and Raoul Island), and in a translocated population (Tiritiri Matangi Island). A total of 101 cloacal samples were tested for *Salmonella* and *Yersinia*. Of these, 82 samples were also tested for *Campylobacter*. None of these micro-organisms were detected. Although our sampling effort was insufficient to detect a low prevalence of *Campylobacter*, modelling of minimum detectable prevalence of *Salmonella* and *Yersinia* indicates that these micro-organisms would have been detected if present as common or chronic conditions of red-crowned parakeets at these sites.

Keywords *Campylobacter*; New Zealand; parakeet; pathogen; *Salmonella*; translocation; *Yersinia*

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INTRODUCTION

Pathogens have major impacts on wild animal populations, and are often introduced to them as a consequence of human activities (e.g., avian malaria in Hawaii (van Riper et al. 1986)). However, data on the prevalence and impact of pathogens are limited for most wild species. This is of concern because pathogens are increasingly cited as major threats to the process and outcome of conservation efforts (Daszak et al. 2000; Cleveland et al. 2002; Tompkins & Poulin 2006).

Translocation is a conservation tool providing an example of a human activity that may significantly alter species density at source populations and species composition at release sites (Armstrong & McLean 1995). Any potential spread of pathogens caused by translocation is therefore directly relevant to the conservation concerns of wildlife managers (Cunningham 1996).

In addition to the threat of introducing exotic microbes during handling and transport, pathogens may also limit the success of a translocation if: (i) released animals are faced with a novel structural and

social environment which, linked with stress, leads to infection by opportunistic pathogens (Alley et al. 1999); (ii) translocations induce artificial bottlenecks associated with reduced immunocompetence, with the result that translocated populations are placed at increased susceptibility to infection (Briskie & Hale 2006); and (iii) translocated individuals are exposed to novel pathogens (Low et al. 2005; Ewen et al. 2007). To deal effectively with pathogen threats in endangered species managed using translocations, there needs to be focused research documenting the range of pathogens infecting the species both at the source location and following their release.

There is limited information on pathogenic threats to translocation operation for New Zealand birds (e.g., Parker et al. 2006; Ewen et al. 2007) and reptiles (e.g., Gartrell et al. 2006; Gartrell et al. 2007). For example, the only information published on the pathogens of New Zealand Psittaciformes is for the flightless endangered kakapo (*Strigops habroptilus*) (Brangenberg et al. 2003; Gartrell et al. 2005).

The red-crowned parakeet (*Cyanoramphus novaezelandiae*) is a species listed as Vulnerable (V) by the International Union for the Conservation of Nature (IUCN) (www.iucn.org). This species, formerly found throughout New Zealand, currently has a fragmented distribution stretching from the Kermadec Islands group, through the North and South Islands, to Stewart Island and the sub-Antarctic Island groups (Juniper & Parr 1998). It has been translocated to several locations, mostly around the Hauraki Gulf (Higgins 1999), and is also commonly kept in aviaries for display at zoos or by individuals under specific Department of Conservation holding permits.

A recent translocation of red-crowned parakeets from Little Barrier Island to Motuihe Island provided an opportunity to record baseline data on the cloacal pathogens of this natural population. We also present results from previous surveys of this species on Little Barrier Island, Tiritiri Matangi Island and Raoul Island. *Campylobacter*, *Salmonella* and *Yersinia* were selected for surveillance, as they have been identified as casual agents of diseases of concern to the New Zealand avifauna (Johnstone 1993; Jackson et al. 2000).

METHODS

Red-crowned parakeets were captured using mist-nets placed along opportunistically observed flying paths and foraging grounds on Little Barrier Island (3000 ha) (36°12′S, 175°04′E) and Raoul Island (2925 ha) (29°15′S, 177°55′W) during three sample collection events. Ten red-crowned parakeets were sampled on Little Barrier Island during February 2005 were part of a mist-netting project documenting haemoparasites of the genera *Plasmodium*, *Haemoproteus and Leucocytozoon* among New Zealand forest birds. A further 50 red-crowned parakeets were sampled during March 2008 as part of a translocation taking birds from Little Barrier Island to Motuihe Island. Samples from Raoul Island (n = 19) were collected in March 2008. Finally, 22 samples were collected on Tiritiri Matangi Island (220 ha) (36°36′S, 174°53′E) during February 2009. One adult male was captured by hand at the nest entrance, while the other 21 samples were collected from approximately 25- to 45-day-old nestlings sampled at the nest from six broods. Samples from Raoul and Tiritiri Matangi Islands were collected as part of an ongoing project surveying for avian malaria, beak and feather disease virus (BFDV) and other pathogens at these and other locations throughout New Zealand (Ortiz-Catedral et al. 2009).

All cloacal pathogen samples, except those from Raoul Island, were collected using sterile transport swabs (Copan, Italy) and kept refrigerated until analysis (5–7 days after collection). Transport constraints from the remote Kermadec Islands to mainland New Zealand meant that samples from Raoul Island had to be kept at ambient temperature for 3 weeks after collection.

Little Barrier Island samples were cultured for *Campylobacter*, *Salmonella* and *Yersinia*, while those from Raoul Island were cultured only for *Salmonella* and *Yersinia*. Non-refrigerated samples are more likely to return false negatives for *Campylobacter*, but *Salmonella* and *Yersinia* are robust organisms and have been isolated from other samples kept in similar ambient conditions (Karen Cooper, Gribbles Veterinary Pathology, pers. comm.). Tiritiri Matangi Island samples were combined into a single brood sample prior to culture. All cultures were analysed at a commercial facility (Gribbles Veterinary Pathology, Auckland).

Salmonella culture

Samples were inoculated into Xylose-Lysine-Desoxycholate (XLD) and Hektoen agars and Selenite-F and/or Rappaport (RVS) selective broths. Agar and broths were incubated at 35–37°C for up to 48 h. The enrichment broths were sub-cultured after 24 h incubation at 35–37°C onto XLD and Hektoen

agars. All suspect colonies were identified using Microbact™ MB12A biochemical identification kits (Li et al. 1988) as per manufacturer's instructions and confirmed by serology at the Enteric Reference Laboratory at Environmental Science and Research (ESR), Wellington.

Campylobacter culture

Samples were inoculated onto Cefoperazone, Amphotericin and Teicoplanin media (CAT) media and *Campylobacter* enrichment broths, and were incubated at 42°C for up to 7 days. The enrichment broths were sub-cultured on CAT agar after 24 h incubation and then discarded. This sub-culture was then also incubated for up to 7 days at 42°C. Any suspect colonies were identified by Gram stain reaction and morphology, oxidase reaction, sensitivity to cephalothin and naladixic acid, hippurate hydrolysis, growth at 25°C, nitrate and hydrogen sulphide production.

Yersinia culture

Yersinia isolation media was incubated at 28°C for up to 48 h. Any suspect colonies were identified using Microbact™ MB24E biochemical identification kits (Ling et al. 1988) as per manufacturer's instructions.

We calculated the minimum detectable prevalence (MDP) of *Salmonella*, *Yersinia* and *Campylobacter* at our study sites using the hypergeometric exact probability formula of Freecalc version 2.0. (Aus Vet, Animal Health Services, Australia) following Gartrell et al. (2007). *Salmonella* is important to the pig industry, so the sensitivity and specificity of multiple culture media for identifying it has been extensively studied (van Winsen et al. 2001; Michael et al. 2003). Reported values for sensitivity vary from 36 to 92%, and specificity from 91 to 100% (Michael et al. 2003). For our models, we assumed a conservative scenario of 50% sensitivity and 90% specificity of culture tests *Campylobacter*, *Salmonella* and *Yersinia* at the 95 and 99% confidence interval (CI).

We assumed a population size of 400 red-crowned parakeets on Tiritiri Matangi Island, and 6000 each on Little Barrier and Raoul Islands, based on an extrapolation from the minimum density of breeding pairs on Tiritiri Matangi Island (1 pair/ha) (L. Ortiz-Catedral unpubl.) to the area sampled. Although there are no precise estimates of population sizes of red-crowned parakeets or prevalence of these micro-organisms in them, these conservative hypothetical values provide a useful initial framework to identify research needs in the area of pathogen screening and avian translocations in New Zealand.

RESULTS

No *Salmonella* or *Yersinia* species were cultured from cloacal samples from Little Barrier Island, Raoul Island or Tiritiri Matangi Island. Similarly, no *Campylobacter* species were cultured from cloacal samples from Little Barrier Island or Tiritiri Matangi Island. The MDP of these micro-organisms varied from 1% on Little Barrier Island (99% CI), 6.7% on Tiritiri Matangi Island (95% CI) and 11.5% (95% CI) on Raoul Island.

DISCUSSION

Health monitoring of captive parrots has previously reported positive diagnoses for *Salmonella*, *Campylobacter* and *Yersinia*, often from post-mortem analysis (Dorrestein et al. 1985; Yogasundram et al. 1989; Ward et al. 2003). In contrast, wild parrot populations have rarely been surveyed for pathogens (Deem et al. 2005) and, to our knowledge, there are no published reports on the incidence of *Salmonella* or *Yersinia* in wild psittacines. *Campylobacter* has been isolated in parrots of the genera *Ara*, *Brotogeris* and *Pionites* in the Peruvian Amazon (Tresierra-Ayala & Bendayan 1998). Our results are consistent with the only other large-scale study of the incidence of *Salmonella* and *Campylobacter* in the kakapo, which reported no positives (Brangenberg et al. 2003).

Our negative results do not necessarily mean these pathogens are not present in these populations, or that these populations are not at risk. Our modelling of MDP indicates that our sampling effort was insufficient to detect either of these micro-organisms at prevalence levels lower than our MDP threshold values (1, 6.7, and 11.5%). Only on Little Barrier Island does our sampling appear representative enough to consider detecting *Salmonella*, *Yersinia* and *Campylobacter* at very low prevalence levels. Our results do suggest, however, that these pathogens are not present as a common and chronic condition at these three sites.

Nevertheless, the risk of infection of native New Zealand parrots by several pathogens still exists, given the number of infection pathways to which individuals are exposed, including avicultural escapees, introduced passerines, and the known sharing of feeding grounds with exotic psittacines (Jackson

et al. 2000). Sulphur-crested cockatoos (*Cacatua galerita*), crimson and eastern rosellas (*Platycercus elegans* and *P. eximius*) and galahs (*Eolophus roseicapillus*) are exotic psittacines which are now widely distributed in New Zealand, and which coexist with native psittacines (Heather & Robertson 1996; Robertson et al. 2007). The risk these exotic species pose as reservoirs of disease is currently not known, and requires study of both the prevalence and health effects of target pathogens in potential reservoir hosts. This is relevant both where exotic host species currently coexist with red-crowned parakeet (such as on Tiritiri Matangi Island) and, more importantly, where these exotic species are present at proposed release sites for translocated red-crowned parakeets.

The costs associated with adequate sampling for *Salmonella*, *Yersinia* and *Campylobacter* can be high. Thus, we advocate experimental studies on the sensitivity of culture tests and alternatives (e.g., molecular screening) for these micro-organisms in the New Zealand avifauna, in order to develop cost-effective screening techniques to be included in translocation programmes. In addition, estimates of numbers of birds available in source populations that might be harvested for translocations should include better planning of micro-organism sampling schemes.

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CHAPTER SIX

First report of beak and feather disease virus (BFDV) in wild red-fronted parakeets (*Cyanoramphus novaezelandiae*) in New Zealand

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First report of beak and feather disease virus (BFDV) in wild Red-fronted Parakeets (*Cyanoramphus novaezelandiae*) in New Zealand

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Abstract. Psittacine beak and feather disease (PBFD) is a highly infectious and potentially fatal viral disease of parrots and their allies caused by the beak and feather disease virus (BFDV). Abnormal feather morphology and loss of feathers are common clinical symptoms of the disease. PBFD also damages the lymphoid tissue and affected birds may die as a result of secondary bacterial or fungal infections. The disease is therefore of concern for conservation biologists and wildlife managers, as it is immunosuppressive and can become an additional threatening factor among critically endangered psittacines. We conducted a PCR-based screening for BFDV in a wild population of the Red-fronted Parakeet (*Cyanoramphus novaezelandiae*) on Little Barrier Island, New Zealand, during a translocation of this species. Fifty-four parakeets were captured and feather samples collected for molecular screening. We detected BFDV DNA from 15 individuals, but only two showed external signs attributable to PBFD, namely abnormal feather morphology or colouration, loss of feathers and haemorrhagic feathers. Our survey represents the first positive identification of BFDV in wild New Zealand endemic psittacines and confirms the risk of spread of the virus between wild populations within this global hotspot of endemic psittacine diversity.

Additional keywords: PBFD, parrot, pathogen, translocation.

Introduction

Psittacine beak and feather disease (PBFD) is a highly infectious viral disease of parrots, cockatoos and their allies (Psittaciformes). The causative agent of the disease is a *Circovirus*, the beak and feather disease virus (BFDV) (Ritchie *et al.* 1989). BFDV has been reported in more than 10% of all known parrot species (Gerlach 1994). The most common clinical signs include weight loss, anaemia, damage of the lymphoid tissue, abnormal plumage and morphological development, and feather loss (Pass and Perry 1984; Ritchie *et al.* 1989). In some clinical cases, particularly in cockatoos (Cacatuidae), abnormal beak development is also associated with PBFD (Pass and Perry 1984). Immunosuppression is often linked with PBFD and affected birds may suffer secondary fungal and bacterial infections leading to death (Todd 2000). PBFD has been widely reported in captive psittacines (Tomasek and Tukac 2007), in wild psittacine populations in Australia and Africa (Paré and Robert 2007) and in feral populations of introduced Eastern Rosellas (*Platycercus eximius*) and Sulphur-crested Cockatoos (*Cacatua galerita*) in New Zealand (Ha *et al.* 2007).

Our current knowledge of the population-level effects of PBFD is limited. PBFD outbreaks in aviaries have been reported around the world (Khalesi *et al.* 2005) and the disease is known to cause mortalities in the avicultural industry in South Africa (Heath *et al.* 2004). Although there are no documented extinctions of parrots attributable to PBFD, the disease can become a further threatening process and increase the risk of extinction of critically endangered taxa by increasing mortality rates of infected individuals. For example, BFDV has been identified in 18% of the remaining endangered Mauritius Parakeets (*Psittacula echo*) and infected Parakeets have a mortality of 83% (Malham *et al.* 2008). Thus, a BFDV outbreak has the potential to hamper conservation management and recovery efforts of threatened psittacines.

All native parrot species found in New Zealand are endemic to the archipelago and numerous populations inhabit small

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geographical ranges. For instance, Reischek's (*Cyanoramphus hochstetteri*) and Antipodes (*C. unicolor*) Parakeets are restricted to the Antipodes Islands (200 ha) and Chatham Parakeet (*C. forbesi*) is found only on Mangere and Little Mangere Islands (130 ha) in the Chatham Islands Group (Juniper and Parr 1998). Formerly widespread species, such as the Kakapo (*Strigops habroptilus*) and the Orange-fronted Parakeet (*Cyanoramphus malherbi*), are now considered critically endangered (Hitchmough 2002). BFDV has not been detected previously in any free-living New Zealand native parrot despite an initial screening on 168 samples from five species (Ha 2005). However, the high prevalence of BFDV among introduced psittacines (Ha *et al.* 2007) raises concerns about the pathogenicity and potential spread of the virus to native species.

The Red-fronted Parakeet (*Cyanoramphus novaezelandiae*) is an endemic New Zealand species listed as Vulnerable by the International Union for the Conservation of Nature (www.iucn.org, accessed 1 April 2009). Red-fronted Parakeets are mostly restricted to offshore islands free of predators (Juniper and Parr 1998). The species has been translocated to several locations, mostly around the Hauraki Gulf of the North Island (Higgins 1999) and is commonly kept in captivity, in zoos and private aviaries under New Zealand Department of Conservation (DOC) holding permits. A recent translocation of Red-fronted Parakeets from Little Barrier Island to Motuihe Island (L. Ortiz-Catedral, D. H. Brunton and M. E. Hauber, unpubl. data) provided an opportunity to carry out a PCR-based survey for the presence of BFDV on Little Barrier Island. While BFDV has been reported in the closely related Tasman Parakeet on Norfolk Island (*Cyanoramphus cookii*) (Hill 2002) it is not known if the virus is present in wild populations of other *Cyanoramphus* species.

Methods

Red-fronted Parakeets were captured between 6 and 16 May 2008 using mist-nets placed along known flight paths or foraging grounds on Little Barrier Island (36°12′S, 175°04′E). All individuals were placed in a black cotton bag for processing. To minimise cross-contamination in the field (i.e. via feather dust from another individual), cotton bags were used only once and washed in Trigene® (MediChem International, Kent, UK) before further use. All Parakeets were banded with a numbered metal band, and each was examined for signs of abnormal plumage development and feather loss. Two morphologically or chromatically abnormal feathers were collected in Parakeets showing irregular plumage development or loss. For individuals that appeared normal, two feathers from the ventrum were collected. All feather samples were placed in individual paper envelopes and stored at room temperature. DNA extraction and BFDV testing were conducted at a commercial laboratory (Equine Parentage and Genetic Services Centre, Massey University, Palmerston North, New Zealand). DNA extraction followed the methodology described in Ha *et al.* (2007). Molecular screening for BFDV followed the methodology described in Ritchie *et al.* (2003*a*) using a positive control (M. Houston, Equine Parentage and Genetic Services Centre, Massey University, pers. comm.). Detection of BFDV via PCR was chosen as it provides a fast and reliable diagnostic tool to process a large number of samples when compared with haemagglutination tests (Khalesi *et al.* 2005). The sex of individuals was also determined using PCR alongside the detection of BFDV, following Griffiths *et al.* (1998).

Results and discussion

BFDV DNA was confirmed in 15 of the 54 samples tested (28%; 9 of 32 females, 6 of 22 males). Two individuals (both males) that tested positive for BFDV, showed some characteristics attributable to the chronic form of the disease including haemorrhagic feathers, abnormally coloured feathers around the head (green feathers turning yellow), morphologically aberrant feathers (lack of barbs along the rachis) and unusual patterns of feather loss. Both these birds lacked tail feathers and more than 50% of the head was featherless (Fig. 1). The condition of the plumage and feather morphology of the other 13 Parakeets testing positive for BFDV was indistinguishable from BFDV negative individuals, suggesting a subclinical infection. All Parakeets testing negative for BFDV showed no signs of abnormal plumage or feather development.

One caveat of our study is that it was not feasible to perform histopathological tests in the field for a full clinical diagnosis of PBFD of all the specimens captured. Abnormalities and loss of feathers similar to those associated with PBFD can be caused by avian polyomavirus, adenovirus, folliculitis, malnutrition and endocrine abnormalities (Ritchie *et al.* 2000). Thus, histopathological examination of skin biopsies for detection of inclusion bodies is recommended (Ritchie *et al.* 2000). Regardless of the ultimate cause of the excessive feather loss noticed in two individuals, the detection of BFDV DNA in a wild endemic New Zealand parrot raises several conservation concerns.

Our survey confirms that Red-fronted Parakeets are susceptible to infection by BFDV and exhibit symptoms attributable to the chronic form of PBFD. A previous large-scale PCR-based screening for BFDV did not detect it in 168 samples of native New Zealand psittacines, including Red-fronted Parakeets from Tiritiri Matangi Island (Ha 2005), a translocated population ~40 km south of Little Barrier Island (Higgins 1999). The finding of BFDV in a natural offshore island population of parakeet and the lack of records of established feral introduced parrots on Little Barrier Island suggest this might be a native New Zealand viral strain. However, several potential transmission paths for a non-native strain exist. One of these is the movements of another parrot inhabiting Little Barrier Island, the Kaka (*Nestor meridionalis*). Kaka are known to fly long distances between remnant populations on mainland New Zealand and offshore islands (Sainsbury *et al.* 2006) and could come into contact with either Eastern Rosellas or Sulphur-crested Cockatoos on nearby mainland North Island. Another potential infection path is via field equipment used at other sites and brought to the island. However, strict quarantine and equipment cleaning protocols enforced by the DOC before arrival on Little Barrier Island minimise this risk, in particular treatment of field equipment and clothing with Virkon® and Trigene®. A potential third infection path includes the illegal release of captive-bred Red-fronted Parakeets and aviary escapes in the Auckland region.

Fig. 1. A Red-fronted Parakeet (male) showing extreme loss of feathers attributable to the chronic form of PBFD: abnormal feather morphology (white arrow), severe feather loss (over 50% of head) and haemorrhagic feathers (black arrow). Photo: L. Ortiz-Catedral.

Three BFDV lineages have been found in New Zealand companion parrots (Ritchie *et al.* 2003*a*) but whether or not these strains can infect native New Zealand psittacines is not known. Furthermore, nothing is known about the pathogenicity of each of these variants. BFDV is putatively highly recombinant (Heath *et al.* 2004) and mixed infections of two PFBD variants have been reported in lovebirds (*Agapornis*) (Ritchie *et al.* 2003*b*). Consequently, infection may be by any of the three variants already known from New Zealand, and variants yet to be identified. Thus DNA sequencing of the viral genotype found on Little Barrier Island is a priority line of research. In addition, we recommend wider geographical surveillance for BFDV throughout free-living populations of New Zealand psittacines, particularly in populations adjacent to endangered parrot taxa, for a better assessment of transmission risk and identification of transmission paths. Finally, we advocate continuing research on Little Barrier Island to determine the population effects of BFDV in Red-fronted Parakeets.

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CHAPTER SEVEN

A new isolate of beak and feather disease virus from endemic wild red-fronted parakeets (*Cyanoramphus novaezelandiae*) in New Zealand

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ANNOTATED SEQUENCE RECORD

A new isolate of beak and feather disease virus from endemic wild red-fronted parakeets (*Cyanoramphus novaezelandiae*) in New Zealand

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Abstract Psittacine beak and feather disease (PBFD) is a viral disease distributed worldwide with a potentially critical impact on many rare parrots. While efforts have been made to determine its prevalence in wild and captive psittacines, only limited work has been done to document complete genomes of its causative agent, beak and feather disease virus (BFDV). Here, we describe five full genomes of BFDV isolated from wild specimens of an endemic New Zealand parrot, the red-fronted parakeet (*Cyanoramphus novaezelandiae*). The isolates share >99% nucleotide similarity amongst themselves and ~91–92% similarity to BFDV isolates from southern Africa, Europe and Australia. A maximum-likelihood (ML) phylogenetic tree including 42 other full-genome sequences indicated that the five isolates from red-fronted parakeets represent an undescribed genotype of BFDV. These isolates are evolutionarily most closely related to the Cacatuini isolates from Thailand and the Lorinae isolates from Australia in the *rep* gene ML tree; however, in the *cp* ML tree, the evolutionary relationship is closer to viruses found in the Psittacini.

Psittacine beak and feather disease (PBFD) is a common viral infection affecting parrots and cockatoos (Aves: Psittaciformes) [19] that has been reported in approximately 40 species in captive and wild populations worldwide [4]. PBFD is characterised by weight loss, development of morphologically abnormal feathers, feather loss and anaemia in affected birds [16, 20]. In severe cases, especially amongst cockatoos, beak deformities have also

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been reported [16]. The disease manifests in the lymphoid tissues, leading to immunodeficiency and a decrease in body condition, and secondary bacterial and fungal infections can occur as a result, often leading to death [21, 26]. Psittacine beak and feather disease virus (BFDV) is a member of the family *Circoviridae*, genus *Circovirus* [2]. This genus includes several species of avian and porcine viruses [2]. Circoviruses are non-enveloped, are 14–16 nm in diameter, and have a circular ssDNA viral genome. The two major open reading frames (ORFs) encode the replication-associated protein (Rep) and the capsid protein (CP) [2, 14]. While there is limited information on BFDV infection rates and associated mortality for wild populations, the disease is known to affect wild psittacines in Australia, New Zealand and southern Africa [6, 8, 10, 17, 19]. PBFD is of conservation concern, as it has the potential to increase the extinction risk of endangered psittaciform species by decreasing survival rates of infected individuals amongst remaining captive or wild populations. Thus, ongoing monitoring for the virus is recognised as a key action to identify and implement measures to limit the potentially threatening impact of the disease on endangered psittacines [6, 8, 15, 21].

In New Zealand, BFDV has been reported in populations of introduced eastern rosellas (*Platycercus eximius*) and sulphur-crested cockatoos (*Cacatua galerita*) as well as in captive rainbow lorikeets (*Trichoglossus haematodus*), yellow-bibbed lorikeets (*Lorius chlorocercus*), Goldie's lorikeets (*Psitteuteles goldiei*), blue-streaked lorikeets (*Eos reticulata*), long-billed corellas (*Cacatua tenuirostris*) and budgerigars (*Melopsittacus undulates*) [6, 21]. Despite various surveys and efforts to monitor BFDV infections in New Zealand, only partial sequences of the CP and/or the replication protein have been documented [21]. Hence, the full-length sequences of BDFV genotypes circulating in New Zealand are unknown. Recently, BFDV was detected in a wild population of an endemic New Zealand parrot, the red-fronted parakeet (*Cyanoramphus novaezelandiae*) at a prevalence of 28% [15].

In this study, we characterise the complete genomes of BFDV isolated from wild red-fronted parakeets and investigate their phylogenetic affinities to isolates from around the world. This is the first study documenting full BFDV genomes from New Zealand. Red-fronted parakeets were captured using mist nets placed around foraging grounds on Little Barrier Island (36°12′S, 175°04′E; 3,000 ha) [15]. Fifty-four blood samples (700 µl each) were collected by venipuncture of the brachial vein of parakeets and placed in Queen's lysis buffer [22]. Five red-fronted parakeet samples that tested positive for BFDV [15] were used to isolate, clone and sequence full BFDV genomes. Total DNA was extracted from 60 µl of blood using the Qiagen QIAamp DNA minikit (Qiagen, Germany) according to the manufacturer's protocols. The genomes of the BFDVs were amplified using non-specific rolling-circle amplification using Phi29 polymerase (TempliPhi™ kit, GE Healthcare) as described by Shepherd et al. [23]. The resulting amplified BFDV genome concatemers were linearised to unit-length genomes (~2 kb) by *Bam*HI restriction digestion. The monomeric genomes were ligated to pGEM®-3Zf(+) (Promega Biotech) and sequenced at Macrogen Inc (Korea) by primer walking. The resulting sequences were assembled and edited using DNAMAN (version 5.2.9; Lynnon Biosoft) and MEGA version 4 [24]. The five assembled sequences were aligned to all BFDV full-genome sequences available in GenBank using the ClustalW-based [25] (gap open penalty = 10; gap extension penalty = 5) sequence alignment tool implemented in MEGA 4 [24]. MEGA 4 [24] was also used to calculate relative sequence similarities (with pairwise deletion of gaps) of full genomes and Rep and CP ORFs.

Within the genomes of the BDFV isolates from red-fronted parakeets, we identified sequences encoding the Rep (encoding 289 amino acids) and the CP (encoding 245 amino acids). All sequences contain a conserved nonanucleotide (**TAGTATTAC**) within a potential stem-loop structure (supplementary Fig. 1) [13]. TATA boxes, polyadenylation signals, direct repeats and inverted repeats were also identified (supplementary Fig. 1). Within the *rep* gene sequences we identified the three motifs (**FTLNN**, **GxxHLQGY**, **YxxK**) that are conserved in most known rolling-circle replicons and a **GKS** box (P-loop [28]; supplementary Fig. 2). A potential nuclear localisation domain within *cp* was identified between residues 11 and 52 (**RRR** x **ARPY** x **RRRH** x **RR** x **R** xx **RRRR** x **FRRRRFST** x **RIYTLRL** x **RQ**; supplementary Fig. 3 [9]).

The five genomes (all 1,988 nucleotides long) isolated from wild red-fronted parakeets share >99% nucleotide similarity amongst themselves and share ~91–92% identity with BFDV isolates from southern Africa, Europe and Australia (Fig. 1; Table 1). Analysis of the frequency of pairwise sequence identities of the 47 BFDV genomes (1,081 pairwise identities) at a 1% frequency indicates that the majority of the sequences have between 89 and 92% identity, and a smaller proportion have between 92 and 96% identity (supplementary Fig. 4; Fig. 1). Six BFDV isolates (GenBank accession # AF311299, AB277750, AB277751, AB277748, AB277749 and GQ386944) from Australia ($n = 1$; *T. haematodus*), Japan ($n = 4$; *M. undulates*) and China ($n = 1$; *M. undulates*) are the most divergent (pairwise distribution between 81 and 87% identity) of all BFDV genomes sequenced (Fig. 1; supplementary Fig. 4). Therefore, BFDV genome sequences that share less than 80–92% identity to any sequenced BFDV isolates represent new genotypes. Our criteria for

genotype demarcations are similar to those for other ssDNA viruses, in particular, geminiviruses [2] (supplementary Fig. 4). Based on the above criteria, the five red-fronted parakeet isolates from New Zealand represent a new genotype of BFDV. A maximum-likelihood (ML) phylogenetic tree including 47 full BFDV genomes currently deposited in GenBank (access date 28 August 2009; see Table 1 for details) was constructed using PHYML [5] with 1,000 full ML bootstrap iterations using the GTR+G4 model (selected under the AIC information criterion as outlined in Ref. [18]; Fig. 1). The red-fronted parakeet BFDV isolates are evolutionarily distinct and form a clade of their own (Fig. 1). We also constructed ML trees (using the best-fit model TN93+I+G4) for the *cp* and *rep* genes (Fig. 2). Our analyses clearly indicated that the five BFDV isolates from red-fronted parakeets are an undescribed genotype of BFDV. The BFDV isolates from red-fronted parakeets are evolutionarily most closely related to the Cacatuini isolates from Thailand and Lorinae isolates from Australia, based on the *rep* gene ML tree; however, in the *cp* ML tree, they are more closely related to the Psittacini isolates. The *cp* and *rep* ML trees (Fig. 2) also highlight that fact that the *cp* genes are more divergent or evolve faster in general that the *rep* genes (other than in the case of the six Platycercini isolates from Japan). This also means that caution should be exercised when genotyping/classifying BFDV isolates using either *cp* or *rep* amplicons in isolation.

Since only a relatively small number of full BFDV genomes have been determined previously, we compared the sequences of the five BFDV isolates from red-fronted parakeets with all partial sequences (PCR amplicons of either the *rep* or *cp* ORFs) available in GenBank. In this analysis, ML trees (Fig. 3) were drawn using the F81+G4 model for *cp* and the TN93+I+G4 model for *rep* (selected as above [18]).

In an analysis of BFDV in New Zealand amongst introduced parrot species, Ritchie et al. [21] identified three

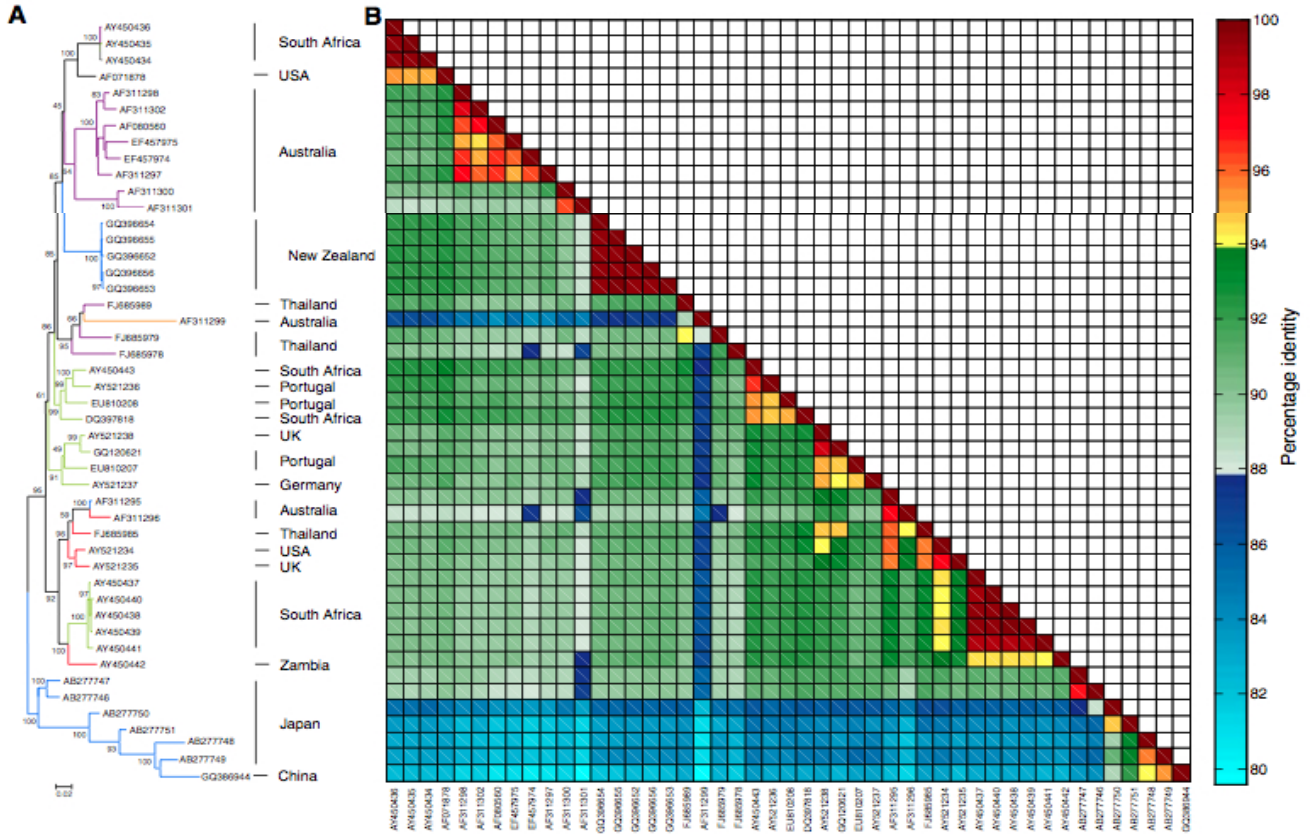

Fig. 1 **a** Maximum-likelihood phylogenetic relationships of the full genomes of red-fronted parakeet BFDV isolates from New Zealand together with all publicly available full-length BDFV genomes (GenBank accession numbers are provided in Table 1). The trees were constructed using PHYML [5] (model GTR+G4), and the *numbers* associated with tree branches are indicative of the percentage of 1,000 full maximum-likelihood bootstrap replicates that support the existence of the branches. **b** Two-dimensional graphical representation of pairwise (pairwise deletion of gaps) sequence identity of all of the 47 BFDV genomes (with percentage identity colour scale)

Table 1 Percentage pairwise similarities (calculated in MEGA 4 [24]; with pairwise deletion of gaps) of the full genome, *cp*, and *rep* nucleotide sequences and amino sequences of MP, CP and Rep

GenBank accession	Country	Common name	Species	Traditional classification	Percentage identity				
					Genome	*rep*	Rep	*cp*	CP
GQ396652	New Zealand	Red-fronted parakeet	*Cyanoramphus novaezelandiae*	Platycercini	–	–	–	–	–
GQ396653	New Zealand	Red-fronted parakeet	*Cyanoramphus novaezelandiae*	Platycercini	99.5	99.5	99.6	100.0	100.0
GQ396654	New Zealand	Red-fronted parakeet	*Cyanoramphus novaezelandiae*	Platycercini	99.5	99.8	99.6	99.6	99.2
GQ396655	New Zealand	Red-fronted parakeet	*Cyanoramphus novaezelandiae*	Platycercini	99.5	99.7	99.6	99.9	99.6
GQ396656	New Zealand	Red-fronted parakeet	*Cyanoramphus novaezelandiae*	Platycercini	99.4	99.7	99.8	99.7	99.6
AF071878	USA	Unknown (pooled blood)	Unknown	–	92.5	94.4	95.7	91.7	90.5
DQ397818	South Africa	Cape parrot	*Poicephalus robustus*	Psittacini	92.3	93.9	96.8	91.3	89.1
AY450436	South Africa	White cockatoo	*Cacatua alba*	Cacatuini	92.3	93.7	94.2	90.8	91.4
AY450434	South Africa	White-bellied caique	*Pionites leucogaster*	Arini	92.3	93.5	93.5	91.1	92.3
AY521235	UK	Rosey-faced lovebird	*Agapornis roseicollis*	Psittaculini	90.5	93.7	96.1	88.2	81.0
AY450443	South Africa	African grey parrot	*Psittacus erithacus*	Psittacini	92.1	93.9	96.1	90.5	86.8
EU810208	Portugal	African grey parrot	*Psittacus erithacus*	Psittacini	92.0	93.1	94.2	91.2	89.6
AY521236	Portugal	African grey parrot	*Psittacus erithacus*	Psittacini	91.8	93.8	96.4	90.4	88.2
EU810207	Portugal	African grey parrot	*Psittacus erithacus*	Psittacini	91.7	94.4	96.8	88.7	78.5
AY521237	Germany	African grey parrot	*Psittacus erithacus*	Psittacini	91.7	94	95.7	88.6	77.5
AF311298	Australia	Galah	*Eolophus roseicapillus*	Cacatuini	91.6	94.5	96.4	89.1	88.6
AF311302	Australia	Sulphur-crested cockatoo	*Cacatua sulphurea*	Cacatuini	91.5	94.4	96.1	89.0	88.6
GQ120621	Portugal	African grey parrot	*Psittacus erithacus*	Psittacini	91.3	94.2	96.1	89.0	78.5
FJ685989	Thailand	Salmon-crested Cockatoo	*Cacatua moluccensis*	Cacatuini	91.3	93.0	90.0	90.1	84.9
AY521238	UK	African grey parrot	*Psittacus eritacus*	Psittacini	91.3	94.0	96.1	89.1	79.0
AF080560	Australia	Sulphur-crested cockatoo	*Cacatua sulphurea*	Cacatuini	91.1	93.1	95.7	89.3	89.1
FJ685985	Thailand	Lovebird	*Agapornis sp*	Psittaculini	90.9	94.0	96.4	88.6	82.4
EF457975	Australia	Cockatiel	*Nymphicus hollandicus*	Cacatuini	90.9	93.2	95.7	88.5	85.3
AY521234	USA	Ring necked parakeet	*Psittacula krameri*	Psittaculini	90.9	92.7	94.6	89.9	82.0
AY450442	Zambia	Black-cheeked lovebird	*Agapornis personata*	Psittaculini	90.9	94.0	96.1	88.1	79.5
AF311297	Australia	Eastern long-billed corella	*Cacatua tenuirostris*	Cacatuini	90.9	93.4	93.5	88.5	86.8
AY450437	South Africa	Cape parrot	*Poicephalus robustus*	Psittacini	90.7	93.2	94.6	88.8	83.5
AY450441	South Africa	Jardine parrot	*Poicephalus gulielmi massaicus*	Psittacini	90.6	92.6	93.1	89.0	84.0
AY450440	South Africa	African red-bellied parrot	*Poicephalus rufiventris*	Psittacini	90.6	93.3	94.2	88.5	82.5
AY450439	South Africa	Ruppell's parrot	*Poicephalus rueppelli*	Psittacini	90.6	93.1	93.9	88.8	83.5
AY450438	South Africa	Cape parrot	*Poicephalus robustus*	Psittacini	90.6	93.1	93.5	88.8	83.5
EF457974	Australia	Cockatiel	*Nymphicus hollandicus*	Cacatuini	90.5	93.1	95.0	88.5	87.7
AY450435	South Africa	African grey parrot	*Psittacus erithacus*	Psittacini	92.1	93.6	93.9	90.8	91.4
AF311295	Australia	Bluebonnet	*Psephotus haematogaster*	Platycercini	90.5	93.7	95.3	89.0	82.0
FJ685980	Thailand	Blue-and-yellow Macaw	*Ara ararauna*	Arini	90.4	92.6	89.3	87.5	82.5
FJ685979	Thailand	Yellow-crested Cockatoo	*Cacatua sulphurea*	Cacatuini	90.3	93.6	89.7	86.1	82.0
FJ685978	Thailand	Sulphur-crested cockatoo	*Cacatua sulphurea*	Cacatuini	90.2	92.7	89.3	87.2	82.5
AB277747	Japan	Budgerigar	*Melopsittacus undulatus*	Platycercini	90.0	93.8	96.1	85.9	81.9
AF311300	Australia	Major Mitchell's cockatoo	*Cacatua leadbeateri*	Cacatuini	89.9	94.4	96.1	84.0	75.3
AB277746	Japan	Budgerigar	*Melopsittacus undulatus*	Platycercini	89.7	93.6	96.8	85.7	81.9
AF311296	Australia	Rosey-faced lovebird	*Agapornis roseicillis*	Psittaculini	89.1	93.0	93.9	89.2	81.5
AF311301	Australia	Sulphur-crested cockatoo	*Cacatua sulphurea*	Cacatuini	88.2	91.6	92.0	84.2	74.8
AF311299	Australia	Rainbow Lorikeet	*Trichoglossus haematodus*	Lorinae	87.0	90.2	85.3	83.9	76.3
AB277750	Japan	Budgerigar	*Melopsittacus undulatus*	Platycercini	85.5	88.3	85.3	84.9	84.0
AB277749	Japan	Budgerigar	*Melopsittacus undulatus*	Platycercini	83.9	84.5	84.1	86.1	83.5
AB277751	Japan	Budgerigar	*Melopsittacus undulatus*	Platycercini	83.4	84.4	84.5	84.3	80.9
AB277748	Japan	Budgerigar	*Melopsittacus undulatus*	Platycercini	83.4	82.0	84.5	86.4	81.4
GQ386944	China	Budgerigar	*Melopsittacus undulatus*	Platycercini	82.0	82.5	82.9	84.2	80.5

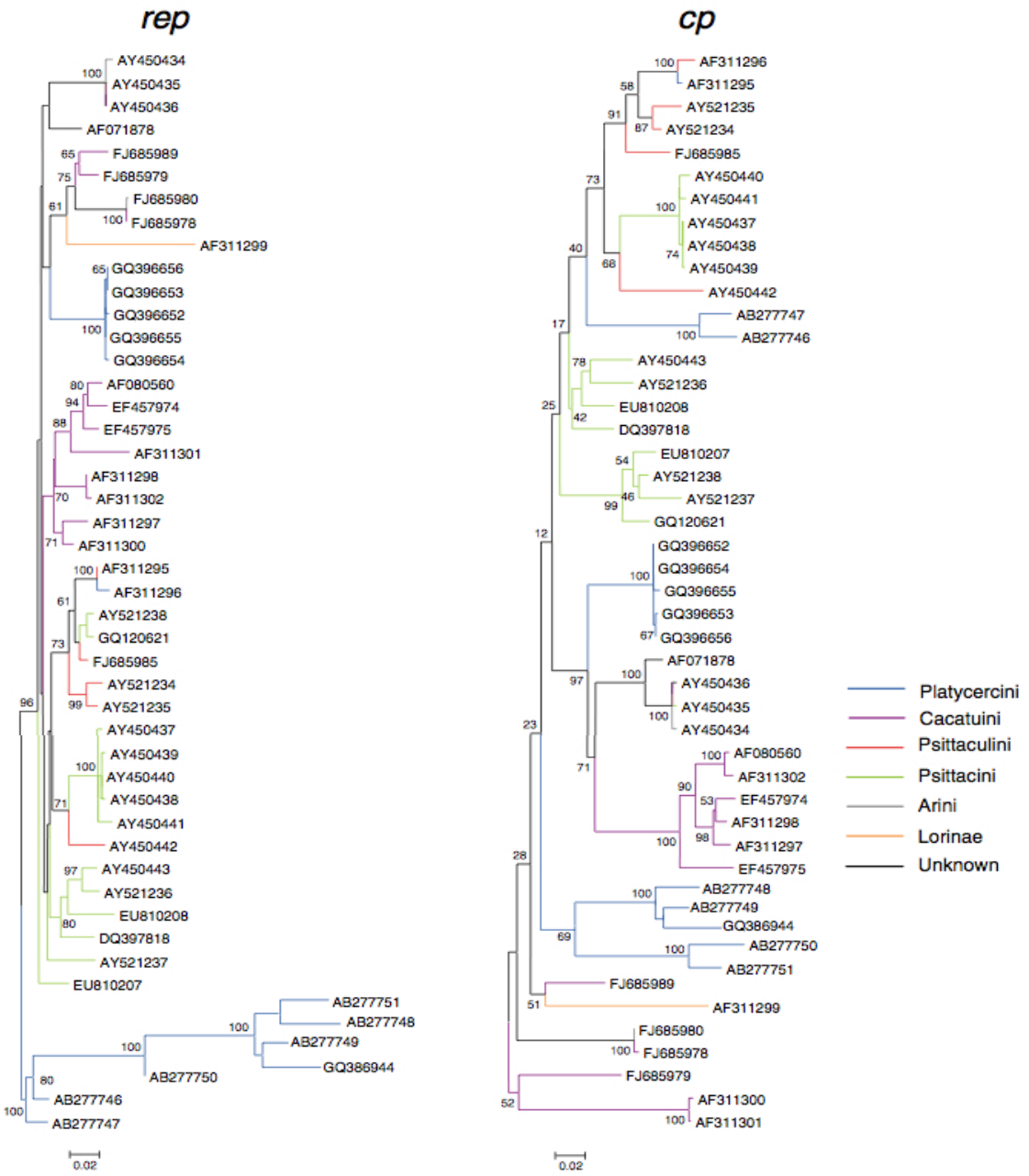

Fig. 2 Maximum-likelihood phylogenetic relationships of the *cp* and *rep* of red-fronted parakeet BFDV isolates from New Zealand together with all publicly available full-length BDFV genomes (GenBank accession numbers are provided in Table 1). The trees were constructed using PHYML [5] (model TN93+I+G4), and the *numbers* associated with tree branches are indicative of the percentage of 1,000 full maximum-likelihood bootstrap replicates that support the existence of the branches

distinct 'lineages' of BFDV (cockatoo, budgerigar and lorikeet). These were based on a 605-nucleotide region of the *rep* ORFs. These three 'lineages' (classified based on *rep* amplicons; Fig. 3) share ~90–92% identity to the new isolates of BFDV from red-fronted parakeets but form a distinct, well-supported clade in the tree (100% bootstrap support). The *cp* amplicons in GenBank that most closely resemble the *cp* genes of the viruses characterised here (sharing ~90–91% identity with these) are from eastern rosella (*P. eximius*), horned parakeet (*Eunymphicus*

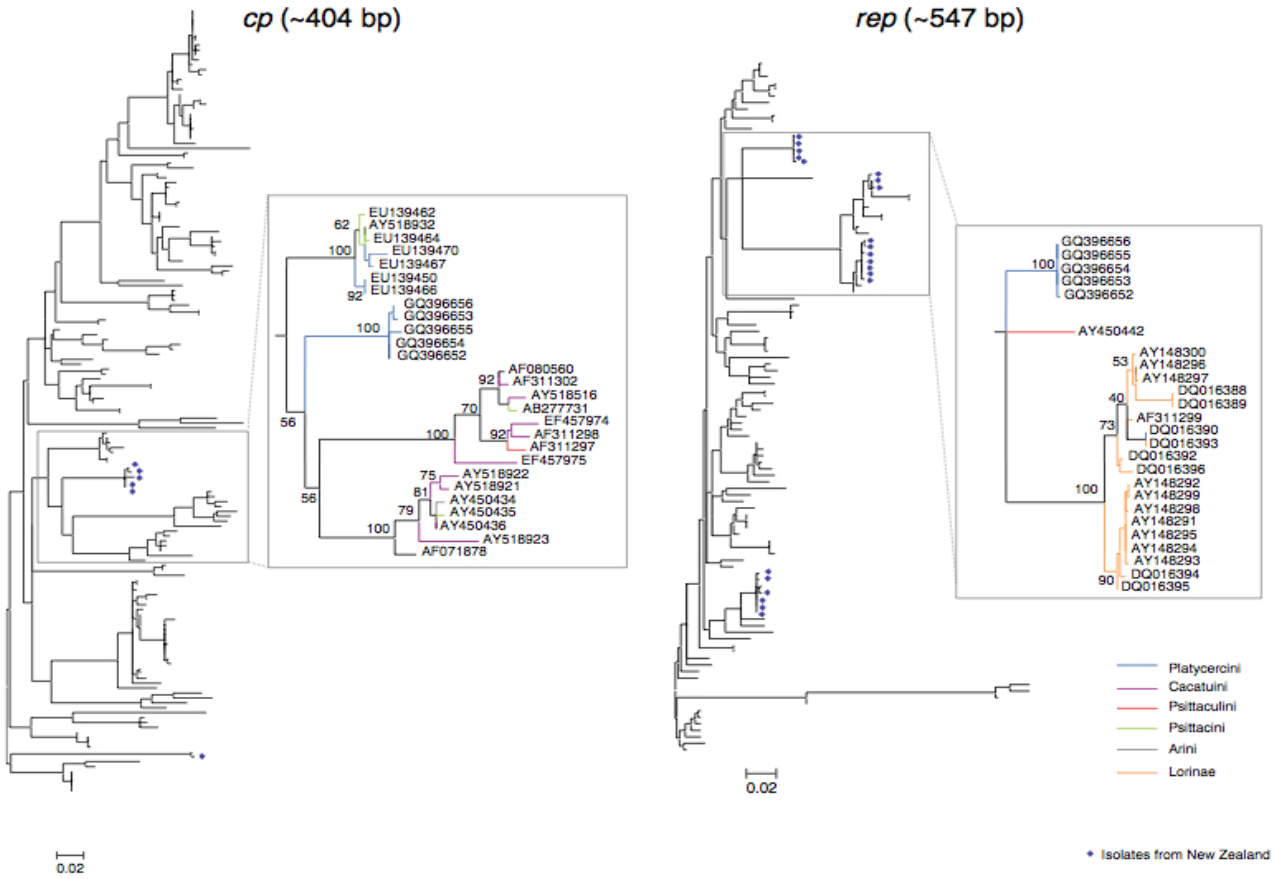

Fig. 3 Maximum-likelihood phylogenetic relationships of partial *cp* (~404 nt) and *rep* (~574 nt) sequences of red-fronted parakeet BFDV isolates from New Zealand together with analogous BDFV genome fragment sequences deposited in GenBank. The trees were constructed using PHYML [5] (model GTR+G4 for *cp* and TN93+I+G4 for *rep*) and the *numbers* associated with tree branches are indicative of the percentage of 1,000 full maximum-likelihood bootstrap replicates that support the existence of the branches. *Filled diamonds* sequences previously isolated in New Zealand from introduced species [21]

cornutus), red-bellied parrot (*Psephotus haematogaster*), northern rosella (*Platycercus venustus*) and grey parrot (*Psittacus erithacus*) isolates from the Czech Republic and a vasa parrot (*Coracopsis vasa*; Psittacini) BDFV isolate from the UK (Fig. 3). The new sequences are well separated and form a well-supported clade (100% bootstrap support). Our analysis using all publicly available data therefore clearly suggests that the BFDV isolates from red-fronted parakeets in New Zealand represent a new genotype of BFDV.

Extensive recombination has been detected amongst most single-stranded DNA virus families [11] and has been reported previously in BFDV [8]. However, we found no evidence of recombination in any of the five red-fronted parakeet isolates when we analysed these together with all the available full BFDV genomes using a battery of seven recombination detection methods implemented in the program RDP3 [12].

The detection of a genotypically distinct population of BFDV genomes infecting native New Zealand parrots raises questions about both BFDV diversity within this region and the potentially harmful effects that this virus might have on endangered endemic species such as Kakapo (*Strigops habroptilus*), Malherbe's parakeet (*Cyanoramphus malherbi*) and Forbes parakeet (*C. forbesi*). Research focusing on New Zealand birds has shown that endangered species that have experienced population bottlenecks exhibit decreased immunocompetence [7, 27] and may potentially have increased susceptibility to novel pathogens. Hence, we argue that it is extremely important for the conservation of endemic psittaforms (a) to establish a screening program that monitors the incidence of BFDV infections within wild and captive New Zealand parrot populations and (b) to characterise the full genomes of isolates found during such a program. The information resulting from these actions is necessary to understand the

genetic diversity of BFDV in New Zealand and to generate a comprehensive framework of the pathogenesis of BFDV genotypes infecting native parrot populations. To decrease the risks of pathogenic BFDV variants spreading on the islands, psittaform breeders and biologists working with psittaforms should be educated on the possible consequences of BFDV outbreaks, which could result in the virus spreading to other wild populations. Beyond New Zealand, with the ongoing illegal trafficking of exotic birds and the under-monitoring of breeding programs, BFDV has become a global problem. Rampant genetic recombination [11] and rates of nucleotide substitution approaching those of RNA viruses [1, 3] are common amongst ssDNA viruses, and the potential for the emergence of novel pathogenic BFDV isolates is probably quite high. There is therefore an urgent need to monitor and document the BFDV genotypes and their virulence within areas of conservation interest. These actions are pivotal for identifying and implementing management programs aimed at containing the dissemination of BDFV to captive and wild populations of species at risk of extinction.

GenBank accession numbers: BFDV-[NZ-CN-B84b-2008], GQ396652; BFDV-[NZ-CN-B77-2008], GQ396653; BFDV-[NZ-CN-B80-2008], GQ396654; BFDV-[NZ-CN-B78-2008], GQ396655; BFDV-[NZ-CN-B81-2008], GQ396656.

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CHAPTER EIGHT

General Discussion

The overall aims of this PhD thesis were to gain insights into the biology, reproduction, and the naturally occurring pathogens of free-living New Zealand parakeets, and provide relevant theoretical context and practical information to conservation planning and management. The thesis accomplished these aims, through extensive planning, field work, analyses, and publication in the peer-reviewed literature, even though several planned experimental translocations of parakeets to understand in detail the role of captive vs. field source, pathogen load, and immunocompetence could not be completed (see Chapter 1 for details). The thesis therefore is representative of a multi-faceted project which encompasses critical and noval aspects of natural history (Chapters 2 and 4), applied management (Chapter 3), baseline research on pathogens (Chapters 5 and 6) and molecular analysis of a viral pathogen (Chapter 7). These results represent a significant advancement in our understanding of parakeet translocations and provide a robust foundation for refining current translocation practices of New Zealand psittaciformes. In this concluding chapter I provide a synopsis and discussion of my work and key recommendations for management and directions for future research.

Animal translocations and the value of the current multi-faceted study

The use of translocations to improve the conservation status of endangered fauna has gained widespread popularity around the world (Conant 1988; Griffith, Scott et al. 1989; Franklin and Steadman 1991; Komdeur, Bullock et al. 1991; Oehler, Boodo et al. 2001) and occupies a preeminent position among insular ecosystems in the Pacific Ocean such as Hawaii (Fancy, Snetsinger et al. 1997; Tweed, Foster et al. 2006; Reynolds, Seavy et al. 2008), French Polynesia (Kuehler, Lieberman et al. 1997), Cook Islands (Robertson, Karika et al. 2006) and New Zealand (Lloyd and

Powlesland 1994; Armstrong and McLean 1995; Armstrong, Castro et al. 1999; Gaze and Cash 2008). Besides the establishment of additional populations of endangered species, translocations have served to advance scientific knowledge in a number of areas (Parker 2008), including: adaptive harvesting from sources for multiple release locations (Dimond and Armstrong 2007), physiology of stress during translocation (Letty, Marchandeau et al. 2000; Teixeira, De Azevedo et al. 2007; Dickens, Delehanty et al. 2009), philopatric behaviour (Clarke and Schedvin 1997; Banks, Norrdahl et al. 2002; VanHeezik, Maloney et al. 2009), habitat use (Armstrong and Ewen 2002) to name a few.

The variety of themes referred in the previous paragraph serve as an example of the multitude of factors affecting the translocation process. Although ideally translocations should be carefully structured studies to address specific questions (Seddon, Armstrong et al. 2007; Armstrong and Seddon 2008), the reality is that numerous translocations occur without even documenting the implementation of the process (as highlighted in Robertson, Karika et al. 2006). For instance, prior to the completion of this thesis, the available information about the issues related to the translocation of New Zealand parakeets was limited and consisted mostly of personal communications from managers/scientists. Experience gained during the research presented here indicates that unanticipated issues arising at all stages of the translocation process (i.e. implementation, harvest and transport, post-release monitoring) offer valuable research opportunities that can serve to improve the practice of translocation. I adopted a multi-faceted approach and established multiple collaborations (see Chapter 1) in an attempt to maximise the outcomes of the various themes that conform this thesis, ranging from natural history to the molecular characterisation of a viral pathogen using two native New Zealand parakeets as study

models. The relevance of the research presented in this thesis can be thus divided into two aspects:

Establishment of new populations of parakeets

Population increase and expansion of native species are two outcomes intuitively perceived from conservation initiatives aimed at eradicating or controlling introduced predators (Ritchie 2002; McQueen 2004; Hawley 2005). Although increases in population numbers of native species following eradication/control actions have been reported (Graham and Veitch 2002; Moorhouse, Greene et al. 2003; Veitch, Miskelly et al. 2004), the range expansion of species of conservation interest following control of introduced species is poorly documented. Two examples include: bellbirds (*Anthornis melanura*) reaching Tawharanui Regional Park following large-scale control or invasive mammals at this site (Brunton, Evans et al. 2008); Also, bellbirds, whiteheads (*Mohua albicilla*) and red-fronted parakeets presumably have established resident populations around the Wellington area following translocations to Karori Wildlife Sanctuary (Miskelly, Epson et al. 2005).

In this thesis, I have documented a case of a population increase and expansion to a previously unoccupied area by Red-fronted parakeets following the eradication of cats and rats (Chapter 2). Also, I have presented evidence of a successful translocation of Red-fronted parakeets from a wild population to a restoring island (Chapter 3, Appendix 3). Lastly, I have also presented evidence of short-distance dispersal and successful breeding of Red-fronted parakeets from Motuihe Island to Motutapu-Rangitoto Islands shortly after a translocation of the species to the former site (Chapter 3). These examples show that parakeet populations

can be established at least in the short-term by natural dispersal of parakeets following the eradication of predators translocation from the wild, dispersal to a restoring site close to were parakeets have recently been translocated. Such short-term assessment of population establishment is based on the evidence of successful breeding, determined by direct observation of active nests and fledglings of two parakeet species on Raoul, Motuihe and Maud Islands. Thus, the implications of my research to the expanding field of parakeet translocations consist of providing the first evidence of the natural recolonisations of parakeets onto restoring habitats (Raoul Island and Motutapu Island) as well as documenting the establishment of a new parakeet population following the classical translocation approach (Motuihe Island).

I have also shown in this thesis that the successful establishment of yet another population of the critically endangered Malherbe's parakeets using captive-bred individuals is a reality (Chapter 4, Appendix 2). Research in psittaciformes indicates that whenever possible, wild individuals should be used for translocation projects (Wiley, Snyder et al. 1992) and the use of captive-bred individuals as secondary or in situations were wild populations no longer exist or are too small to withstand harvest (Derrickson and Snyder 1992; Wiley, Snyder et al. 1992; Wilson, Kepler et al. 1994; Juniper 2002). In the New Zealand context, a number of captive-breeding programs for endangered species have been developed with the aim of improving the conservation status of birds (West, Tisdall et al. 1995; Holmes and Caskey 2001; Greene, Powlesland et al. 2004), reptiles (Blanchard 2002) and invertebrates (Winks, Fowler et al. 2002). My contribution in this area relates to my observations on Malherbe's parakeets on Maud Island in Chapter 4. The information I present, highlights previously undocumented feature of captive-bred New Zealand parakeets

released into the wild including successful breeding at an early age (see Table 1, Chapter 4) and use of native and exotic food items present at a restoring site (see Appendix 4). In addition to these observations I have also provided evidence of use of diverse nesting sites in an island setting, which was previously known for Red-fronted parakeets (Ortiz-Catedral and Brunton 2009) but not for Malherbe's parakeets (Kearvell 2002). A large body of evidence in endangered psittacines indicates that nesting sites are a crucial resource (Snyder, Wiley et al. 1987; Igag 2002; Juniper 2002; Heinsohn, Murphy et al. 2003; Vaughan, Nemeth et al. 2003; Walker, Cahill et al. 2005; Murphy and Legge 2007; Pizo 2008). Not surprisingly, nest management is often cited as a key element to consider when planning conservation management for psittacines worldwide (Snyder, McGowan et al. 2000). Although behavioural studies of Malherbe's parakeets are limited (Kearvell, Young et al. 2002, Appendix 5) my own observations during the project presented here indicate that captive-bred Malherbe's parakeets share what is considered normal reproductive features to wild parakeets (see Discussion Chapter 4). Further, my own research on Malherbe's parakeets indicate that captive-bred individuals not only use diverse sites for successful nesting, but also make use of diverse food items in contrast to previous views about the species (Kearvell, Young et al. 2002; van Hal and Small 2005). The value of such information from a management perspective is that not only captive-breeding provides a valuable tool to establish new populations of this species to aid its recovery and conservation (see Appendix 2) but also, a larger suite of potential release sites might exist given the apparent phenotypic plasticity of captive-bred Malherbe's parakeets released on Maud Island (Chapter 4). In this sense, my contribution to the management of this critically endangered species consist of having laid groundwork on the biology of captive-bred parakeets released onto an island,

stressing the high reproductive potential of the species on an offshore island (Chapter 4) and the need to evaluate the recovery potential of the species under current management to ensure the the long-term persistence of the species (Chapter 4, Appendix 2).

Baseline research on parakeet pathogens

My research has also shown that at least one of four pathogens of conservation concern for native New Zealand parrots occurs in the wild. This has been the result of the most thorough baseline research on pathogens affecting wild populations of Red-fronted parakeets. My sampling efforts resulted in the analysis of samples from two wild populations (Little Barrier Island and Raoul Island, Chapters 5 and 6) as well as one translocated population (Tiritiri Matangi Island) (Chapters 5). The pathogen revelaed during these sampling efforts, is represented by a previously unknown genome of the beak and feather disease virus (BFDV) detected at a prevalence of 28% in the sampled parakeets on Little Barrier Island (Chapters 6 and 7). These findings combined indicate that whilst the technical resources necessary for establishing further parakeet populations exists and can be successfully applied (i.e. eradication of pests, capture and transfer of wild parakeets, captive breeding etc.), management of pathogens in the context of parakeet translocations is an arising challenge in need of attention. My own research did not assess the effects of BFDV on survival of individual parakeets following translocation, however research on other New Zealand species serve as a lesson of the potential effects pathogens might have in a translocation context. For instance, during a translocation of Hihi to Mokoia Island in 1994, Hihi were transferred from Little Barrier Island to Mokoia Island in the middle

of Lake Rotorua as part of the conservation strategy for the species (Armstrong, Castro et al. 1999). The individuals transferred appear to establish successfully in the short term as indicted by foraging and reproductive activities but mortality remained high during the three years following releases (Armstrong, Castro et al. 1999). A study on recovered hihi corpses revealed *Aspergillus fumigatus* infection in 66% of the individuals examined (Alley, Castro et al. 1999). Such finding led to the development of a hypothesis linking *Aspergillus fumigatus* and hihi mortalities as a plausible explanation for the high mortalities observed in adult birds, resulting in the removal of hihi from Mokoia Island and subsequent transfer to Mt. Bruce and Kapiti Island in 2002 (Low 2010). However, a competing hypothesis has been developed, linking *Aspergillus* infection to a higher susceptibility of hihi to predation by Morepork (*Ninox novaezelandiae*), resulting in high adult mortality rather than a "death by *Aspergillus* only" (Low, 2010). Despite the ultimate explanation for the phenomena observed on the population of hihi on Mokoia Island, this example serves to illustrate the relevance of considering pathogens in a translocation context as important management decisions (i.e. the removal of hihi) can arise from it.

The role of infections pathogens and diseases in the conservation of endangered species in general (Cleveland, Hess et al. 2002) and of translocated (Cunningham 1996; Gartrell, Jillings et al. 2006) and captive populations in particular (Wolff and Seal 1993; Wilson, Kepler et al. 1994; Brown, Holdsworth et al. 1995) is increasingly being acknowledged. However, the causal link between pathogens, diseases and species extinctions has been debated due to the paucity of evidence obtained through rigorous studies (Smith, Sax et al. 2005). Nevertheless, there is mounting evidence in New Zealand (Bell, Carver et al. 2004) and overseas of the

primary role of diseases behind dramatic vertebrate population declines (Hawkins, Baars et al. 2006) or extinctions (Wyatt, Campos et al. 2008).

The occurrence of beak and feather disease virus (BFDV) in a wild population of a New Zealand parakeet is likely to reshape the progression of parrot translocations throughout the archipelago. As discussed in chapter six, BFDV infection causes immune suppression rendering infected individuals more susceptible to potentially lethal pathogens (Todd 2000). In support to this view, the preliminary PHA essay I conducted during my PhD shows a relationship between BFDV and no T-cell-mediated immunocompetence (Ortiz-Catedral, 2010). Available evidence indicates BFDV is transmissible both horizontally (between related or unrelated individuals) as well as vertically (from parent to offspring) (Rahaus, Desloges et al. 2008). Thus, exposure of populations or species to bfdv as an unintentional byproduct of translocations should be avoided in future translocations by following stringent quarantine protocols. Exposure to BFDV can occur as a result of confinement of infected and non-infected individuals in aviaries prior to translocation, as part of a captive breeding program or during the release on areas where more than one parrot species is considered in management plans for translocation (Ritchie 2002; McQueen 2004). Besides red-fronted parakeets (Chapter 6), BFDV has been detected in captive kea (*Nestor notabilis*) (Raue, Johne et al. 2004) but to date there are no studies on the effect of BFDV in native New Zealand parrots or their response to treatment. Alongside quarantine measures, strategic studies on the effects of BFDV in New Zealand parakeets should be carried out particularly in critically endangered species such as Malherebe's parakeets and kakapo (*Strigops habroptilus*), ideally integrating conservation biologists and veterinary scientists (see Directions for Future Research).

Directions for future research

The New Zealand parrot fauna is unique. Its eight species are endemic (Heather and Robertson 1996; Boon, Kearvell et al. 2000; Boon, Daugherty et al. 2001; Kearvell, Grant et al. 2003) and currently all of them are classified under categories of threat (www.iucn.org). During this project I have been fortunate to witness the establishment of two additional populations of Red-fronted and Malherbe's parakeets, while at the same time provide elements for planning of future translocations. Considering the results of my own research I have identified two general areas in need of research in the context of parakeet translocations and conservation. Research on these two areas is likely to provide valuable elements to facilitate the establishment of future parakeet populations, contributing to reduce the extinction risk of New Zealand parakeet populations. I discuss these briefly below:

1. *Role of dispersal in the outcome of parakeet translocations in New Zealand*

   Dispersal from release site can have a significant effect in outcome of translocations. Studies on captive-bred and wild-sourced birds have shown that considerable dispersal from the target conservation area can occur (Clarke and Schedvin 1997; Fancy, Snetsinger et al. 1997; VanHeezik, Maloney et al. 2009), which can reduce the efficiency of conservation translocations aimed at establishing new populations or supplementing remaining ones. During the course of the present research, the dispersal from the release location (Motuihe Island) back to the source population (Little Barrier Island) of one red-fronted parakeet was recorded (Ortiz-Catedral 2010). Also, dispersal to an adjacent site were mammalian predators are being controled (Motutapu Island) was registered (Ortiz-Catedral and Brunton 2010). However, it is still unclear to

what extent the dispersal away from release locations is a determinant of success for parakeet translocations in New Zealand. Ideally, future translocations of parakeets should attempt to quantify the number of individuals dispersing beyond the target conservation area and if possible identify methods that could reduce or halt dispersal. For instance, soft-released birds might be less likely to undertake long-distance movement than hard-released individuals (Wiley, Snyder et al. 1992). Also, source (i.e. captive vs wild) might affect site fidelity. In Kaka, it has been documented that captive-bred individuals show higher site fidelity than wild individuals (Berry 1998). During my own research, I encounter captive-bred Malherbe's parakeets released on Maud Island starting breeding activities within a month of their release and at an early age (see Table 1, Chapter three), but given the access restrictions in this study site (see Methods, Chapter three) I was unable to quantify what proportion of the released individuals engaged in breeding activities and what proportion dispersed away from Maud Island. Further, during the translocations of Red-fronted parakeet I carried out during my research (Chapter 3) successful breeding at the release site and nearby Motutapu were registered, however it is unknown what proportion of parakeets were lost to dispersal to the source site (Appendix 6). Thus, ideally future research should target the effect of source, release methodology and site fidelity of New Zealand parakeets sourced from the wild or from captive-breeding facilities.

2. *Determining the current distribution of BFDV among populations of parrots in New Zealand*

Determining a "disease front" is an important step for conservation planning of threatened species affected by infectious diseases (Bell, Carver et al. 2004; Hawkins, Baars et al. 2006; Bode, Hawkins et al. 2009). For New Zealand parrots, preliminary work has identified infectious avian diseases that could potentially affect the conservation status of natural populations (Jackson, Morris et al. 2000) but the current geographic distribution of these is unknown. As discussed in Chapters 6 and 7, an important infectious pathogen that could affect threatened New Zealand Psittaciformes is BFDV. In this thesis it has been established that the virus occurs in at least one natural population in the Auckland region, although it is unclear at this stage whether this represents a viral agent present in New Zealand historically or a recent introduction resulting from Australian imports of species of avicultural interest. In spite of that, an important new stage in conservation planning and translocations of parrots in New Zealand is the demarcation of the current spread of BFDV among free-living populations of Psittaciformes. Given the recombinant nature of ssDNA viruses, such as BFDV spread among different species of parrots is a possibility (Varsani, Regnard et al. 2011). Thus, the accidental exposure of New Zealand parrots of conservation interest to recombinant BFDV strains during movements of individuals from source to release site, should be a high priority in planning of conservation projects for New Zealand parrots. It would be unwise for instance, to translocate captive-bred Malherbe's parakeets to a location within the dispersal range of Red-fronted parakeets from Little Barrier Island since the chances of Malherbe's parakeets coming into contact with BFDV would increase. Viral infection has the potential of becoming yet a further threatening process for such critically

endangered species.

The potential unintentional exposure to pathogens during conservation management has long been highlighted (Conant 1988; Griffith, Scott et al. 1989; Griffith, Scott et al. 1993; Woodford 1993). Further, for other psittacines threatened with extinction, particularly those for which captive-breeding is an important component such Orange-bellied parrot (*Neophema chrysogaster*) (Commonwealth of Australia 2005), Norfolk Island Parakeet (*Cyanoramphus cookii*) (Hill 2002) and Mauritius parakeet (*Psittacula echo*) (Malham, Kovac et al. 2008) disease and pathogen management is a central element in the recovery of populations. Moreover, the disastrous effects of virulent pathogens among immunologically naïve populations, and island species is well documented (van Riper, van Riper et al. 1986; Thorne and Williams 1988; Smith, Sax et al. 2005; Wyatt, Campos et al. 2008). Yet, pathogen management in the context of parakeet translocations in New Zealand is an arising field. The results I have presented in this thesis warrant further work on the current distribution and potential spread of BFDV and other pathogens that might affect parakeets.

In general terms, translocations of psittacines have had limited success, owing to the slow sexual maturation and pairing of some of the most endangered species (Snyder, Wiley et al. 1987; Derrickson and Snyder 1992), limited supply of suitable nesting cavities (Snyder, Wiley et al. 1987; Juniper 2002) and food resources (Snyder, Wiley et al. 1987) loss of individuals to predators (Brown 2000; White, Collazo et al. 2005), maladaptations resulting in suboptimal social behaviour (Brightsmith, Hilburn

et al. 2005) and mortalities caused by individuals colliding with man-made structures (Juniper 2002). Although there are no documented examples of pathogens causing parrot translocations to fail, timely management of pathogens and diseases of captive and free-living populations of endangered parrots is repeatedly stressed as a key element to consider when developing strategies for parrot conservation including translocations (Wilson, Kepler et al. 1994; Hill 2002; Commonwealth of Australia 2005; Deem, Noss et al. 2005; Deem, Ladwig et al. 2008).

New Zealand parakeets have high reproductive potential (Ortiz-Catedral and Brunton 2008; Ortiz-Catedral, Kearvell et al. 2010) and attain reproductive status at an early age (Greene 2003; Ortiz-Catedral, Kearvell et al. 2010). Furthermore, New Zealand parakeets can nest successfully in a variety of nesting sites readily available in restoring areas providing these are free of mammalian predators (Ortiz-Catedral and Brunton 2009; Ortiz-Catedral, Kearvell et al. 2010) which limit their breeding success (Kearvell, Young et al. 2002; Greene 2003). Moreover, New Zealand parakeets have broad diets and consume native and introduced plant species (Greene 1998; Kearvell, Young et al. 2002; Ortiz-Catedral and Brunton 2009). Also, in at least one study (Ortiz-Catedral, Kearvell et al. 2010) no evidence of maladaptive behaviour has been found. Lastly, New Zealand parakeets occur and are currently managed away from significant human settlements or structures such as offshore islands. Thus, it becomes clear that translocations will continue to be central to parakeet conservation in New Zealand given that the biological features of the species facilitates them to establish in restoring habitats. However, greater emphasis on the potential threats posed by pathogens such as decreased immunocompetence (Ortiz-Catedral 2010) should be developed to understand how dramatically pathogens and diseases could affect the outcome of translocation efforts.

In conclusion, the work I have presented in this thesis constitutes a comprehensive body of knowledge that benefits conservation practice opens, up directions for future research and significantly improves the published record on parakeet biology and management in New Zealand.

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APPENDICES

APPENDIX 1

Proposal to translocate 110 red-fronted parakeets from Little Barrier Island to three sites in the Auckland Region.

Proposal sent to DOC

Note: *The original format of the translocation proposal template has been kept*

Department of Conservation
Te Papa Atawhai

High Impact, Research and Collection Application Form

Applicants are required to cover the costs of processing their application. A processing fee deposit of $380 + GST, is payable in advance. The Department will consider your application and supply you with an estimate of further charges that may be incurred to process your application. Application processing fees are not refundable if your application is unsuccessful.

Applicants will be advised if further information is required before this application can be fully processed by the Department. The Department recommends that the applicant contact the relevant Conservancy Officer to discuss the application prior to filling in this application form.

Office Use Only Application processing fee deposit $ received on: / /

A. The Applicant

Applicant (company/individual in full)	Luis Ortiz-Catedral (PhD Student)
Research Institute	Ecology and Conservation Lab, Institute of Natural Resources, Massey University
Contact Person	Dianne Brunton (PhD Supervisor)
Postal Address	Ecology and Conservation Lab, Institute of Natural Resources, Building 5, Oteha Rohe, Massey University, Albany Campus, Private Bag 102-904 North Shore Mail Centre, Auckland

Phone	4140800 ext 41197	Cell Phone	0210733351	E-mail	l.ortiz-catedral@massey.ac.nz

B. The Area

Describe the areas of your operation in detail (eg track names and hut names) and attach map. Identify the status of the area(s) (ie national park, conservation area, forest park, recreation reserve etc). If you are unable to identify the areas or you do not know them, seek the assistance of departmental staff.

LOCATION	STATUS
Little Barrier Island (Hauturu) (The source)	Scientific Reserve
Motuihe Island (Experimental site)	Recreation Reserve

Tawharanui Open Sanctuary (Experimental site)	Regional Park
Rakino Island (Experimental site)	Privately owned

C. Details of Proposed Activity

What is the proposed activity? Include details of the reason for the collecting or undertaking research. (Append a copy of the research outline. Include FORST programme reference if applicable.)

ACTIVITIES ON THE SOURCE (LITTLE BARRIER ISLAND) -Harvesting of 110 red-crowned kakariki (Cyanoramphus novaezelandiae) on Little Barrier Island, for translocation to Motuihe and Rakino Islands and Tawharanui Open Sanctuary (experimental sites).
-Attachment of tail-mount transmitters to a group of 55 red-crowned kakariki to be released at experimental sites.
-Quantification of immune response in a group of 55 red-crowned kakariki using the phytohemagglutinin (PHA) skin test.
ACTIVITIES ON EXPERIMENTAL SITES
Release of red-crowned kakariki according to the following design: Motuihe Island: Age: Adults Sex ratio: Even sex ratio Number of individuals: 40 Proposed dates for translocation: 9th May-17th May 2008. Tawharanui Regional Park: Age: Breeding adults Sex ratio: Even sex ratio Singles/pairs: see above Number of individuals: 40. Proposed dates for translocation: 9th August-17th September 2008 Rakino Island: Age: Breeding adults Sex ratio: Even sex ratio Singles/pairs: see above Number of individuals: 30. Proposed dates for translocation: Late April-Early May 2009.
Unlike other transfers of kakariki, intense monitoring will follow after release. A 3-year monitoring program is guaranteed since this translocation is part of a PhD by the applicant (L. Ortiz-Catedral). Birds will be monitored once a week for the first two months after release and twice per month thereafter for one year. After this period, monthly visits to release sites will follow. If individuals are found dead, corpses will be collected for necropsy to establish cause of death. If skins or skeletons are in good condition after necropsy these will be deposited at the Auckland War Memorial Museum. The monitoring programme has three components:

Radio tracking
Broadcasting of calls
Distance sampling
Monitoring of breeding
Radio tracking: First two months after release (approximate battery life of tail-mount transmitters). Release sites will be visited on a weekly basis and location of the birds will be determined by homing on signal strength. Recorded data will include date, time, bird identification, location, perch type (plant species, height above the ground, vegetation type). The software "Ranges V" will be used to analyse radio-tracking data.
Broadcasting of calls: once per month from month three of release. A variety of kakariki calls will be played for 5 minutes (2 minutes calls, 1 minute break and 2 more minutes play) along main tracks to cover most of the area of the release sites. Playback spots will be located every 100 meters.
Distance sampling: Once per month outside the broadcasting period. A total of 25 transects (100 m long each) will be randomly chosen on Motuihe and Rakino Island. On Tawharanui Peninsula a total of 50 transects will be chosen given the larger area of this site. These transects will be walked once per month and any kakariki seen will be recorded. The perpendicular distance from the kakariki to the observer will be estimated using a laser rangefinder. Detectability of kakariki will be analysed using the programme DISTANCE (Buckland, Anderson et al. 2001).
Estimates obtained from broadcasting and distance sampling will be compared to determine the most effective monitoring technique for newly translocated populations of kakariki.
Monitoring of breeding: During late spring throughout early autumn potential natural nesting sites will be inspected on an opportunistic basis. In addition, Saddleback nesting boxes placed on Motuihe Island will be inspected twice per month. Also, kakariki exhibit a series of stereotypical nesting behaviours that make nest-finding a straightforward task. Potential breeding pairs will be identified by opportunistic observations of pre-nesting behaviours such as cavity inspection, pair roosting, courtship feeding, and aggressive displays towards conspecifics in or around potential nesting sites. Natural nests will be located by inspection of tree cavities, rock crevices, vegetation clusters, trunks and burrows for signs of kakariki activity (i.e. droppings, feathers, egg shells). For every natural nest found, location and plant species will be recorded. Nests will be visited at least once per week to document nest development and success. For a detailed summary of research methods refer to approved permit DOC permit Ak-19621-FAU.

Please describe the methods of collection / research.

RED-CROWNED KAKARIKI HARVESTING
It is proposed to capture a total of 110 red-crowned kakariki on Little Barrier Island (Hauturu) using standard mist-netting techniques over three main harvesting sessions. The duration of the harvesting sessions will vary between seven to fourteen days since good weather is required to operate mist-nets. It is anticipated that target numbers will be reached within 9 mist-net days. One transfer per site (or two per site if target numbers are not obtained) is proposed and no further releases are planned at this stage. Capture and transfer is proposed to take place outside the breeding season, in late April-May 2008 (Motuihe Islands), late August-September 2008 (Tawharanui Regional

Park) and finally late April-May 2009 (Rakino Island).
Adults will be favoured for translocation to minimise any age-related mortality. An even sex ratio will also be targeted. Kakariki will be weighed, measured and given a unique combination of colour and metal bands. Kakariki will be held in an aviary already constructed on Little Barrier Island. All handling and sampling will adhere to methods approved by the Animal Ethics Committee of Massey University (application under evaluation).
Once the mist-nets are erected, one to two team members will check it continuously to ensure any trapped birds are removed as soon as possible in order to minimise stress. It is known that parakeets are susceptible to handling, with mortality reported in yellow-crowned parakeets and red-crowned parakeets (Terry Greene, pers. comm., 2004) and Chatham Islands red-crowned parakeet X Forbes parakeet (Dan Tompkins, pers. Comm., 2007). Therefore, minimising handling time will be a priority.
Following capture, all parakeets will be measured, weighed, given a unique combination of metal and colour bands, and blood and feather samples will be taken, After individual parakeets have been processed they will be transferred to an on site aviary where a thick cover of branches and foliage will be installed inside the aviary to provide shelter. Also a mixture of natural foods (i.e. Coprosma, Mahoe, Cabbage tree berries) and artificial food (jam water, fruit, vegetables, millet sprays) will be provided ad libitum along with clean drinking water.
It is anticipated that target numbers for each harvesting session will be obtained within nine days based on experiences from a disease screening trip to Little Barrier Island carried out 19th to 26th of February 2008 (L. Ortiz-Catedral, unpub.). Kakariki chosen for translocation will be thus held in captivity at the Little Barrier Island for up to nine days. During the translocation of this species from Kapiti Island to Matiu/Somes Island, kakariki were held on an aviary for nine days without showing adverse effects (Adams, Airey et al. 2003). If up to five parakeets die during holding at the aviaries, replacement individuals will be captured to reach the target number. However, if more than five parakeets die while at the aviary and time constrains prevent more captures, parakeets will be released despite a lower number than originally planned. If some kakariki die while in transit to release sites further captures might be considered but first necropsies will be performed on birds to establish cause of death. In previous translocation of kakariki mortalities have been minimal.

PHYTOHAEMAGGLUTININ SKIN TEST
During each harvesting session, a subgroup of parakeets will be held individually in pet-carry boxes lined with closed-cell foam with hessian over the foam so the parakeets can hold to it (Lyn Adams, pers. Comm., 2007). This subgroup will be used to quantify induced immune response by injecting subcutaneously into the patagium a solution of phytohaemagglutinin (PHA; 0.5 mg of phytohaemagglutinin dissolved in 0.1 mL phosphate buffered saline). This injection will cause local inflammation. Such swelling response will be measured using plastic callipers at 6, 12 and 18 hrs after injection. Handling during this period will be short, limited to the necessary time to measure swelling of patagium. Once measurements are completed and if the target number of parakeets has not been obtained, PHA treatment parakeets will be released into the aviary. In case the total number of parakeets has been obtained by the time the patagium measuring regime finishes then birds will be kept in the pet-carry box and released at experimental sites (Motuihe Island, Tawharanui Peninsula and Rakino Island).
The treatment with PHA on the parakeets will be used to analyse the correlation

between immune response of founders and survival, pairing, exploratory movements and breeding success.

Purpose of collecting/research	Research	X	Educational		Commercial Use	

Type of material to be collected/researched	Live red-crowned kakariki
Quantity of material to be collected/researched	110 individuals for translocation
How many people are involved in the research activity? (please provide names of the field staff or assistants involved in the research)	A team of up to 14 people per trip will visit Little Barrier Island. Of these at least 7 will be qualified wildlife researchers with experience in bird mist-netting, banding and blood sampling. Additional team members may vary in level of experience and they will assist as volunteers. The following people are likely to visit LBI during this project (apart from the applicant): Massey University: Dianne H. Brunton Weihong Ji Michael Anderson Marleen Baling Kevin Parker Doug Armstrong The University of Auckland: Mark E. Hauber Auckland Zoo, New Zealand Centre for Conservation Medicine: Richard Jakob-Hoff

Proposed dates	7th May 2008	to	10th June 2009	Alternative dates	

Method of transportation to the site	Arrival to Little Barrier Island by water taxi or in the Hauturu boat. Departure from Little Barrier Island will be via helicopter for three to four members of the party together with the collected birds. The rest of the party will depart the island via water taxi or the Hauturu boat.

Will any of the material be used for genetic modification outside of gene sequencing for taxonomic purposes? (if yes, please attach ERMA application)	NO

Will any of the material or its DNA be leaving New Zealand? (yes/no)	NO
If yes where will the sample be stored?	Not applicable
Please list any Department facilities that will be used	Bunkhouse on Little Barrier Island Aviary on Little Barrier Island

D. Identification of Actual and Potential Effects of Proposed Activity

Please describe the direct and indirect effects that your proposal will have on the following conservation values. Failure to complete this section may result in a decline of your application. All activities have effects.

Describe the effect of your activity on the species or its habitat

HARVESTING
Study species
Red-crowned kakariki will suffer temporary stress during mist-netting and handling (i.e. taking of measurements, banding). Also, the birds will suffer minor feather loss during handling in the net. After capture, birds will be transferred to an aviary already present on Little Barrier Island. Therefore red-crowned kakariki will also suffer temporary stress during visits to the aviary to provide additional food or clear water (or also when adding more birds to the aviary). Taking of measurements, banding and sampling (feathers and blood) will be performed under approved permit (PERMIT NUMBER HERE).
Habitat of study species
Mist-netting will be carried out mostly in the area known as "The flats". Setting up mist-nets will cause negligible disturbance (i.e. a few branches will be trimmed to fit nets, strings will be attached around trees). A number of branches carrying fruits will be cut to provide natural food to aviary birds. The species of plants chosen for this purpose are:
Karamu Coprosma sp.
Mahoe Melycitus ramiflora
Ti Kouka Cordyline australis
Mapou Myrsine australis
Kanuka Kunzea ericoides
Five-finger Pseudopanax arboreus
Pohuehue Muehlenbeckia complexa
Inkweed Phytolacca octandra
In addition to these, other foods such as apples, millet sprays, jam, peas, carrot will be provided inside the aviaries. Branches of species with thick foliage will also be installed inside the aviary to provide shelter, some species useful for this are:
Kanuka Kunzea ericoides
Karo Pittosporum umbellatum
Mamaku Cyathea medularis (only fronds)

PHA SKIN TEST
Red-crowned kakariki will suffer moderate stress during the PHA skin tests. This tests require handling of the kakariki, measuring of the thickness of both patagium (right and left, three times each) before injection of PHA using a digital micrometer. After

injection, thickness of the patagium will be measured again and repeated measures of the pathagium (three times at the time) will be performed at 6, 12 and 18 hours after injection. This tests produces temporary swelling of the patagium. During injection of PHA birds will experience momentary discomfort, not major than that caused by venipuncture when sampling for blood.

Natural waterways or bodies of water?

Minimal effect. Is it possible that some mist-nets will be placed close to waterways but research activities are unlikely to adversely affect these

Any disturbance of native vegetation?

Little disturbance mainly while preparing sites for mist-netting or choosing branches for aviary (see above).

Disturbance to soils, wetlands or any other natural feature either during the initial start-up phase or on an ongoing basis?

None

Wildlife species either within or near the area where you want to operate? eg kea

Non-target species will certainly be caught while operating mist-nets; these will be processed quickly (i.e. taking note of species, weight and standard measurements).

Historic or archaeological sites?

None

What other visitor will be present? Describe the effect of your activity on other visitors, whether they are on commercial tours or a private visit?

Not applicable

What aspects of your activity will be visible from within or adjoining the areas where you want to conduct your activity (please explain)?

While placing mist-nets it is possible that some branches, fronds etc will be cut. Such minimal modification might be visible from tracks.

Is it possible that your activity will introduce weeds, including lake weeds, or seeds of weeds into the area (please explain)?

Unlikely. Every field-work item will be inspected for seeds or invertebrates carefully prior to landing on the island. Members of mist-netting trips are familiar with DOC regulations regarding landing on Island reserves so the risks of introducing weeds or others is negligible

What is the risk of fire from your activity (please explain)?

None. No matches or lighters are carried while placing mist-nets.

What noise will be caused by your activity (please explain)?

There will be a lot of shouting between researchers, mainly if help is needed to process a bird quickly or to remove a mist-net. Apart from that, noise will be kept to a minimum.

Is there any aspect of your activity that will effect current or future public access to the area (please explain)?

It is likely that after release of the kakariki, the experimental sites will become more appealing for visit by tourists or local residents. In this regard the translocation of this species will enhance the visitation rate of these locations.

What effects will your activity have on plants, animals or sites of traditional importance to Maori and who have you consulted over this matter?

Ngati Manuhiri. Mr Terrence Hohneck (General Manager Manuhiri Omaka Kaitiakitanga Ora o Moko) has been consulted via telephone and he agrees with the objectives outlined in this proposal. So far his only request for this project to go ahead is full approval of the methods described in this application by the Department of Conservation and Animal Ethics Committe. He has also been offered the opportunity for a welcome ceremony when the birds arrive at release sites.
THIS ASPECT OF THE PROJECT IS BEIGN LOOKED AFER BY THELMA WILSON (WARKWORTH OFFICE)

Will your activity have any positive effects on natural or historic values (please explain)?

Red-crowned kakariki are “destructive feeders and seed predators” crushing, husking and piercing food items before ingesting them (Higgins 1999), a common feature among parrots. Seeds and berries are mashed and crushed against the underside of the upper mandible (Forshaw 1989) and only in rare occasions seeds are eaten whole (Juniper and Parr 1998). This “destructive” feeding behaviour potentially plays an important role in seed production and recruitment dynamics of plants but has not been studied so far. Studies in American species however, suggest that predation of seeds by parrots is

related to forest diversity (Renton 2001). Thus, red-crowned kakariki might play a role as "ecosystem engineers" by affecting the composition and abundance of the seed bank and shaping vegetation communities.
Tui (Prostemadera novaeseelandieae) are known to mimic red-crowned kakariki calls (Robertson 1996) and there are also anecdotal accounts of "kakariki-like" calls in the repertoire of Hihi (Rose Thorogood and Sarah Whiters, pers. comm.). It is thus likely that phonetic diversity (i.e. diversity of calls due to species present on a given area) might influence repertoire and dialect structure of forest birds. Therefore, red-crowned kakariki are likely to "enrich" the aural environment on Motuihe and Rakino Island and possibly the dialects of for instance saddleback (already on Motuihe and Tawharanui), bellbirds (Anthornis melanura) (already on Rakino) and kokako (Callaeas cinerea).
Red-crowned kakariki are good flyers and are likely to disperse to adjacent areas such as Rangitoto, Motutapu etc which are currenly undergoing ecological restoration (http://www.beehive.govt.nz/ViewDocument.aspx?DocumentID=26100). The species is known to disperse from Tiritiri Matangi to Shakespear (Rimmer 2004).
Furthermore, these translocations will establish additional populations of a vulnerable species in restoring areas with community involvement; therefore the potential for educational purposes is huge. Thus, the translocation of the species to Motuihe and Rakino is likely to positively affect other ecological restoration projects in the Auckland region.

Will your activity promote understanding of conservation (please explain)?

YES. This project has been designed to advance the ecological restoration of the experimental sites by translocating a vulnerable species (IUCN) to three areas within its historical distribution. These translocations has the following specific objectives:
1. Establishment of three self-sustaining populations of red-crowned kakariki in areas undergoing restoration: Motuihe and Rakino Islands and Tawharanui Open Sanctuary.
2. Range expansion for the species in the Auckland Region.
3. Advance in biological knowledge of newly translocated populations of red-crowned kakariki
4. Establishment of three accessible populations of red-crowned kakariki for scientific research and public recreational enjoyment.

The proposed translocations supports two goals described in the New Zealand Biodiversity Strategy:
1. Goal one "Enhance community and individual understanding about biodiversity, and inform, motivate and support widespread and coordinated community action to conserve and sustainably use biodiversity (…)".
2. Goal three: "(…) Maintain and restore viable populations of all indigenous species and subspecies across their natural range and maintain their genetic diversity." (www.biodiversity.govt.nz)

The translocations are high-profile conservation activities that easily attract attention for media coverage. A story in the newspaper or on TV will certainly give an opportunity to the public to learn about conservation effort sin New Zealand and the collaboration between researchers in partnership with community projects and the Department of Conservation towards the preservation of New Zealand endemic fauna.

E. Measures to Avoid, Remedy or Mitigate

Where you identified actual or possible adverse effects in your description, please also describe the actions you propose to take to avoid, remedy or mitigate those effects.

Example: Weeds may be introduced on sampling equipment. Proposed action to avoid this: washing of sampling equipment before arriving in sampling area.

Unnecessary stress or even dead during mist-netting and blood sampling of red and yellow-crowned kakariki and non-target species. Proposed action to avoid this: Only qualified individuals with experience in bird handling and blood sampling will process mist-netted birds.
Given the novelty of the PHA trials on red-crowned parakeet and the uncertainty repeated handling will have on the birds, two precautionary steps will be followed: Before the PHA trials start, the injection of PHA and associated handling at 6, 12 and 18 hours after injection will be studied in a single parakeet. If this individual shows any adverse effects or signs of high stress, or death the PHA trials will be suspended. If the experimental bird survives and does not show adverse effects 24 hours after treatment the trials will proceed. However, if during these experimental manipulations up to three parakeets die, PHA-related handling will be immediately suspended and the experiment abandoned altogether On the day of translocation, parakeets will be captured inside the aviary and held in carton pet-carry boxes. From Little Barrier Island, parakeets will be taken by Helicopter to Motuihe and the target number for this locality released (40 parakeets). Later in the year, additional parakeets from Little Barrier Island (second harvesting trip) will be transferred from Little Barrier to Tawharanui Regional Park and finally a third harvesting session will take place to capture kakariki destined to Rakino Island during April-May 2009. The total numbers of parakeets used for the PHA treatment will be half of the founder flock per release site, namely: Motuihe Island: Founder flock of 40 kakariki, of these 20 will be used for the PHA treatment. Tawharanui Regional Park: Same as above. Rakino Island: Founder flock of 30 kakariki, of these 15 will be used for the PHA treatment.

Thank you for your application. Please ensure that:

* You have attached any maps, plans and additional information relevant to your application.
* Your application processing fee deposit of $380 + GST is included with your application.

If you have any queries on the application process, please contact the nearest Conservancy Office of the Department of Conservation.

I certify that the information provided on this application form and attached additional information is to the best of my knowledge true and correct:

Signature of Applicant		Dated:	
Signature of Witness		Dated:	
Address of Witness			

This application is made pursuant to sections 17R and 17S of the Conservation Act 1987 [and (where applicable) section 49 of the National Parks Act 1980/Section 59A of the Reserves Act 1977].

All costs relating to the application are payable by the applicant to the Department of Conservation (see section 60B of the Conservation Act 1987).

Applicants should be aware that provisions of the Official Information Act may require that some or all information in this application be publicly released if so requested.

Translocation Proposal Template
Return to SOP
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Complete the template using the instructions, and do not delete the instructions.

1. Translocation Summary

Translocation Title	Proposal for transfer of red-crowned kakariki (*Cyanoramphus novaezelandiae*) from Little Barrier Island "Hauturu" to Motuihe Island, Rakino Island and Tawharanui Regional Park.
Translocation Overview	The translocation of the red-crowned kakariki from Little Barrier Island is proposed: 1. To establish three self-sustaining populations of red-crowned parakeets on Motuihe and Rakino Islands and Tawharanui Regional Park and for public advocacy. 2. To advance the ecological restoration of these locations by translocating a vulnerable species (IUCN) to three areas within its historical distribution. 3. To investigate the relationship of induced immune response and survival during translocation. 4. To conduct research on the patterns of habitat use, social behaviour and reproductive success of translocated wild caught red-crowned kakariki. These translocations will be carried out with the support of the Motuihe Trust (Motuihe Island Restoration Project), Tawharanui Open Sanctuary Society, Massey University and private funds.
Project Manager	Luis Ortiz-Catedral PhD Student Ecology and Conservation Lab, Massey University Albany Campus, Private Bag 102-904 North Shore Mail Centre, Auckland Phone 09 4140800 ext. 41192, Mobile 0210733351. Matt Maitland Open Sanctuary Coordinator Auckland Regional Council, Northern Parks PO Box 332, Orewa 09 426 1200 or 0274 555 445
Proposal Writer	Luis Ortiz-Catedral.
Lead Conservancy	Auckland Conservancy.
Affected Conservancy/ies	Auckland Conservancy.
RGM Concurrence	RGM concurrence is required
Inform RGM	Translocations will be to locations where the species no longer exists but within the historical range of the species (Forshaw 1989; Higgins 1999).
Translocation Approver	Sean Goddard, Conservator, Auckland Conservancy.

Project Team	1. Luis Ortiz-Catedral: Luis has extensive theoretical and field-based research experience in parrot research in Mexico and New Zealand. Luis gained basic training in parrot research in Mexico in 2001 collecting data on the endangered Mexican endemic Lilac-crowned amazon (*Amazona finschi*) and from 2001-2002 he collaborated in a project looking at the current distribution of the endangered Military Macaw (*Ara militaris*) in Western Mexico. Since 2004 he has studied translocated red-crowned kakariki on Tiritiri Matangi Island and since March 2007 he has monitored translocated captive-bred orange-fronted kakariki (*Cyanoramphus malherbi*) on Maud Island. The latter species is New Zealand's most endangered kakariki species. Since 2004 Luis has handled over 100 red-crowned kakariki as part of his research and has conducted the most detailed study to date on the breeding biology of this species in a predator-free population (Tiritiri Matangi Island). This project was part of Luis' Master of Science degree at Massey University. Luis' research in New Zealand has been done under the supervision of Assoc. Prof. Dianne Bruton (Massey University) and advice of Terry Greene (Department of Conservation). Luis has ample experience in bird banding, blood sampling radio-tracking and mist-netting of birds (to date he has mist-netted and handled over 400 birds in the field). He has also been involved in two mist-netting trips to capture hihi (*Notiomistys cincta*) on Tiritiri Matangi Island for translocation to Ark in the Park, Auckland. Since 2006 Luis has been enrolled in a PhD in Conservation Biology at Massey University under the supervision of Assoc. Prof. Dianne Brunton, Assoc. Prof. Doug Armstrong (Massey University) and Dr. Mark Hauber (The University of Auckland). Luis's PhD project investigates the ecology of captive-bred and wild-caught translocated red-crowned and orange-fronted kakariki. In addition to his PhD project, Luis studies the nest-attendance behaviour of the critically endangered Kakapo (*Strigops habroptilus*) through analysis of video footage. Luis' background will provide valuable input in research design, and data collection and analyses. 2. Dianne Brunton: Assoc. Prof. Dianne Brunton has wide experience in bird ecology and behavioural ecology as well as statistical modelling. She has been involved in several translocations of birds and reptiles in New Zealand (six bird and three reptile translocations). Dianne has extensive field and theoretical experience with birds and reptiles and to date has supervised over 20 MSc and 12 PhD projects. Dianne has also published over 16 papers in scientific journals. Currently, Dianne manages a captive-breeding facility of Duvaucel's geckos (*Haplodactylus duvaucelli*) and Shore Skinks (*Oligosoma smithi*) established via translocation of wild individuals into captivity. Her strong theoretical background and ample skills in field-based research will be crucial for the development of the translocation of red-crowned kakariki. 3. Doug Armstrong: Assoc. Prof. Doug Armstrong is the leading scientist in translocations within New Zealand and chairman of the Oceania Section of the Reintroduction Specialists group. Doug's research has focused on population dynamics of translocated New Zealand birds, mainly North Island Robins (*Petroica longipes*), saddleback (*Philesturnus carunculatus*) and Hihi (*Notiomistys cincta*).

Project Team (cont.)	Doug's role is highly valuable given his matchless knowledge of dynamics of translocated populations of translocated New Zealand birds. 4. Mark Hauber: Dr. Mark Hauber has ample knowledge in bird behaviour and has published influential papers in this area. Mark has studied an ample spectrum of birds in North America and New Zealand including cowbirds (Icteridae), Grey warblers (*Gerygone igata*) and Australasian gannets (*Morus serratus*) to name a few. Mark has recently published a paper studying the maintenance of behavioural traits in captive chicks of the endangered New Zealand kaki (*Himantopus novaezelandiae*). Mark's role is pivotal for the appropriate development of this project given his expertise in behavioural ecology, strong theoretical background, skills handling native New Zealand birds and his familiarity with data analysis. 5. Kevin Parker: Kevin is currently studying a PhD at Massey University. Kevin has worked as a consultant in numerous translocations of New Zealand birds and has unrivalled experience with mist-netting, bird handling and blood sampling. 6. Matt Baber: Matt has ample experience in the fields of restoration ecology and vertebrate monitoring. Matt has field experience with native New Zealand birds such as kokako (*Callaeas cinerea*) and Takahe (*Porphyrio hochstetteri*). Matt has worked as a Senior Environmental Policy Advisor for the Auckland Regional Council and is Chair of the Biodiversity Committee for the Motuihe Island Restoration Project. 7. John Laurence: John is chairman of the Motuihe Island Restoration Project since 2002 and has organised the weed programme on the island, volunteer program and funding as well as tree propagation and planting. John is also a very passionate conservationist. 8. John MacKenzie: John owns a property on Rakino Island and since 2002 has monitored bait stations and tracking tunnels to alert on any invading animal on Rakino. He was awarded the Weedbusters award for individual excellence in 2005 and is a highly committed naturalist. In addition to the people listed here, a group of volunteers will be part of mist-netting trips and post-release monitoring. Volunteers will be assigned task on the basis of their level of experience with wildlife to maximise efficiency and ensure proper handling of birds. 9. Matt Maitland: Matt is currently the coordinator of the Tawharanui Open Sanctuary, Auckland Regional Council (Feb 2007 to present) and is responsible for all aspects from strategic and operational planning; creation and maintenance of pest free environments; ecological restoration (including revegetataion, reintroductions, recovery of extant biota); manage community partnerships. He has been involved in translocations North Island robin (Tiritiri Matangi to Tawharanui); whitehead (Tiritiri Matangi to Tawharanui); Lead: NI brown kiwi (Motuora to Tawharanui Nov 07); Pateke (captive to Tawharanui (Feb 08 - May 2010, application approved). His previous experience includes Rotoiti Nature Recovery Projet Team Leader, Department of Conservation, Nelson Lakes from 1998-2006; oversight of all ecological restoration activities of high profile experimental mainland island; specific portfolio responsibility for reintroductions. Great Spotted kiwi (Gouland to Rotoiti 2004 and 2006); planning for mohua and SI saddleback.
Emergency Translocation	N/A.
Temporary Translocation	N/A.
Species to be Transferred	Species to be translocated: Red-crowned kakariki (*Cyanoramphus novaezelandiae novaezelandiae*). Not listed in (Molloy *et al*. 2002) but listed as "vulnerable" by the IUCN (species added in June 2005) (www.iucn.org).
Source Location	Little Barrier Island "Hauturu".

Release Location	Motuihe and Rakino Islands and Tawharanui Regional Park. All within the Auckland Region.

2. Justification

Refer to Chapter 2 **Need and Appropriateness**	There are two main objectives to this proposal. 1. To establish self-sustaining populations of red-crowned kakariki on managed islands in the Hauraki Gulf and Tawharanui peninsula to support ecological restoration, advocacy and education. In addition these populations are likely to play a strategic role in the potential long-term natural dispersal of the species to adjacent sites given the geographic proximity of release islands to The Noises, Rangitoto and Motutapu Islands. 2. To study in detail the establishment phase of translocated populations of red-crowned kakariki. New Zealand kakariki (*Cyanoramphus* spp) have experienced an ongoing decline since human colonisation in the archipelago and associated introduction of mammals (Higgins 1999). This genus of parrots is the one that has experienced more extinctions in the South Pacific to date with two extinct species and several subspecies (Taylor 1979; Taylor 1985; Forshaw 1989). At the time of European settlement, three species inhabited mainland New Zealand in addition to off-shore islands: the yellow-crowned kakariki *Cyanoramphus auriceps,* orange-fronted kakariki *C. malherbi* and red-crowned kakariki (*C. novaezelandiae*) (Forshaw 1989). While the first two still persist on mainland (albeit in a much reduced area especially for the orange-fronted kakariki), the red-crowned kakariki is currently restricted to Stewart Island and off-shore islands free of mammalian predators (Greene 1998). Models of extinction risk have been developed for vertebrates and the results show that habitat fragmentation and isolation between sub-units increase the extinction risk of a species (Reed 2004). It is therefore a matter of concern the currently fragmented and isolated distribution of remaining populations of red-crowned kakariki. Especially since the dispersal capacity to neighbouring populations, genetic connectivity and regulatory processes occurring at present in populations of red-crowned kakariki are mostly provisional. Translocations are one way to expand the distribution of range-restricted species and also offer a unique opportunity to advance our knowledge of the regulatory mechanisms acting in populations (Armstrong, Davidson et al. 2002; Taylor, Jamieson et al. 2005). Translocation can also increase numbers of declining species when individuals are transferred to areas undergoing restoration such as Motuihe Island, Rakino Island and Tawharanui Reginal Park. The red-crowned kakariki has been repeatedly translocated into its historical range (i.e. Tiritiri Matangi, Cuvier and Matiu-Somes Islands) using captive-bred (i.e. Tiritiri Matangi) and wild-caught individuals (i.e. Matiu-Somes). However there is still uncertainty regarding the appropriateness of using captive bred *vs* wild caught kakariki (Ortiz-Catedral and Russell in prep.).

	It has been argued that captive-bred individuals show poor behavioural adjustment to new environments and hence higher mortality (Snyder, Wiley et al. 1987; Juniper 2002), however there are abundant examples of successful translocations using captive individuals (Sanz and Grajal 1998; van Hal and Small 2005; Butchart, Stattersfield et al. 2006). A clear benefit of using captive-bred individuals is that the pressure on remaining populations can be reduced and it could be logistically more efficient (i.e. quarantine measures, availability of birds of known sex and age for release etc.). Despite the above, at present the use of wild-sourced individuals is preferred unless the genetic background of captive individuals is known (Rod Hitchmough and Pam Cromarty, pers. comm.).
Context	The wider context of the translocations outlined here is the increase in numbers and geographic expansion of the red-crowned kakariki within the Auckland Region and the potential long-term increase in the likelihood of natural dispersal to adjacent sites (i.e. The Noises, Rangitoto Island etc.). Within the same context we aim to develop models of population growth for the red-crowned kakariki at restoring habitats. Motuihe and Rakino Islands (in combination with ongoing research on Tiritiri Matangi Island by Luis Ortiz-Catedral) will serve as research units for a better understanding of the processes associated with translocation of native parakeets. These translocations will also help refine forthcoming transfers for this species as well as acting as surrogate models for rarer forms such as Orange-fronted kakariki (*C. malherbi*) and Forbes' parakeet (*C. forbesi*). These translocations also for part of the Motuihe Restoration Plan. The red-crowned kakariki are listed in the Tawharanui Regional Park-Open Sanctuary Operational Plan 2000-2005 as a potential early candidate for translocation (Ritchie, 2002). Finally, these translocations are integral part of the PhD research project of Luis-Ortiz-Catedral.

3. Outcomes and Targets

Refer to Chapter 2

Conservation Outcome(s)	1. Establishment of three self-sustaining populations of red-crowned kakariki in areas undergoing restoration: Motuihe and Rakino Islands and Tawharanui Regional Park. 2. Range expansion for the species in the Auckland Region. 3. Advance in biological knowledge of newly translocated populations of red-crowned kakariki 4. Establishment of three accessible populations of red-crowned kakariki for scientific research and public recreational enjoyment.

Operational Target(s)	**Conservation Outcome** Establishment of three breeding populations of red-crowned kakariki at the following release sites: Motuihe Island Rakino Island Tawharanui Regional Park **Operational Targets** *Motuihe Island* April 2008 to April 2009 (Year 1): Successful transfer of 40 red-crowned kakariki to Motuihe Island. Evidence of survival of 60% of released individuals within the first three months after release. Evidence of survival of 60% of released individuals six months after release. Evidence of pairing and breeding within the first 12 months after release. May 2009 to May 2010 (Year 2): Evidence of recruitment of locally-bred fledglings into the breeding population (i.e. sightings of pairing and/or breeding). *Tawharanui Regional Park* September 2008 to September 2009 (Year 1): Successful transfer of 40 red-crowned kakariki to Tawharanui Regional Park. Evidence of survival of 60% of released individuals within the first three months after release. Evidence of survival of 60% of released individuals six months after release. Evidence of pairing and breeding within the first 12 months after release. October 2009 to October 2010 (Year 2): Evidence of recruitment of locally-bred fledglings into the breeding population (i.e. sightings of pairing and/or breeding). *Rakino Island* April 2009 to April 2010 (Year 1): Successful transfer of 30 red-crowned kakariki to Motuihe Island. Evidence of survival of 60% of released individuals within the first three months after release. Evidence of survival of 60% of released individuals six months after release. Evidence of pairing and breeding within the first 12 months after release. May 2009 to May 2010 (Year 2): Evidence of recruitment of locally-bred fledglings into the breeding population (i.e. sightings of pairing and/or breeding).

Research objectives	Assessment of: 1. Habitat use and foraging ecology of translocated red-crowned kakariki post-release translocation. 2. Population trends over time after translocation. 3. Dispersal from release site. 4. Relationship between immune response and survival.

4. Strategic Directions

Refer to Chapter 2

Strategic Directions (DOC staff to provide relevant extracts from these documents)	The proposed translocations support two goals described in the New Zealand Biodiversity Strategy: 1. Goal one "*Enhance community and individual understanding about biodiversity, and inform, motivate and support widespread and coordinated community action to conserve and sustainably use biodiversity* (…)". 2. Goal three: "(…) *Maintain and restore viable populations of all indigenous species and subspecies across their natural range and maintain their genetic diversity.*" (www.biodiversity.govt.nz)
Management Plans and Strategies	• Motuihe Restoration Plan • Conservation Management Strategy for Auckland • Tawharanui Regional Park-Open Sanctuary Operational Plan The relevant legislation to this proposal includes the following (**NOTE:** This section prepared with the assistance of Rosalie Stamp and Tim Lovegrove, Auckland Regional Council): Resource Management Act 1991, Conservation Act 1987, Local Government Act 1974, Local Government Amendment Act 1992, Local Government Act 2002 and the Reserves Act 1977. Under the Conservation Act 1987, The New Zealand Department of Conservation is required to develop Conservation Management Strategies. For the Auckland Conservancy, Tawharanui is identified as having wildlife, vegetation and geological sites of significance. The Auckland Regional Council in conjunction with the Department of Conservation is implementing its Conservation Management Strategy with reference to Tawharanui Regional Park. Under the Reserves Act 1977, Tawharanui Regional Park is administered so that the public will have access to indigenous wildlife and the conservation value of the area is maintained. Under the Auckland Regional Council's Regional Parks Management Plan (Auckland Regional Council 2003) the following actions are listed: *2.Development of the park as an open sanctuary with initial focus beign given to enhancing and restoring existing habitats. Once habitat conditions are suitable, the feasibility of introducing* ***birds which are currently rare or which are absent from the Auckland mainland*** *will be investigated in conjunction with the Department of Conservation.* *3.Ecological restoration and enhancement through the:* *(...)* ***introduction of flora and fauna formerly present but now absent ncluding a range of locally extinct bird species.***

Recovery Group	There is no Recovery Group for the red-crowned kakariki

5. Source Population

Refer to Chapter 2

Potential Sources	Little Barrier Island "Hauturu", Hen and Chicken's Islands (Northland Conservancy), Stanley Island, Mercury Islands Group (Waikato Conservancy), Poor Knights Island (Northland Conservancy).
Preferred Source	• Little Barrier Island "Hauturu" is the preferred site due to its proximity to the release sites, the large population size of the resident population (which would allow the harvest of numbers proposed) and because the available evidence suggests that it represents the genetic type of the Auckland region (Boon, Kearvell et al. 2000).
Effects of Removal	The removal of 110 red-crowned kakariki from Little Barrier Island is not expected to affect significantly the viability of the source population. There are no current published estimates of population numbers on Little Barrier or any other population in the Auckland region. However, the species is known to occur at high densities even on small islands. For example, on Macauley Island (282 ha), Greene estimated population size for the Kermadec Islands subspecies (*C. novaezelandiae cyanurus*) 8000 to 10 000 individuals (Greene, Scofield et al. 2004). Furthermore, the species has a high reproductive potential with clutches of up to nine eggs (Greene 2003) and up to seven fledglings in some nests on Tiritiri Matangi (Ortiz-Catedral 2006). Over two breeding seasons, Ortiz-Catedral (2006) found that the average number of fledglings was 2.55 per clutch (averaged between 30 nests). This suggests that even in a single breeding season, the harvested number of red-crowned kakariki could be replenished. During a recent visit to Little Barrier Island during February 2008 large numbers of red-crowned parakeets were noticed around the Titoki Point and West Landing.

6. Establishment of Captive Fauna Populations

Refer to Chapter 2

Captive Fauna Population	N/A.
Fauna - Long Term Plans	N/A.

7. Establishment of Cultivated Threatened Flora Populations

Flora – Long Term Plans	N/A.

8. Release Location

Refer to Chapters 2 & 6

Legal Requirements	Motuihe Island is an ongoing community restoration project led by the Motuihe Island Trust in partnership with the Department of Conservation (DOC). Motuihe is a Recreation Reserve in the Hauraki Gulf and its Restoration Plan includes the introduction of " (…) *compatible birds, reptiles and invertebrates including threatened species*" (Motuihe Restoration Plan, 2005). Rakino Island is mostly privately owned with residential areas surrounded by rural blocks of roughly 10 acres. Also two small DOC reserves occur on Rakino. Rakino Island's land use is regulated under an approved community strategy by the Auckland City Council. Under this strategy, one of the key community issues is the "*protection and enhancement of the island's character and environment*" (www.aucklandcity.govt.nz/council/documents/rakino). Under the local government Act 1974 Tawharanui Regional Park is freehold land owned by the Auckland Regional Council on behalf of the citizens of the Auckland region. The local Government Act provides for the management of regional parks in perpetuity by the Auckland Regional Council in accordance with approved management plans. Under this Act a Regional Park is "*held in perpetuity for the purpose of protecting and preserving its intrinsic worth*" All three sites meet the statutory land management purpose for release of red-crowned kakariki.
Ecological Requirements	Red-crowned kakariki are generalists and occur in a wide variety of habitats from sub-Tropic to sub-Antarctic islands (Higgins 1999). They forage from ground level to tree canopies and have been observed to move between strata according to seasonality of food resources (Greene 1998). On Little Barrier Island, red-crowned kakariki occurs at all altitudes and forage in all vegetation types, seen more commonly in open vegetation (Greene 1998). On Tiritiri Matangi Island red-crowned kakariki successfully nest in all vegetation types (i.e. grassland, regenerating forest, remnant forest) and in a wide variety of nesting sites such as tree-hollows, rock crevices, bases of harakeke (*Phormium tenax*) and clusters of Pohuehue (*Muelenbeckia complexa*) from ground level to tree-tops (Ortiz-Catedral 2006). Red-crowned kakariki were first transferred to Tiritiri Matangi Island between 1974 and 1976, when more than 50% of the island's area was covered by grassland (Dawe 1979). The original number of birds was 84 (Dawe 1979). Currently their density on Tiritiri Matangi Island is estimated at 3 birds per ha, giving an approximate population size of 700 (D. Brunton and R. Stamp, unpublished). Numbers have increased since the eradication of kiore from this site (Graham and Veitch 2002).

•	Red-crowned kakariki feed on a large variety of buds, flowers, leaves, fruits and seeds (Forshaw 1989; Greene 1998). Some examples of food items include (based on Higgins (1999) and personal observations by Luis Ortiz-Catedral): FRUITS karamu *Coprosma* sp., Mahoe *Melicytus ramiflorus,* Ti Kouka *Cordyline australis*, Puahou *Pseudopanax arboreus* and Mapou *Myrsine australis*; LEAVES Pohutukawa *Metrosideros excelsa*, Pohuehue *Muelenbeckia complexa*, Kohekohe *Dysoxylum spectabile*; BUDS Harakeke *Phormium tenax*, Puriri *Vitex lucens*, Kanuka *Kunzea ericoides*; Manuka *Leptospermum scoparium*. They also feed on flowers and fruits of a large number of weeds such as inkweed *Phytolacca octandra*, nightshade *Solanum americanum*, *Modiola caroliniana*, *Raphanus raphanistrum* and *Plantago lanceolata.* Motuihe and Rakino Islands and Tawharanui Regional park have been visited to record plants that serve as foods for kakariki. Over 35 species where identified on Motuihe and at least 23 species of food plants on Rakino. On Tawharanui over 40 species have been identified as potential food sources for red-crowned kakariki. Both islands and Tawharanui have large open areas in addition to regenerating vegetation and different degrees of remnant forest. The three sites experience continuous replanting of native species and several of the species selected for replanting also serve as foods for kakariki (i.e. mahoe, *Carex spp.*, Mapou). In addition to native species, there are exotic orchad and/or garden plants that will potentially serve as foods (i.e. apples, prickly-pears). On the three sites, there are a large number of potential nesting sites including cavities in Pohutukawa, Puriri and Mahoe. In addition, along the coast a large number of crevices are found plus abundant clusters of harakeke and pohuehue, which also serve as nesting and roosting sites for the species. Furthermore, nesting boxes were installed on Motuihe to increase nesting sites of saddleback (*Philesturnus carunculatus*) and these are also likely to be used by kakariki. Both islands are free of introduced mammalian predators, except for a few old de-sexed domestic cats on Rakino Island (John Mackenzie pers, comm.). Both islands present therefore, suitable habitat for the translocation of the species. Tawharanui Regional Park is kept free of mammalian predators by means of a predator-proof fence.
Species Distribution • **Outside historic range** **Reinstatement**	Motuihe and Rakino Islands and Tawharanui Regional Park are within the historic range of the species (Higgins 1999). The red-crowned kakariki **no longer exist** at the release sites. At this stage the RGM has not been informed

1. **Threats**

Management of Threats	Potential threats: 1. Domestic cats prey on red-crowned kakariki (Taylor 1979) and thus potentially represent a threat on Rakino Island. 2. Disease transmission from Eastern Rosellas (*Platycercus eximius*) to red-crowned kakariki. 3. Disease transmission from potential migrant red-crowned kakariki (Tiritiri Matangi Island) to translocated individuals. 4. Predation of ground-nests by natural predators (i.e. Pukeko *Porphyrio porphyrio* could potentially feed on eggs or nestlings). 5. Predation of adults and juveniles by aerial predators such as Ruru *Ninox novaeseelandiae* and Australasian Harrier *Circus approximans*. 6. Re-invasion of introduced mammalian predators (i.e. rats or cats crossing the redator-proof fence at Tawharanui, arrival of mammalian species on boats of visitors to Rakino and Motuihe). 7. Currently Luis Ortiz-Catedral carries out research on Te Hoiere (Maud Island) and gets in direct contact with Orange-fronted kakariki (*C. malherbi*) and Kakapo (*Strigops habroptilus*). There is therefore a risk of disease transmission between native parrots in either direction (i.e. from red-crowns to orange-fronts and kakapo and viceversa). Management of threats 1. Domestic cats held on Rakino Island are unlikely to increase in numbers since they are non-reproductive individuals. The pet owners of these cats will be required to keep them from roaming and maintain them well feed. Also, new cats are no longer allowed on Rakino (J. McKenzie pers. Com).. 2. Risk of disease transmission will be minimised by assessing the current occurrence of diseases at source populations (i.e. Little Barrier and captive stock) and Tiritiri Matangi Island in collaboration with Richard Jakob-Hoff from the New Zealand Centre of Conservation Medicine. Eastern Rosellas occur at low densities on all sites but are nevertheless likely to associate with red-crowned kakariki (i.e. flocking at foraging sites, roosting sites). At this stage nothing is known about the health status of eastern rosellas at release sites. This species occurred on Tiritiri Matangi Island and was commonly seen foraging with red-crowned kakariki (Morag Fordham, pers. comm.). The species is now seen only rarely on Tiritiri Matangi Island, possibly due to the increase in kakariki numbers, but this has not been confirmed. Gartrell (2006) found an 8.56-20.44% prevalence of Psittacine circovirus (PBFDV) in feral Eastern rosellas in New Zealand (n=162). A potential management of this risk is the culling of Eastern rosellas, however the efficiency of such method is questionable since these parrots are common in the Auckland region (Wright and Clout 2001) and re-occurrence at release sites is very likely. Another approach is sampling Eastern rosellas in Auckland to test for the prevalence of PBDV (Gartrell's studied focused on birds from Wellington, Te Puke and Dunedin).

	3. Predation of nests by natural predators (i.e Pukeko, Ruru) was not observed on Tiritiri Matangi Island on a sample of 60 nests monitored over two consecutive breeding seasons (Ortiz-Catedral 2006). Predation of adults by Ruru and Australian Harrier has been observed at the same site (Tamara Henry and Morag Fordham pers. Obs.) and it is likely to occur on Motuihe and Rakino Islands. However, predator-avoidance behaviour by kakariki and the role of predators in the survival of translocated individuals has not yet been researched and thus this translocation offers the opportunity to address these issues. For this reason, no measures are considered to eliminate or reduce either Ruru or Australian Harriers. 4. The risk of reinvasion by introduced predators is considered under the Auckland Regional Pest Management Strategy 2007-2012 (www.arc.govt.nz). 5. Risk of disease transmission from native parrots as a result of research project on Te Hoiere (Maud Island) is minimised by using different sets of field clothing and by washing clothing and field gear with Tri-gen and Virkon. 6. Dispersal to adjoining areas is acknowledged as a risk and not subject to control. The habitat conditions at release sites are seen as benign for the parakeets but these might disperse away from study sites due to non-habitat related factors.
Current Site Management	BENEFITS: Motuihe and Rakino Islands and Tawharanui Regional Park have numerous volunteers and residents (Rakino) working on site (i.e. re-planting, track maintenance etc.). Most of them have a detailed knowledge of the island and have skills in bird identification. Thus re-sighting of animals will be increased, a clear benefit for the translocations. Volunteers have expressed interest in post-release monitoring as well (a simple basic training is required), therefore continuous monitoring at release sites is guaranteed.
Appropriate Security	The Department of Conservation (DOC) administers Motuihe Island as a recreation reserve. Rakino Island is mostly private land but DOC administers a section of the island. Management of Tawharanui Regional Park is done by the Auckland Regional Council.

9. Ecological Impacts

Refer to Chapters 2 & 6

Related Species	No related species occur either on Motuihe or Rakino Island.

Interactions and Impacts	BENEFICIAL: Red-crowned kakariki are "destructive feeders and seed predators" crushing, husking and piercing food items before ingesting them (Higgins 1999), a common feature among parrots. Seeds and berries are mashed and crushed against the underside of the upper mandible (Forshaw 1989) and only in rare occasions seeds are eaten whole (Juniper and Parr 1998). This "destructive" feeding behaviour potentially plays an important role in seed production and recruitment dynamics of plants but has not been studied so far. Studies in American species however, suggest that predation of seeds by parrots is related to forest diversity (Renton 2001). Thus, red-crowned kakariki might play a role as "ecosystem engineers" by affecting the composition and abundance of the seed bank and shaping vegetation communities. Tui (*Prostemadera novaeseelandieae*) are known to mimic red-crowned kakariki calls (Robertson 1996) and there are also anecdotal accounts of "kakariki-like" calls in the repertoire of Hihi (Rose Thorogood and Sarah Whiters, pers. comm.). It is thus likely that phonetic diversity (i.e. diversity of calls due to species present on a given area) might influence repertoire and dialect structure of forest birds. Therefore, red-crowned kakariki are likely to "enrich" the aural environment on Motuihe and Rakino Island and possibly the dialects of for instance saddleback (already on Motuihe and Tawharanui), bellbirds (*Anthornis melanura*) (already on Rakino) and kokako (*Callaeas cinerea*). Red-crowned kakariki are good flyers and are likely to disperse to adjacent areas such as Rangitoto, Motutapu etc which are currenly undergoing ecological restoration (http://www.beehive.govt.nz/ViewDocument.aspx?DocumentID=26100). The species is known to disperse from Tiritiri Matangi to Shakespear (Rimmer 2004). Furthermore, these translocations will establish additional populations of a vulnerable species in restoring areas with community involvement; therefore the potential for educational purposes is huge. Thus, the translocation of the species to Motuihe and Rakino is likely to positively affect other ecological restoration projects in the Auckland region.
Additional Management Requirements	There is no requirement for additional management
Restrict Options	It is unlikely that these translocations will prevent or negatively affect forthcoming translocations to either site.
Introduction of Weeds and Pests	The transfer of red-crowned kakariki is unlikely to increase the current risk of weed invasion to either site given the feeding habits of the species (see section 9). Clothing and field equipment will be inspected for seeds prior to translocations to minimise risk of seed dispersal as a result of translocations.

10. Disease Management

Refer to Chapter 6

Disease screening	Currently there is no disease screening of the source population, however a disease screening expedition prior to translocation is being planned in collaboration with Richard Jakob-Hoff from New Zealand Centre of Conservation Medicine (DOC permit Application currently being processed). Transferred birds will be thoroughly screened for diseases as well. Advice from Richard Jakob-Hoff will be followed as to whether risk of disease transfer is of an acceptable level to transfer the parakeets or not.
Source Population Pathogens	It is not known whether pathogens occur on both the source and release locations. The necessary tests include: skin scrape exam for mites, gross feather exam, feather bacterial culture, feather fungal culture, PBFD (viral) PCR, complete blood count, bile acids, AST, Total protein (information provided by Richard Jakob-Hoff).

Release Location Pathogens	There is no information regarding pathogens already present on either Motuihe or Rakino. For Tawharanui Regional Park, a number of bird translocations have taken place and thus information about presence of pathogens is available for a few taxa: Malaria (*Plasmodium* spp) has been found in four species on Tawharanui Regional Park: Silvereye (*Zosterops lateralis*) Bellbird (*Anthornis melanura*) Blackbird (*Turdus merula*) Thrush (*Turdus philomenos*) *Haemoproteus* has been found in two species: Blackbird (*Turdus merula*) Silvereye (*Zosterops lateralis*) It is not clear at this stage wheter the *Plasmodium* reported here is a "native" strain or an introduced pathogen. Genetic studies are needed to clarify this. This information has been provided by R.K. Barraclough (pers. Comm. 2007) and Barraclough, Cope et al. 2007 . The following information has been prepared with help of Rosalie Stamp and Tim Lovegrove (Auckland Regional Council): Also, faecal sampling of Putangitangi (*Tadorna variegata*) by Mark P. Delaney (Massey University) has yielded negative results for *Chlamydia*, *Cryptosporidium*, *Coccidia* oocysts, *Giardia* cysts, *Salmonella*, *Yersinia*, *Campylobacter*, *Clostridia*, *Aspergillus*, *Staphylococcys aureus* and *Streptococcus suis*. Similarly, during the same study no *Ascarid*, *Capillaria*, *Heterakis* or *Strongyle* eggs were isolated. Water troughs for cattle on Tawharanui have been also screened for *Escherichia coli* and Salmonella. Seven trough water samples revealed E. coli counts between 9 to 11200 cfu/100 ml but no *Salmonella*.
Spreading Potential Pathogens	Measures will be taken to minimise spread of potential unwanted pathogens, for instance all field gear will be cleaned and treated with Virkon© before and after mist-netting trip. Source populations will be sampled before catching for translocation. If any potentially harmful disease is found, infected individuals will not be used for translocation.

Note: Translocations involving terrestrial vertebrates must also meet the requirements of the SOP for Health Management of Terrestrial Vertebrate Protected Under the Wildlife Act for Fauna Only.

11. Translocation

Refer to Chapter 6

Results of Past Translocations	The red-crowned kakariki has been translocated at least nine times between 1968 and 2003 to mainland sites and off-shore islands (McHalick 1999; Adams, Airey et al. 2003). In addition, there have been a number of undocumented translocations (Higgins 1999). The translocations for which we have information are: Tiritiri Matangi, Cuvier, Whale and Matiu/Somes Islands and a mainland translocation to Huia. To date, translocations to mainland sites have failed (MacMillan 1990). Translocations to off-shore islands are considered successful, the most recent being the translocation of red-crowned kakariki to Matiu/Somes Island (Adams, Airey et al. 2003) <u>SUCCESFUL</u> **Tiritiri Matangi Island**: Around 80-90 individuals where translocated between 1974-1976 (Dawe 1979; MacMillan 1990). These birds where obtained from Mt. Bruce Wildlife Centre. Numbers have notoriously increased since eradication of

	kiore (*Rattus exulans*) (Graham and Veitch, 2002). Over two consecutive breeding seasons more 60 nests where found and birds fledged during this period have been noticed breeding afterwards indicating recruitment into the population (Ortiz-Catedral 2006). Current population on the island estimated at 700 individuals (Brunton and Stamps, 2004 unpublished). **Cuvier Island**: 30 individuals released in 1974, from Mt. Bruce Wildlife Centre. Translocation cited as successful (Higgins 1999) but there are no studies to date on their population status. On a recent visit to the localities, the species was seen and heard frequently (Dianne Brunton and Kevin Parker, pers. Comm.). **Whale Island**: Cited as an established population (Higgins 1999) but virtually nothing is known about current densities and trends in population numbers. Birds originally from Bay of Plenty. **Matiu/Somes Island**: Eleven males where first translocated from Kapiti Island in 2003 and a subsequent release of 20 individuals including females took place in 2004. For the first translocation, a soft-release approach was followed and an aviary constructed on site (the birds spent nine days in aviary). A number of volunteers spent at least nine weekends monitoring released birds and at present breeding has been reported. The translocation is deemed as successful (www.doc.govt.nz/templates/news.aspx?id=42379). FAILED **Huia:** approximately 33 captive-bred individuals where released in two attempts in 1977. Little is known about the fate of these birds. Subsequent visits to the location revealed no kakariki and the translocation is considered a failure (MacMillan 1990). In addition to transfers of red-crowned kakariki, a number of translocations of the closely related yellow-crowned and orange-fronted kakariki have taken place: TRANSLOCATIONS OF CLOSELY RELATED SPECIES **YELLOW-CROWNED KAKARIKI** were transferred from Te Kakaho Island to Motuara Island, using a hard-release approach. Birds were held in a portable aviary no longer than three days before being transferred in two lots to Motuara. Birds are regularly seen and heard (Bill Cash, DOC pers. Com.). The species has also been successfully translocated from the Chetwode Islands to Mana Island (T. Greene, DOC pers. Com). **ORANGE-FRONTED KAKARIKI** has been successfully reintroduced from a captive breeding facility to Chalky Island in Fiordland and into Maud Island in the Marlborough Sounds (J. vanHal DOC pers. Com).

2. **Transfer design**

Composition	Motuihe Island: • Age: Adults • Sex ratio: Even sex ratio • Singles/pairs: Pairing in most monogamous parrots (such as kakariki) is idiosyncratic (Stone, Millam et al. 1999; Spoon 2002) and thus pairs are expected to be formed on site. On a recent translocation of orange-fronted kakariki, a pair was formed within a week of release (Simon Elkington, 2007, pers. Comm.) Thus the prospects of pairing shortly after the translocation of the closely related red-crowned kakariki are good. • Number of individuals: 40 • Proposed dates for translocation: Late April-Early May 2008. Tawharanui Regional Park: • Age: Breeding adults • Sex ratio: Even sex ratio • Singles/pairs: see above • Number of individuals: 40. Rakino Island: • Age: Breeding adults • Sex ratio: Even sex ratio • Singles/pairs: see above • Number of individuals: 30. • Proposed dates for translocation: Late April-Early May 2009. Little is known about the secondary sex ratio in current populations. At fledgling, the proportion of males and females does not differ from parity (Ortiz-Catedral 2006) but it is not known if post-fledging survival is biased towards one sex. It has been suggested that males have higher survival rates than females on the basis of banding and re-capture of kakariki on Poor Knights Islands, but this might be the result of differences in activity between sexes and thus likelihood of capture (Sagar 1988; Higgins 1999). This composition has been chosen to test whether or not post-release survival is different between sexes and also to maximize the number of potential breeding pairs on site.
Threshold of Success	1. Survival of 60% of released birds (per site) 6 months after translocation 2. Pairing and breeding one year after the translocation or sooner. In the closely related Orange-fronted parakeet released on Maud Island, pairing and nesting occurred within the first month after release (L. Ortiz-Catedral, pers. Obs.). The same pattern was observed on Chalky Island in 2006 (Jack van Hal, pers. Comm.). For yellow-crowned parakeets translocated to Long Island, breeding was also recorded within the first year after translocation (Bill Cash, pers com.)
Dispersal	Potential dispersal to The Noises, Motutapu and Rangitoto Islands. Refer to Section 9 "Interactions and Impacts".

Transfer methods **Methods**	It is proposed to capture a total of 110 red-crowned kakariki on Little Barrier Island (Hauturu) using standard mist-netting techniques **over three main harvesting sessions**. The duration of the harvesting sessions will vary between seven to fourteen days since good weather is required to operate mist-nets. It is anticipated that target numbers will be reached within 9 mist-net days. One transfer per site (or two per site if target numbers are not obtained) is proposed and no further releases are planned at this stage. Capture and transfer is proposed to take place outside the breeding season, in late April-May 2008 (Motuihe Islands), late August-September 2008 (Tawharanui Regional Park) and finally late April-May 2009 (Rakino Island). Adults will be favoured for translocation to minimise any age-related mortality. An even sex ratio will also be targeted. Kakariki will be weighed, measured and given a unique combination of colour and metal bands. Kakariki will be held in an aviary already constructed on Little Barrier Island. All handling and sampling will adhere to methods approved by the Animal Ethics Committee of Massey University (application under evaluation). Once the mist-nets are erected, one to two team members will check it continuously to ensure any trapped birds are removed as soon as possible in order to minimise stress. It is known that parakeets are susceptible to handling, with mortality reported in yellow-crowned parakeets and red-crowned parakeets (Terry Greene, pers. comm., 2004) and Chatham Islands red-crowned parakeet X Forbes parakeet (Dan Tompkins, pers. Comm., 2007). Therefore, minimising handling time will be a priority. Following capture, all parakeets will be measured, weighed, given a unique combination of metal and colour bands, and blood and feather samples will be taken, After individual parakeets have been processed they will be transferred to an on site aviary where a thick cover of branches and foliage will be installed inside the aviary to provide shelter. Also a mixture of natural foods (i.e. *Coprosma*, Mahoe, *Cabbage* tree berries) and artificial food (jam water, fruit, vegetables, millet sprays) will be provided *ad libitum* along with clean drinking water. It is anticipated that target numbers for each harvesting session will be obtained within nine days based on experiences from a disease screening trip to Little Barrier Island carried out 19th to 26th of February 2008 (L. Ortiz-Catedral, unpub.). Kakariki chosen for translocation will be thus held in captivity at the Little Barrier Island for up to nine days. During the translocation of this species from Kapiti Island to Matiu/Somes Island, kakariki were held on an aviary for nine days without showing adverse effects (Adams, Airey et al. 2003). If up to five parakeets die during holding at the aviaries, replacement individuals will be captured to reach the target number. However, if more than five parakeets die while at the aviary and time constrains prevent more captures, parakeets will be released despite a lower number than originally planned. If some kakariki die while in transit to release sites further captures might be considered but first necropsies will be performed on birds to establish cause of death. In previous translocation of kakariki mortalities have been minimal. During each harvesting session, a subgroup of parakeets will be held individually in pet-carry boxes lined with closed-cell foam with hessian over the foam so the parakeets can hold to it (Lyn Adams, pers. Comm., 2007). This subgroup will be used to quantify induced immune response by injecting subcutaneously into the patagium a solution of phytohaemagglutinin (PHA; 0.5 mg of phytohaemagglutinin dissolved in 0.1 mL phosphate buffered saline). This injection will cause local inflammation. Such swelling response will be measured using plastic callipers at 6, 12 and 18 hrs after injection. Handling during this period will be short, limited to the necessary time to measure swelling of patagium. Once measurements are completed and if the target number of parakeets has not been obtained, PHA treatment parakeets will be released into the aviary. In case the total number of parakeets has been obtained by the time the patagium measuring regime finishes then birds will be kept in the pet-carry box and released at experimental sites (Motuihe Island, Tawharanui Peninsula and Rakino Island). The treatment with PHA on the parakeets will be used to analyse the correlation between immune response of founders and survival, pairing, exploratory movements and breeding success.

	Given the novelty of the PHA trials on red-crowned parakeet and the uncertainty repeated handling will have on the birds, two precautionary steps will be followed: Before the PHA trials start, the injection of PHA and associated handling at 6, 12 and 18 hours after injection will be studied in a single parakeet. If this individual shows any adverse effects or signs of high stress, or death the PHA trials will be suspended. If the experimental bird survives and does not show adverse effects 24 hours after treatment the trials will proceed. However, if during these experimental manipulations up to three parakeets die, PHA-related handling will be immediately suspended and the experiment abandoned altogether On the day of translocation, parakeets will be captured inside the aviary and held in carton pet-carry boxes. From Little Barrier Island, parakeets will be taken by Helicopter to Motuihe and the target number for this locality released (40 parakeets). Later in the year, additional parakeets from Little Barrier Island (second harvesting trip) will be transferred from Little Barrier to Tawharanui Regional Park and finally a third harvesting session will take place to capture kakariki destined to Rakino Island during April-May 2009. The total numbers of parakeets used for the PHA treatment will be half of the founder flock per release site, namely: *Motuihe Island*: Founder flock of 40 kakariki, of these 20 will be used for the PHA treatment. *Tawharanui Regional Park*: Same as above. *Rakino Island*: Founder flock of 30 kakariki, of these 15 will be used for the PHA treatment.
Contingency Plan	If target numbers per harvesting session are not attained within nine mist-net days, captured kakariki will be released on site and a second attempt to reach target number will occur within a month of the first attempt. If the translocations fail (i.e. more than 60% of transferred birds die within the first three months and no breeding is recorded after one year) the translocation programme will be reviewed and an additional translocation might be considered. However, no further translocations will take place **unless the causes of failure are clearly identified.** This in order to prevent additional failures.

12. Monitoring and Post Release Management

Monitoring Programme	Unlike other transfers of kakariki, intense monitoring will follow after release. A 3-year monitoring program is guaranteed since this translocation is part of a PhD by the applicant (L. Ortiz-Catedral). Birds will be monitored once a week for the first two months after release and twice per month thereafter for one year. After this period, monthly visits to release sites will follow. If individuals are found dead, corpses will be collected for necropsy to establish cause of death. If skins or skeletons are in good condition after necropsy these will be deposited at the Auckland War Memorial Museum. The monitoring programme has three components: 1. Radio tracking 2. Broadcasting of calls 3. Distance sampling 4. Monitoring of breeding *Radio tracking*: First two months after release (approximate battery life of tail-mount transmitters). Release sites will be visited on a weekly basis and location of the birds will be determined by homing on signal strength. Recorded data will include date, time, bird identification, location, perch type (plant species, height above the ground, vegetation type). The software "Ranges V" will be used to analyse radio-tracking data. *Broadcasting of calls*: once per month from month three of release. A variety of kakariki calls will be played for 5 minutes (2 minutes calls, 1 minute break and 2 more minutes play) along main tracks to cover most of the area of the release sites.

	Playback spots will be located every 100 meters. *Distance sampling*: Once per month outside the broadcasting period. A total of 25 transects (100 m long each) will be randomly chosen on Motuihe and Rakino Island. On Tawharanui Peninsula a total of 50 transects will be chosen given the larger area of this site. These transects will be walked once per month and any kakariki seen will be recorded. The perpendicular distance from the kakariki to the observer will be estimated using a laser rangefinder. Detectability of kakariki will be analysed using the programme DISTANCE (Buckland, Anderson et al. 2001). Estimates obtained from broadcasting and distance sampling will be compared to determine the most effective monitoring technique for newly translocated populations of kakariki. *Monitoring of breeding*: During late spring throughout early autumn potential natural nesting sites will be inspected on an opportunistic basis. In addition, Saddleback nesting boxes placed on Motuihe Island will be inspected twice per month. Also, kakariki exhibit a series of stereotypical nesting behaviours that make nest-finding a straightforward task. Potential breeding pairs will be identified by opportunistic observations of pre-nesting behaviours such as cavity inspection, pair roosting, courtship feeding, and aggressive displays towards conspecifics in or around potential nesting sites. Natural nests will be located by inspection of tree cavities, rock crevices, vegetation clusters, trunks and burrows for signs of kakariki activity (i.e. droppings, feathers, egg shells). For every natural nest found, location and plant species will be recorded. Nests will be visited at least once per week to document nest development and success. For a detailed summary of research methods refer to approved permit DOC permit Ak-19621-FAU.
Post Release Management	No need for any post-release management is being considered

13. Consultation and Community Relations

Tangata Whenua	Ngati Manuhiri. Mr Terrence Hohneck (General Manager Manuhiri Omaka Kaitiakitanga Ora o Moko) has been consulted via telephone and he agrees with the objectives outlined in this proposal. So far his only request for this project to go ahead is full approval of the methods described in this application by the Department of Conservation and Animal Ethics Committe. He has also been offered the opportunity for a welcome ceremony when the birds arrive at release sites.
Affected and Interested Parties	Motuihe Island Restoration Project: involved in financial assistance, post-release monitoring. Rakino Island community: involved in post-release monitoring. Tawharanui Open Sanctuary Society Incorporated (TOSSI): Financial assistance under evaluation. All three groups are supportive of the translocation. Support letters to be received.
Public Participation	-Opportunity for Media Release during welcome ceremony for the birds on Motuihe and Rakino Islands and Tawharanui Regional Park. -Subject to availability of accommodation on Little Barrier Island, media crew might have the opportunity to cover the capture of kakariki.
Public Relations	A positive reaction is anticipated. Motuihe Island and Tawharanui Regional Park are highly visited and the translocation of kakariki represents a further step in the ongoing ecological restoration project. The same applies for Rakino Island.

14. Budget

Business Plan (DOC proposals only)	NA.
Resources Required	•

Description	Budget	Source
Pre-translocation disease screening (40 samples)	10 000	Auckland Regional Council Environmental Initiatives Fund (EIF) (Under evaluation) Application under evaluation Private Funds
Disease screening during translocation (110 samples)	20000	Motuihe Island Trust Massey University Private Funds
Holohil Tail mount transmitters (50)	10000	Motuihe Island Trust/Massey University/Private Funds
Helicopter transportation by Helicopter from Hauturu to Motuihe	1700	Motuihe Island Trust
Helicopter transportation by Helicopter from Hauturu to Tawharanui Regional Park	1700	British Ornithologists Union (under evaluation)
Helicopter transportation by Helicopter from Hauturu to Rakino Island	1700	Australia and Pacific Science Foundation (under evaluation)
Mist-nets and basic field equipment	2000	Massey University
Sampling consumables (needles, gloves, etc.)	500	Massey University
Food and accommodation of field trips crew	2000	Massey University/Private Funds
Transportation boxes	250	Private Funds
Contingency budget for additional trips to Hauturu and additional Helicopter transportation	5000	Motuihe Island Trust Massey University Private Funds
	$54, 850	

15. Permits and Approvals

Permits and Approvals	Submitted to the Auckland Conservancy Submitted to Department of Conservation, Auckland Area Office To be submitted to Massey University Animal Ethics Committee

Note: all permits and approvals must be obtained prior to the transfer occurring.

16. Specialist Advice

Planning Transfer	Copies of Draft have been sent to the following: Terry Greene, Department of Conservation, Christchurch Conservancy Jack van Hal, Department of Conservation, Christchurch Conservancy Mike Aviss, Department of Conservation, Marlborough Sounds Area Office Rosalie Stamp, Auckland Regional Council Tim Lovegrove, Auckland Regional Council Doug Armstrong, Massey University Lyn Adams, Department of Conservation, Wellington Conservancy

Recovery Group	There is no recovery group for the red-crowned kakariki
Legal	N/A

17. Concurrence

Concurrence of Affected Conservancy/ies	AUCKLAND CONSERVANCY
Dissenting Views	
RGM Concurrence	

18. Approval

Refer to Chapter 6

This translocation proposal is **Approved / Not Approved**

Lead Conservators Name: _____

Signature: _____

Date: _____ /_____ /_____.

The Lead Conservator may request that the RGM approve the proposal because of the nature of the issues e.g. highly contentious. In this case the Lead Conservator is to send a cover note to the RGM stating issues, indicating whether they support the proposal and requesting that the RGM exercise the approval.

19. References

For example, references cited in the text, such as scientific papers.
References are to be specific and traceable.

20. Appendices

For example:

- Contact details for Tangata Whenua
- Endorsement from Tangata Wheuna
- Contact details for Affected and Interested Parties
- Table of Resources Required
- Endorsement from Recovery Group

Return to SOP
Go to Checklist

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APPENDIX 2

Re-introduction of captive-bred Mahlerbe's parakeet to Maud Island, Marlborough Sounds, New Zealand

Published in Soorae, P. S. (ed.) (2010) GLOBAL RE-INTRODUCTION PERSPECTIVES: Additional case-studies from around the globe. IUCN/SSC Re-introduction Specialist Group, Abu Dhabi, UAE, xii + 352 pp.

Full book available at: http://www.iucnsscrsg.org/rsg_book.php

Re-introduction of captive-bred Malherbe's parakeet to Maud Island, Marlborough Sounds, New Zealand

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Introduction

The Malherbe's parakeet (*Cyanoramphus malherbi)* is a critically endangered New Zealand endemic (Juniper & Parr, 1998; Kearvell *et al.*, 2003) confined to three remnant populations in the South Island (Robertson *et al.*, 2007) and two populations on offshore islands established by the release of captive-bred individuals (Elliot & Suggate, 2007). The species has a long taxonomic history, in large part due to its morphological and phenotypic similarity to the yellow-crowned parakeet (*Cyanoramphus auriceps*) and only recently has been recognized as a distinctive species (Boon *et al.*, 2000). By the time the species was recognized as a separate evolutionary unit, the global population was thought to be around 500 individuals in the wild (Kearvell, 1997 cited in Boon *et al.*, 2000).

As with other *Cyanoramphus* species, introduced predators such as mustelids (*Mustela* spp.) and rats (*Rattus* spp.) and human-induced habitat modification are thought to be the major drivers of the species decline (Grant & Kearvell, 2000). Following the recognition of the Malherbe's parakeet as a distinctive species in urgent need of conservation action, the Department of Conservation in partnership with the Isaac Wildlife Trust, established a captive-breeding program aimed at providing individuals for later re-introduction to offshore islands free of introduced predators (Grant & Kearvell, 2000). Starting in 2005, captive-bred individuals have been released on Chalky Island, Fiordland and in 2007 on Maud Island, Marlborough Sounds. The release of captive-bred Malherbe's

Malherbe's parakeet (*Cyanoramphus malherbi*)

parakeets has provided a unique opportunity to study its biology on island environments free of mammalian predators, which provide a safe environment for this critically endangered species.

Goals

- Goal 1: Establishment of a self-sustaining population of Malherbe's parakeets on Maud Island.
- Goal 2: Geographic expansion of the species.

Success Indicators

- Indicator 1: 50% survival of first founder flock three months after release.
- Indicator 2: Successful breeding on Maud Island within a year of translocation.

Project Summary

Maud Island (also known as "Te Hoiere") is a Scientific Reserve (296 ha) located in the Marlborough Sounds of the South Island, New Zealand and administered by the Department of Conservation. Maud Island was identified as an eligible release site for Malherbe's parakeets due to the presence of remnants of coastal forest (47 ha) and remnants of regenerating forest (220 ha), which contain mature trees likely to provide nesting sites. Three areas of *Pinus radiata* (former pine plantations, 17 ha) and grassland (2 ha) are also present on the island. Maud Island does not have other resident parakeet species, which was considered an important feature to prevent hybridization (Grant & Kearvell, 2000). Most significantly, Maud Island is considered mammalian-predator free except for the sporadic incursions of stoats (*Mustela erminea*) (Elliot *et al.*, 2001). Finally, Maud Island is accessible by boat and helicopter and has a track network that allows monitoring of the parakeets (Ortiz-Catedral and Brunton, 2009).
Starting in March 2007, 68 Malherbe's parakeets bred in captivity at the Isaac Wildlife Trust in Christchurch, were transferred by plane from Christchurch to Blenheim airport and by helicopter from Blenheim airport to Maud Island. Parakeets have been released onto Maud Island on eight occasions. Groups released have varied from three to 14 individuals ranging in age from two months to approximately four years. Although the proportion of males and females varied between releases, an overall even sex ratio has been achieved by the release of 34 females and 34 males. The releases were planned according to the number of fledglings available at the captive breeding facility and consequently, the releases occurred two to 11 months apart and consisted of flocks of three to 14 birds. Prior to release, all parakeets were given a unique metal numbered band and a combination of plastic coloured bands for individual identification. Also, 20 parakeets were fitted with tail mount transmitters prior to release.

Teams of four observers undertook monitoring approximately every two months. Three months after the first release (which consisted of 11 individuals), eight individuals (72%) were confirmed alive, six of them in breeding pairs. The first evidence of breeding behaviour was noticed within a month of release when courtship behaviour was observed in a pair. Subsequently, two actively incubated clutches were found within two months of the first release. The first confirmed

fledged juveniles (3) were recorded three months after the first release. Sightings of unbanded Malherbe's parakeets have been made consistently across the island since. In November 2008, two breeding pairs of unbanded adults were observed nesting near ground level. A clutch of two eggs was confirmed in one nest. Since the first release, Malherbe's parakeets have been recorded foraging in all vegetation types around the island on native and exotic plant species as well as taking invertebrates (Ortiz-Catedral and Brunton, 2009) indicating that captive-bred individuals make use of all available habitats of Maud Island.

Parakeet habitat on Maud Island

Major difficulties faced

- Hard to monitor: Limited access to areas on Maud Island where other critically endangered species occur (i.e. Maud Island frog *Leiopelma pakeka*) meant that monitoring of parakeets had to be restricted to the track network (Ortiz-Catedral & Brunton, 2009) and the shoreline of the island. This means that during the first two years after the first release only limited information was obtained in this low-density population.
- Discrepancies between management priorities by the Department of Conservation and research needs from academics originated conflict over techniques for data collection and the level of acceptable handling of individuals. Such situation developed an agreement over a minimum of research goals to study the biology of this species on an island for the first time. Consequently, the breeding biology of this species remains poorly studied.

Major lessons learned

- Long-term monitoring schemes must be implemented considering the access limitations on site.
- Discrepancies between the management and research approaches need to be negotiated further to encourage further field research for this critically endangered species. Both approaches are complementary and when combined have the potential to advance the improvement of the conservation status of Malherbe's parakeets.

Success of project

Highly Successful	Successful	Partially Successful	Failure
√			

Reason(s) for success/failure:

- The re-introduction of captive-bred Malherbe's parakeets on Maud Island has resulted in an increase of the global population of this taxon.
- In addition, the geographic range of the species has been expanded

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APPENDIX 3

Conservation translocations of red-fronted parakeets on Matiu/Somes Island and Motuihe Island, New Zealand

Published in Soorae, P. S. (ed.) (2010) GLOBAL RE-INTRODUCTION PERSPECTIVES: Additional case-studies from around the globe. IUCN/SSC Re-introduction Specialist Group, Abu Dhabi, UAE, xii + 352 pp.

Full book available at: http://www.iucnsscrsg.org/rsg_book.php

Conservation translocations of red-fronted parakeet on Matiu/Somes Island and Motuihe Island, New Zealand

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Introduction

The red-fronted parakeet (*Cyanoramphus novaezelandiae*) is a vulnerable species (CITES App. I) endemic to New Zealand and its outlying islands (Juniper & Parr, 1998). Sub-fossil evidence and accounts by early ornithologists indicate the species was widely distributed throughout the archipelago (Higgins, 1999). Natural populations of the red-fronted parakeets are currently restricted to predator-free offshore islands with sporadic sightings on North and South Islands and a few locations on Stewart Island (Higgins, 1999; Robertson *et al.*, 2007).

This species marked population decline and reduction in geographic range has been attributed to a combination of predation by introduced mammals (mainly rats (*Rattus* spp.), stoats (*Mustela erminea*) and cats (*Felis catus*)), hunting and large-scale anthropogenic habitat modification (Higgins, 1999). Red-fronted parakeets are commonly kept in captivity under specific permits by the Department of Conservation, New Zealand. Since 1974 the species has been repeatedly translocated to islands and mainland sites undergoing community-led ecological restoration resulting in at least five successfully established island populations. Earlier releases of captive-reared red-fronted parakeets were prompted by the widespread availability of captive stock but little consideration was given to the potential of remaining natural populations to act as sources for translocation or to conservation issues such as, hybridisation, genetics, disease prevalence, meta-population dynamics and susceptibility to pathogens. Accordingly, in 2005 the Department

Red-fronted parakeet
© L. Ortiz-Catedral

of Conservation made a recommendation to stop further releases of captive-bred parakeets because preliminary analyses showed that much of the captive-bred stock has been hybridised with the closely related yellow-crowned parakeet (*Cyanoramphus auriceps)* (Triggs & Daugherty, 1988). Starting in 2003, we have carried out a series of translocations of red-fronted parakeets using wild individuals caught from natural populations which has allowed the improvement of capture, housing, transport and translocation techniques for this species.

Goals

- Goal 1: The identification of potential source and predator-free release sites within the natural range of the species.
- Goal 2: The generation of baseline information on pathogen load on Little Barrier Island (LBI).
- Goal 3: The translocation of at least 30 individuals per site.

Success Indicator

- Indicator 1: 50% survival of founders six months after release (for translocations from LBI).
- Indicator 2: Successful breeding at release sites within a year of translocation.
- Indicator 3: Unassisted dispersal to adjacent conservation management sites.

Project Summary

Between 2003 and 2007 we identified two prospective island source populations of red-fronted parakeets for conservation translocation: Kapiti Island and Little Barrier Island. The species is common on both islands and the sites are easily accessible by boat and helicopter. We also identified two potential release islands following requests by community groups directly involved with the ecological restoration of such sites: Matiu/Somes and Motuihe Islands. The most important criteria for the selection of release sites was the sustained absence of introduced mammals; a factor that has been linked to the disappearance of this species across its historic range (Ortiz-Catedral *et al.*, 2009b). Ship rats (*Rattus rattus*) were eradicated from Matiu/Somes in 1989 while Norway rats (*Rattus norvegicus*) were removed from Motuihe in 1997 (Clout & Russell, 2006). Matiu/Somes and Motuihe Islands have been revegetated with native plant species and numerous nesting sites were identified before the release of parakeets. These nesting sites include burrows, rock crevices, holes in trunks and vacant sacred kingfisher (*Todiramphus sanctus*) nests. One hundred artificial nest boxes were also installed on Matiu/Somes Island. Additionally, Matiu/Somes and Motuihe Island are in close vicinity to other areas undergoing restoration and/or pest control, which would allow red-fronted parakeets to naturally disperse. Suitable sites in the proximity of Matiu/Somes Island include Zealandica, Karori Wildlife Sanctuary, Eastbourne's Mainland Island Restoration Operation and Regional Council land within Wellington City. For Motuihe Island, the Rangitoto/Motutapu Island restoration project is less than 2 km away. Thus Matiu/Somes and Motuihe were considered ecologically suitable for translocation.

There are no published studies on the genetics of remnant red-fronted parakeets to assist management decisions regarding provenance of founder flocks.

Natural habitat on Little Barrier Island
© L. Ortiz-Catedral

However, due to the geographic proximity of Kapiti Island to Matiu/Somes Island and Little Barrier Island to Motuihe Island and because both source islands have large populations that have not undergone significant historic declines it was decided these would be the most appropriate source/ release site associations. Finally, Kapiti and Little Barrier Islands have excellent field logistical support with existing aviaries and accommodation from ongoing fauna management practices. Kapiti, Little Barrier, Matiu/ Somes and Motuihe Island are administered by the Department of Conservation, New Zealand in partnership with local indigenous communities (Te Atiawa ki Whakarongotai, Te Ati Awa, Ngati Manuhiri, Ngati Wai) and community trusts such as Matiu/Somes Island Charitable Trust and Motuihe Island Trust. Red-fronted parakeets commonly forage in grassland and coastal forest fragments allowing operation of mist nets. A total of 31 parakeets were captured on Kapiti Island between 27th and 29th of May 2003 (11 birds) and 19th to 23rd April 2004 (20 birds) and transferred by boat, car and/or helicopter to a purpose-built aviary on Matiu/Somes on 30th May 2003 and 23rd April 2004. No disease screening was undertaken. The parakeets were released directly from the aviary eight and three days later, respectively. Monitoring was undertaken by volunteers with variable bird observation skills and so reliable monitoring results were sporadic. Mating was first observed two months after the first release but the first juveniles were not confirmed until a year later, soon after the second release. No efforts were made to find or monitor nests although nest boxes were checked monthly for the first two years and were apparently not used. Subsequently juveniles have been seen on a regular basis (identified by the absence of bands and by their juvenile plumage) and a healthy population is considered to be established, although no population census has been attempted. Red-crowned parakeets are now occasionally seen in the adjacent areas of Wellington City

On Little Barrier Island, 49 red-fronted parakeets were captured in two events: 5th to 18th of May 2008 (31 individuals) and 3rd to 9th of March 2009 (18 individuals). Capture was by mist-nets placed along known foraging grounds. All birds destined for translocation were held in an aviary on site for up to eight days. Screening for *Salmonella*, *Campylobacter*, *Yersinia* and Beak and Feather Disease Virus (BFDV) were conducted (Ortiz-Catedral *et al.*, 2009b, 2009c). On the day of release, parakeets were placed individually in pet-carry cardboard boxes and transferred via helicopter to Motuihe Island where they were released.

Twenty parakeets had radio-transmitters mounted on two tail feathers. Parakeets were radio-tracked once per week for three months (the total duration of the battery life). Additional monitoring consisted of observer walks across the whole track system on Motuihe Island once every two weeks for three months after release. Six months after release parakeets on Motuihe Island were monitored once per month in addition to sporadic sightings by volunteers who visit the island weekly to plant trees or remove weeds. Six months after the release of the first flock (31 birds), eight breeding pairs and their territories were identified. The first evidence of breeding on Motuihe was a female visiting a cavity in a Puriri (*Vitex lucens*) tree five months after release. Subsequently, four fledglings in two groups were seen on January 2009, eight months after initial release. Unbanded juveniles have been sighted consistently since and there have been reports of pairs of red-fronted parakeets on nearby Rangitoto Island and Motutapu Island (Graham, 2009). We successfully transferred a minimum of 31 red-fronted parakeets to target restoration islands and there is evidence of high survival of founders within the first semester after translocation. Further, successful breeding was recorded within a year of the first release and unassisted dispersal to neighboring areas has occurred. We thus consider these translocations highly successful.

Major difficulties faced

- Seasonal changes in numbers of parakeets available for capture. Time of capture is also crucial. Catching rates were high during April-May on LBI and numerous juveniles were noticed and thus these are considered ideal months for capture and transfer. One attempt to capture parakeets in September on LBI resulted in only two individuals being captured and subsequently released locally due to insufficient catching rates

- Holding aviary design and management of birds while in the aviary is important to ensure weight loss is minimised and to avoid mortality from flushing/fright in the aviary. Three birds held on Kapiti Island died from collision into the aviary and two deaths occurred on LBI.
- Red-crowned kakariki are known to die from stress associated with handling. Of the 80 birds transferred (31 Kapiti-Matiu.Somes; 49 LBI-Motuihe Island) one individual destined for release on Matiu/Somes and one released on Motuihe Island apparently died from stress related causes.
- Management of diseases: Neither *Salmonella*, *Yersinia* or *Campylobacter* were found on Little Barrier Island (Ortiz-Catedral, Ismar *et al*., 2009) however, BFDV was detected in 28% of 54 individuals screened (Ortiz-Catedral, McInnes *et al*., 2009). Only non-infected individuals and infected but sub-clinical individuals were released on Motuihe Island. Because this finding represents the first report of the virus in wild New Zealand parrots a major revision of translocation practices for New Zealand psittacines is underway.
- Hard to monitor. Need experienced people to be able to identify individuals by their colour bands and calls. The introduced and widely distributed eastern rosella (*Platycercus eximius*) is often mistaken for red-fronted parakeets by less experienced observers.

Major lessons learned

- Communication between wildlife managers, academic researchers, community groups and local indigenous communities is crucial for timely capture and transfer of parakeets.
- Once transferred, parakeets appear to quickly establish a breeding population with minimal management needed after release. The addition of nesting boxes seems to have little influence in likelihood of establishment and parakeets readily make use of any available nesting sites such as tree-holes.
- The recent finding of BFDV during a translocation of wild red-fronted parakeets has prompted a revision of translocation priorities, policies and risks associated with the management of all New Zealand parrots.

Success of project

Highly Successful	Successful	Partially Successful	Failure
√			

Reason(s) for success/failure:

- Establishment of two additional populations using wild sourced animals.
- Successful breeding shortly after release.
- Natural dispersal to neighbouring islands and mainland areas where predator control occurs has been noticed, thereby increasing the chances of new populations establishing without intervention.

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APPENDIX 4

Notes on the diet of the critically endangered orange-fronted parakeet (*Cyanoramphus malherbi*) on Maud Island

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Notes on the diet of the critically endangered orange-fronted parakeet (*Cyanoramphus malherbi*) on Maud Island

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Abstract We conducted opportunistic observations on the diet of translocated orange-fronted parakeets (*Cyanoramphus malherbi*) on Maud Island to provide a first account of the diversity of food types ingested in the wild by this critically endangered species. Orange-fronted parakeets consumed fruits and leaves of 14 plant species as well as non-dietary items such as bark sticks and grit. Of dietary items, 96% were on plant species and 4% invertebrates. Of the plant species ingested 10% were non-natives. A major dietary component consisted of fruits and leaves of mahoe (*Melicytus ramiflorus*). In contrast to the only other published account of the diet of orange-fronted parakeets, invertebrates constituted a minor part of identified ingested items. This may be related to the different composition of vegetation at the study sites, the low parakeet population density during the time of our study and methodological restrictions during our survey. Our observations on undocumented food items add information about the biology of New Zealands' rarest parakeet species and indicate dietary flexibility of the species highlighting the potential of other regenerating islands as release sites to expand the geographic distribution of orange-fronted parakeets.

Keywords diet; orange-fronted parakeet; New Zealand; translocation

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INTRODUCTION

The orange-fronted parakeet (*Cyanoramphus malherbi*) also known as "Malherbe's parakeet" and "orange-fronted kakariki" has been recognised as a separate species since 2000 on the basis of mtDNA analysis (Boon et al. 2000). This taxon is at present the rarest of all New Zealand *Cyanoramphus* species and it is internationally recognised as critically endangered (www.iucn.org) with a global population of around 300 individuals (www.birdlife.org). The geographic distribution of remaining orange-fronted parakeets is restricted to three valleys in the Canterbury region, were it inhabits *Nothofagus* forest and scrubland (Grant & Kearvell 2002). Since 2005, the species has been bred in captivity at the Isaac Wildlife Trust, Christchurch and reintroduced to Chalky Island (Te Kakahu o Tamatea) and Maud Island (Te Hoiere). At the latter site between March 2007 and January 2009, 62 individuals were released. There are at present no studies on the biology of reintroduced captive-bred orange-fronted parakeets. In addition to its rarity, the species is secretive, and often dwell in the high forest canopy making systematic observations difficult. During a study on the breeding biology of the species on Maud Island (Ortiz-Catedral et al. unpubl.) we made opportunistic observations on feeding orange-fronted parakeets to qualitatively document the diversity of food types eaten by the species. Here we present the first descriptive account of the diet of translocated orange-fronted parakeets to update current knowledge of this poorly known and critically endangered species.

METHODS

Maud Island (41°1′28″S, 173°53′19″E) is a 296 ha scientific reserve managed by the Department of Conservation in the Marlborough Sounds, New Zealand. The island is covered by remnant native broadleaved coastal forest (47 ha), regenerating scrub dominated by manuka (*Leptospermum*

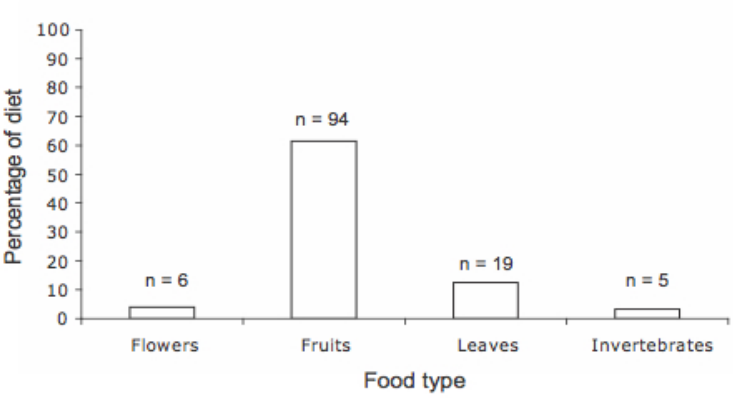

Fig. 1 Feeding bouts recorded over 22 months for orange-fronted parakeets on Maud Island.

scoparium) and kanuka (*Kunzea ericoides*) (220 ha), introduced pine forest (*Pinus radiata*) (17 ha) and grassland (2 ha). From March 2007 to January 2009 we visited Maud Island, approximately every second month (total 17 visits to site). Two to three times per week between 7:00 and 18:30 h during each visit to the island, four observers in two teams walked the entire track network on Maud Island to record sightings of orange-fronted parakeets as part of the monitoring programme for this population (Ortiz-Catedral et al. unpubl.). During these events, we recorded opportunistic sightings of foraging orange-fronted parakeets. We restricted our observations to the track network on the island to minimise disturbance (i.e., noise around nesting or foraging areas, vegetation clearing for access) to other critically endangered species found in dense forested patches of Maud Island, such as the Maud Island frog (*Pakeka* sp.), takahe (*Porphyrio mantelli*) and kakapo (*Strigops habroptilus*) following advice by the New Zealand Department of Conservation. We recorded feeding observations for individuals or groups of orange-fronted parakeets, taking note of their band combination (every captive-bred individual is given a unique metal and colour band combination by the New Zealand Department of Conservation) and their height from the ground. We also recorded the classified the material ingested as "dietary" and "non-dietary" as well as plant species. We separated dietary items into food types such as "fruit" (including unripe and ripe), "flower" (including flower buds and inflorescences), "leaves", or "invertebrates". Non-dietary items were classified as "bark" (including loose bark picked from the ground), "sticks" and "grit" (either collected from the floor or from banks). Our unit of sampling was "feeding bouts" (Altman 1974; Galetti 1993). When an individual or a group of orange-fronted parakeets moved foraging between plants, we recorded these observations as separate feeding bouts unless they moved to an adjacent plant of the same species. Our sampling methodology was aimed at providing an overview of the species eaten by orange-fronted parakeets rather than a quantitative analysis of the diet. Pairs, trios or groups of more than three individuals foraging together in the same plant species were recorded as a single feeding bout. Although large areas of the island were not included in our sampling scheme and our observations can not be regarded as independent, opportunistic observations along the tracks provide useful information to compile the first account on the diversity of food types ingested by translocated captive-bred orange-fronted parakeets.

RESULTS

We recorded 153 feeding bouts from 25 banded individuals and 13 unbanded individuals hatched on Maud Island. Of these, 132 feeding bouts were recorded from individual birds, 17 on pairs, two on trios and two on groups of four parakeets. A total of 124 observations (81%) consisted of dietary items and 29 (19%) of non-dietary items. Orange-fronted parakeets consumed mostly fruits (61.4%) and leaves (12.4%), whereas much smaller quantities of flowers (3.9%) and invertebrates (3.3%) were also ingested (Fig. 1). Most feeding bouts (96%) were plant material, and only 4% consisted of unidentified invertebrates. Orange-fronted parakeets foraged between 3 and 8 m above the ground on both native

(90% of observations) and introduced plant species (10% of observations) (Table 1). Orange-fronted parakeets also consumed non-dietary items such as bark and sticks of tutu (*Coriaria arborea*), manuka, mahoe (*Melycitus ramiflorus*), akiroha (*Olearia paniculata*), pine, karo (*Pittosporum* sp.) and whauwhaupaku (*Pseudopanax arboreus*). Finally, grit ingestion from a sand bank was also recorded in one instance.

DISCUSSION

Prior to our study there was only one descriptive account of the foods consumed by orange-fronted parakeets. Kearvell et al. (2002), report that the remnant population in the South Island feeds almost exclusively on *Nothofagus* spp. They also noted that invertebrates constitute nearly 70% of the food items recorded during spring observations. In contrast, on Maud Island we observed ingestion of a diverse array of foods from 14 plant species and ingestion of invertebrates was observed only rarely. It is likely that invertebrates were being taken by parakeets when foraging on what we classified as non-dietary items but we were unable to quantify this during our observations. Invertebrates are a significant proportion of food items for red-crowned (*C. novaezelandiae*) and yellow-crowned parakeets (*C. auriceps*) representing 25–60% of feeding observations during spring (Greene 1998). Other parrot species have been reported consuming bark and grit but the specific function of these in parrots in unclear (Gilardi et al. 1999; Symes & Perrin 2003).

Orange-fronted parakeets on Maud Island were noticed mostly foraging solitarily. In the remaining mainland populations, orange-fronted parakeets are known to feed in flocks, sometimes mixed with other species, like its close relative the yellow-crowned parakeet (Kearvell et al. 2002). The low density of orange-fronted parakeets on Maud Island and the restriction of our sampling to the track network might explain the low occurrence of group foraging, i.e., it is possible that parakeets forage in groups in the remnant patches of mature forest on Maud Island.

Although our sampling scheme prevents us from statistically quantifying the relative importance of food types between seasons or habitats, it allowed us to obtain the first account of the diversity of species that translocated orange-fronted parakeets feed on. Our observations on banded parakeets correspond to 40% of all released individuals up until January 2009 on Maud Island, meaning a significant proportion of the total population was sampled.

Cyanoramphus parakeets can be regarded as food generalists. A great diversity of species used as food has been recorded throughout New Zealand (Higgins 1999). Such broad diet of close relatives and the vegetation structure of our study site (mostly regenerating scrub) could explain the foraging on previously unreported introduced food species such as sycamore, pine and tree lucerne.

Table 1 Plant species and food types ingested by reintroduced Malherbe's parakeets on Maud Island.

Species	Type	Proportion of diet (feeding bouts in brackets)
Sycamore (*Acer pseudoplatanus**)	Fruits	3.36 (4)
Titoki (*Alectryon excelsus*)	Fruits	1.68 (2)
Makomako (*Aristotelia serrata*)	Fruits, leaves	13.44 (16)
Putaputaweta (*Carpodeus serratus*)	Fruits, leaves	5.88 (7)
Karamu (*Coprosma robusta*)	Fruits	8.40 (10)
Tree lucerne (*Cytisus palmensis**)	Flowers, leaves	5.04 (6)
Akeake (*Dodonea viscosa*)	Leaves	0.84 (1)
Kohekohe (*Dysoxilum spectabile*)	Flowers	0.84 (1)
Koromiko (*Hebe stricta*)	Flowers	1.68 (2)
Manuka (*Leptospermum scoparium*)	Fruits	7.56 (9)
Mahoe (*Melycitus ramiflorus*)	Fruits, leaves, flowers	43.70 (52)
Whauwhaupaku (*Pseudopanax arboreus*)	Fruits	5.04 (6)
Pine (*Pinus radiata**)	Leaves	1.68 (2)
Karo (*Pittosporum* sp.)	Fruits	0.84 (1)

*Introduced species.

Previous experiences with red-crowned (pers. obs.) and yellow-crowned parakeets indicate that translocated individuals can establish and increase in numbers despite substantial differences in habitat structure between the source and the release locations. For example, translocation of yellow-crowned parakeets from the Te Kakaho Island to Mana Island and red-crowned parakeets from Kapiti Island to Matiu/Somes Island (L. Adams, Department of Conservation, pers. comm.). Such flexibility in diet of these closely related species is an encouraging prospect for the conservation recovery of critically endangered parakeets as it suggests that other regenerating offshore islands free of predators could be used for subsequent releases of captive-bred orange-fronted parakeets. Future research on translocated orange-fronted parakeets should focus on quantitative aspects of their diet and the dietary quality of plant species found on offshore islands.

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APPENDIX 5

Some observations on the behaviour of the critically endangered orange-fronted parakeet (*Cyanoramphus malherbi*) on Maud Island, New Zealand

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SHORT NOTE

Some observations on the behaviour of the critically endangered orange-fronted parakeet (*Cyanorampus malherbi*) on Maud Island, New Zealand

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The orange-fronted parakeet (*Cyanoramphus malherbi*) is New Zealand's rarest parakeet species with a remnant population size estimated at 200-300 (Grant & Kearvell 2001). In addition to 2 mainland populations found in the South Is, the Department of Conservation has established 2 populations on Chalky Is and Maud Is using individuals bred in captivity at the Isaac Wildlife Trust, Christchurch (Elliot & Suggate 2007, Gaze & Cash 2008). During a study on the breeding biology of this species on Maud Is, non-nesting behaviours of 10 banded individuals were recorded. Given the precarious state of the species and the scarcity of published information about the behaviour of translocated captive-bred parakeets, I present here a summary of these observations as a basis for future research.

Between Mar 2007 and Jan 2009, Maud Is was visited 18 times at intervals of about every 2 months and each trip lasted 1 or 2 weeks. During each trip 4 observers in 2 pairs, covered the track network of the island between 07:00 and 18:30 hrs in search of nests or potential breeding pairs. We excluded monitoring of the forested patches on the island to minimise disturbance of Maud Is frog (*Leiopelma pakeka*) and Takahe (*Porphyrio mantelli*). Occasionally, parakeets were encountered (by aural or visual cues) along or near the tracks. On these occasions, observers took note of the band combination and conducted behavioural bouts (Altmann 1974). Behaviours were classified into 6 predefined categories: sleeping, foraging, resting (sitting quietly, not sleeping), preening, calling, or moving (walking along a branch or thru vegetation). The duration of each behaviour was recorded to the nearest minute. Data are presented as means ± SD. Observation bouts lasted an average of 23 ± 19 min (range 3-79 min, n = 16), and a total of 61 behavioural bouts were conducted.

Like orange-fronted parakeets in remnant populations on mainland New Zealand (Kearvell *et al*. 2002), the most commonly observed behaviour was foraging (n = 26; 42.6 % of bouts), with each feeding bout lasting 5 ± 0.2 min (range 1-52 min). Preening and resting bouts were also common and lasted 4 ± 9 min (range 1-32 min, n = 10; 16.5% of bouts) and 2 ± 3 min (range 1-10 min, n = 8; 13.1% of bouts), respectively. Calling lasted 3 ± 5 min (range 1-15 min, n = 7; 11.5% of bouts) and moving bouts 4 ± 5 (range 1-15 min, n = 7; 11.5% of bouts). Sleeping was the most infrequent behaviour observed with each bout lasting 6 ± 6 min (range 1-13 min, n = 3; 4.9% of bouts).

As observations were restricted to the track network, it is possible the frequency and duration of behaviours may not be representative of that occurring in closed forest habitats. The low density of parakeets during the study (62 captive-bred parakeets released to Jan 2009) might also affect the time birds spent in each activity. However, the open nature of the environment allowed close approach

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and a clear view in which to record observations. The vegetation along the tracks consists mostly of low to medium regenerating scrub allowing a broader visual field whilst on the mainland parakeets commonly dwell high in the canopy (Kearvell *et al*. 2002). Although observers attempted to stay about 25-30 m away to prevent stress on the focal individuals, parakeets often moved close to observers and on 2 occasions even landed briefly on the observer. The greater ease of conducting observations on Maud Is indicates that this population of the orange-fronted parakeet would be ideal for future detailed quantitative studies.

The release of captive-bred individuals on Chalky Is in 2005 (Hirschfeld 2008) and on Maud Is between 2007-2009 has resulted in 2 additional populations of the species. Despite claims that both populations are self-sustaining (Elliot & Suggate 2007, Hirschfeld 2008), there are no updated estimates of the global population size or population growth either on Chalky or Maud Is. Our understanding of the species' biology is largely limited to studies on the mainland (Kearvell 2002, Kearvell *et al*. 2002) and unpublished reports on individuals in captivity. Thus, it is clear that efficient management of the species would benefit from further field studies on translocated populations. The long-term survival of orange-fronted parakeets in managed island environments cannot be guaranteed without additional field studies aimed at monitoring population growth and assessment of arising threats to these new island populations, such as Psittacine Feather and Beak Disease (PBFD), recently detected in wild *Cyanoramphus* in New Zealand (Ortiz-Catedral *et al*. 2009). Improvement of current management of the species on the mainland would also benefit from such studies.

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Key words orange-fronted parakeet; time budget; *Cyanoramphus malherbi*; Maud Island

APPENDIX 6

Homing of a red-crowned parakeet (*Cyanoramphus novaezelandiae*) from Motuihe Island to Little Barrier Island, New Zealand

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SHORT NOTE

Homing of a red-crowned parakeet (*Cyanoramphus novaezelandiae*) from Motuihe Island to Little Barrier Island, New Zealand

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The red-crowned parakeet (*Cyanoramphus novaezelandiae*) is New Zealand's most widespread parakeet species, with a range extending from the Kermadecs Archipelago, across the North and South Is, to the Chatham and Antipodes Is (Higgins 1999; Juniper & Parr 1998). As the species has declined on the main islands of New Zealand, it has been translocated to a number of offshore islands over the last 40 years including Cuvier, Matiu/Somes, Tiritiri Matangi and Whale Is (Dawe 1979; McHalick 1999; Miskelly *et al.* 2005). In May 2008, a group of 31 red-crowned parakeets captured on Little Barrier I was released on Motuihe I as part of an island restoration project. This was followed by an additional flock of 18 parakeets released on Mar 2009 (Ortiz-Catedral & Brunton 2010). Here I report the homing of 1 adult female red-crowned parakeet that was recaptured on Little Barrier I 50 days after its release on Motuihe I.

The female parakeet (band number 189392) was initially captured on Little Barrier I on 2 Mar 2009 in the area known as Te Maraeroa flats. On capture she weighed 67 g and was transferred to an aviary on site together with other parakeets and held in captivity for 1 day. She was then transferred to Motuihe I by helicopter together with 18 other parakeets on 4 Mar 2009. The parakeets were released by members of the Motuihe Island Trust and the general public in a remnant of coastal bush on the west side of the island. In Apr 2009, I returned to Little Barrier I with a team of volunteers to capture parakeets destined for translocation to Tawharanui Regional Park. Mist netting took place between 21 and 25 Apr in Te Maraeroa flats. On 23 Apr, a banded female was captured and confirmed as one of the parakeets released on Motuihe I the previous month. Thus, this bird had flown a minimum of *ca.* 65 km between Motuihe and Little Barrier Is. On recapture on Little Barrier I, the recaptured female weighed 70.5 g and appeared in good condition.

Sixty days after releasing the 1st flock, 13 individuals were confirmed to be alive on Motuihe I (Ortiz-Catedral & Brunton 2010), but it is unclear if the unsighted parakeets on Motuihe I died on site, dispersed to adjacent islands or returned to Little Barrier I. Despite further mist netting trips to Little Barrier I, the homing of additional parakeets has not been confirmed.

Red-crowned parakeets have successfully colonised many remote islands throughout New Zealand, indicating they have the potential to undertake relatively long dispersal flights. There are also reports of red-crowned parakeets appearing in urban and suburban areas in the Wellington area, possibly as dispersers from Kapiti I (a wild population) or Matiu/Somes I (a translocated

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population) (Miskelly *et al.* 2005), further supporting the conclusion that red-crowned parakeets are able to disperse naturally. Alternatively, these sightings in urban areas might represent occasional avicultural escapees. Information on the homing and dispersal behaviour of other parrot species is limited. A close relative of the red-crowned parakeet, the Ouvea parakeet (*Eunymphicus cornutus uvaeensis*) was transferred from Ouvea I to Lifou I, *ca.* 60 km in distance, and it was suggested that most of the parrots returned to Ouvea (Delacour 1966, cited in Wiley *et al.* 1992).

Prior to the recapture of female 189392 it was unknown whether wild red-crowned parakeets would return to their source population following translocation. In line with other translocation projects, the capture and transfer of red-crowned parakeets on Little Barrier I coincided with the end of the breeding season of the species in the Hauraki Gulf, which usually extends from Oct to Mar (Greene 2003; Ortiz-Catedral 2006). Such timing has been recommended to minimise the likelihood of homing (Oppel & Beaven 2002). Despite taking such precautions, my observations suggest that at least a few individual parakeets may home after translocation. The loss of individuals through homing may necessitate an increase in the number of birds initially translocated to ensure enough individuals remain to form a viable population.

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Key words red-crowned parakeet; *Cyanoramphus novaezelandiae*; homing behaviour; translocation

APPENDIX 7

No T-cell-mediated immune response detected in a red-crowned parakeet (*Cyanoramphus novaezelandiae*) infected with the beak and feather disease virus (BFDV)

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No T-cell-mediated immune response detected in a red-fronted parakeet (*Cyanoramphus novaezelandiae*) infected with the Beak and Feather Disease Virus (BFDV)

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Abstract Here I report on a small scale study aimed at generating baseline information on the immune response of wild red-fronted parakeets, as assessed by blood cell counts, and subcutaneous challenge with phytohaemagglutinin (PHA), a mitogen that causes swelling at the point of injection. Eleven parakeets captured in mist-nets were injected into the right patagium with 0.5 mg PHA and the resulting swelling measured at 6 hours post-injection. Prior to PHA challenge, feather and blood samples were collected for detection of beak and feather disease virus and *Plasmodium*. Blood smears were also prepared for blood cell counts. Swelling occurred 6 hours post-injection in all but one individual, which tested positive for beak and feather disease virus. In this individual, no measurable swelling was detected. Estimated leucocyte counts, lymphocyte counts and heterophil counts of the same individual were similar to values of beak and feather disease virus negative individuals. *Plasmodium* DNA was detected in 2 individuals and their immune response was similar to that of parakeets testing negative for both beak and feather disease virus and *Plasmodium*. Estimated leucocyte counts, lymphocyte and heterophil counts did not differ between *Plasmodium* infected and non-infected individuals. The fact that the only individual testing positive for beak and feather disease virus showed no immune response to PHA challenge suggests increased susceptibility to other pathogenic infections. Although preliminary, this study highlights the potential damaging consequences of the accidental introduction of beak and feather disease virus in conservation programmes of threatened New Zealand parrots, some of which might already suffer from decreased immunocompetence resulting from reduced genetic diversity.

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Keywords *Cyanoramphus novaezelandiae*; phytohaemagglutinin; Little Barrier Island; leucocyte counts; PHA

INTRODUCTION

The Beak and Feather Disease Virus (BFDV) is the causative agent of Psittacine Beak and Feather Disease (PBFD), an infection of parrots and cockatoos that has been the subject of extensive research since its description (Pass & Perry 1984). The clinical signs of the disease are highly variable among hosts, but include deformed feathers (i.e., clubbed, curled shape), feather lesions (i.e., breaking of emerging shafts, bleeding shafts), abnormal feather loss and feather colouration, and necrosis of the beak (Gerlach 1994a). Viral particles can be confirmed by microscopy of affected tissue, antigen tests, or by PCR detection of viral DNA (Latimer *et al*. 1990; Ramis *et al*. 1994). One advantage of PCR-based diagnosis is the ability to detect viral DNA among individuals not showing symptoms of PBFD, particularly in feather samples (Khalesi *et al*. 2005), which allows for field surveys of the virus in locations of interest (Ortiz-Catedral *et al*. 2009b).

PBFD is considered an immunosuppressive disease due to its damage to the thymus and Bursa of Fabricius and secondary bacterial and fungal infections commonly found in PBFD birds (Gerlach 1994a). For example, long-billed corellas (*Cacatua*

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tenuirostris) experimentally infected with BFDV show reduced estimated leucocyte counts than non-infected individuals (Bonne *et al.* 2009), which indicates a potential decrease in the cell-mediated immune response following viral infection. However, research on immune function and BFDV infection is limited.

Recent studies in New Zealand have highlighted the usefulness of the phytohaemagglutinin (PHA) test to investigate immunocompetence of native species of conservation concern such as Forbes parakeets (*Cyanoramphus forbesi*) (Tompkins *et al.* 2006) and New Zealand robins (*Petroica longipes*) (Hale & Briskie 2007). This study was aimed at producing baseline information about the immunocompetence of a New Zealand endemic: the red-fronted parakeet (*Cyanoramphus novaezelandiae*). Red-fronted parakeets are vulnerable to extinction (www.iucn.org) and currently restricted to islands free of introduced predators and a few mainland sites (Robertson *et al.* 2007).

METHODS

A total of 11 red-fronted parakeets were captured using mist nets on Little Barrier Island (LBI) from 5 to 17 May 2008. All captured parakeets exhibited normal plumage and no external indication of current infection with BFDV. Every captured bird was weighed, measured and given a uniquely numbered metal band following guidelines by the New Zealand Department of Conservation (DOC). Blood was obtained by puncture of the brachial vein. To prepare blood smears, a drop of blood was collected with a non-heparinised capillary tube, transferred onto a microscope slide, and then smeared to a thin layer following the "push-slide" method (Walberg 2001). Slides were air-dried, fixed in 100% methanol (Bennett 1970), and then stained with May Grunwald-Giemsa followed with a phosphate buffer/rinse (Robertson & Maxwell 1990) (Technecult Laboratories Ltd., Napier, New Zealand). White blood cell counts were completed by haematologists at Gribbles Veterinary Pathology (Auckland, New Zealand), and involved counting 10 random fields at 100 x magnification, following the methodology described in Parker *et al.* (2006) to determine estimated leucocyte count, lymphocyte count and heterophil count. Other blood cell types such as monocytes and eosinophils are also found in avian blood, but for this study the focus was on lymphocytes and heterophils due to their role in immune function following Hale & Briskie (2007). In addition to blood, 2 contour feathers from the ventral region were collected with tweezers for molecular determination of sex following the methodology described by Griffiths *et al.* (1998) and for detection of BFDV DNA following the methodology described by Ha *et al.* (2007). Molecular sexing and detection of BFDV DNA was done at the Equine and Parentage and Animal Genetics Centre at Massey University.

Given that immune response can be affected by other pathogens in addition to BFDV, I also tested parakeets for presence of *Plasmodium* DNA in blood samples. *Plasmodium* infection has been confirmed in a number of native and exotic birds species in New Zealand (Sturrock & Tompkins 2008; Tompkins & Gleeson 2006). As some of these bird species occur on LBI (i.e., blackbird *Turdus merula*; song thrush *T. philomelos*), this pathogen was screened also in parakeets. Approximately 70 µl of blood were collected using a heparinized capillary tube. Its ends were sealed with plasticine and kept at 4 °C until PCR analysis 2 days after blood collection. DNA extraction and PCR amplification of *Plasmodium* followed Tompkins & Gleeson (2006) and was completed at Landcare Research, Auckland. The parakeets used in the PHA essay were also tested for *Salmonella*, *Campylobacter* and *Yersinia*, but none of these pathogens was detected (Ortiz-Catedral *et al.* 2009a).

To experimentally test the strength of the immune response, parakeets were injected subcutaneously with 0.5 mg PHA dissolved in 0.1 mL phosphate-buffered saline into the right patagium as described by Tompkins *et al.* (2006). PHA induced swelling was measured using callipers to the nearest 0.05 mm prior to injection, then at 6 hours post-injection (average of 3 measures on the same point). After injection, parakeets were held in card boxes padded with fresh kanuka (*Kunzea ericoides*) branches and provided with food and water *ad libitum*. Food consisted of sliced apple, fresh peas, freshly collected karamu (*Coprosma robusta*) berries, and corn on the cob. Data collection was completed under full approval by DOC (permits AK-22658-FAU, AK-15300-RES, AK-20666-FAU and AK-22857-FAU). Capture, sample collection and handling of parakeets were conducted following approved protocols by the Massey University Animal Ethics Committee (protocols MUAEC 07/138 and 08/24).

Statistical analysis

The amount of swelling after 6 hours post-injection with PHA was compared using the Mann-Whitney U test in StatView version 5.0.1©. Traditionally, PHA assays compare swelling after 24 hours of injection; however, measuring the resulting swelling at 6 hours post-injection has been shown to result in reliable estimate of PHA responsiveness (Smits *et al.* 1999). Further, this methodology has been successfully used in native New Zealand parakeets previously (Tompkins *et al.* 2006). A significance level at $\alpha = 0.05$ was set for comparisons between BFDV negative *vs.* BFDV positive birds. The same statistical approach

was used to compare *Plasmodium* negative *vs.* *Plasmodium* positive individuals. All individuals that tested negative for either *Plasmodium* or BFDV are referred to as the uninfected group.

RESULTS

Of the 11 captured parakeets for this research, only 1 tested positive for BFDV DNA in feather samples. This individual showed no external signs indicative of PBFD; its plumage appeared normal and indistinguishable from the uninfected group (n = 8). In 2 other parakeets, *Plasmodium* DNA was detected. These two parakeets also appeared normal on inspection of plumage. During the PHA test, there was no measurable swelling response 6 hours post-injection in the parakeet where BFDV DNA was confirmed. The swelling in the uninfected group averaged 1.2 ± 0.26 mm. When contrasting the swelling response of the BFDV positive individual and the uninfected group, the difference only approached significance (BFDV positive mean rank: 1.0; uninfected group mean rank: 6.5; Z = -1.5, P = 0.11). Of 11 parakeets sampled, only 9 blood smears were suitable for white blood cell counts. Estimated leucocyte counts did not differ between the BFDV positive individual *vs.* the uninfected group (n = 6) (uninfected group: 7.12 ± 2.13 x $10^{9\text{-}1L}$, BFDV positive individual: 4.6 x $10^{9\text{-}1L}$, Z = - 0.29, *P* = 0.77). Similarly, there was no difference in the lymphocyte count between the uninfected group and the BFDV positive individual (lymphocyte count uninfected group: 75.8 ± 4.15 x$10^{9\text{-}1L}$; BFDV positive individual: 76 x $10^{9\text{-}1L}$; Z = - 0.29, *P* = 0.77). Finally, no difference was detected in heterophil count between the same groups (heterophil count uninfected group: 10.6 ± 3.32 x$10^{9\text{-}1L}$; BFDV positive individual: 4 x$10^{9\text{-}1L}$; Z = -1.46, *P* = 0.14).

The swelling response of parakeets infected with *Plasmodium* averaged 1.82 ± 0.55 mm. Such swelling was not statistically different from the uninfected group (*Plasmodium* positive mean rank: 8.5; uninfected group mean rank: 5.44; Z = -1.16, P = 0.24). Estimated leucocyte count did not differ statistically between the *Plasmodium* positive group (n = 2) and the uninfected group (estimated leucocyte count uninfected group: 7.12 ± 2.13 x $10^{9\text{-}1L}$; *Plasmodium* positive group: 4.7 ± 0.5 x$10^{9\text{-}1L}$; Z = -0.39, *P* = 0.69). Likewise, lymphocyte count did not differ significantly between *Plasmodium* infected and uninfected individuals (lymphocyte count uninfected group: 75.8 ± 4.15 x $10^{9\text{-}1L}$; *Plasmodium* positive group: 58.5 ± 6.5 x $10^{9\text{-}1L}$; Z = - 0.77, *P* = 0.44). Lastly, the heterophil count was similar between infected and uninfected parakeets (heterophil count uninfected group: 10.6 ± 3.32 x$10^{9\text{-}1L}$; *Plasmodium* positive group: 12.5 ± 1.5 x$10^{9\text{-}1L}$; Z = 1.16, *P* = 0.24).

DISCUSSION

The recent discovery of PBFD in a natural population of red-fronted parakeets has raised concerns over the potential effects of this viral disease among threatened New Zealand parrots (Ortiz-Catedral *et al.* 2009b). While it is well established that PBFD causes mortality of parrots and allies in aviculture (Heath *et al.* 2004) and in some captive-breeding programmes (Commonwealth of Australia 2005), the effects of the disease in wild populations are not well documented. The results in this study indicate that BFDV occurs in a free-living population of parakeets in New Zealand and that infection may be associated with lack of responsiveness to challenge with PHA. The PHA test has been shown to be a good indicator of acquired T-cell immunocompetence of birds (Tella *et al.* 2008). Thus, BFDV may render the infected individual unable to mount T-cell immunocompetence, even when there are no clinical signs of PBFD, as it is the case for the BFDV positive individual in this study.

The results presented here should be confirmed with a larger group of parakeets, ideally including individuals with sub-clinical as well as clinical BFDV infection to better understand the immunosuppressive effects of the virus in free-living parakeets. It is unclear why infection with either *Plasmodium* or BFDV was not associated with higher heterophil and overall leucocyte counts indicative of current parasitic infection (Campbell 1994), and lower lymphocyte counts, often associated with immunosuppression (Walker *et al.* 1983) and virus infection (Bonne *et al.* 2009). It is likely that the limited sample size used is insufficient to detect such differences. Another possibility is that haematologic changes would be detected as these infections develop. As mentioned previously, the uninfected group and the *Plasmodium* and BFDV infected parakeets were undistinguishable on external inspection. However, since the birds used are free-living nothing is known about infection date and pathogenesis of the infections. One limitation of this study is that only one response of the avian immune system was assessed (T-cell immunocompetence). Another component of the avian immune system is the humoral response (production of immunoglobulins) to antigens (Gerlach, 1994b). Ideally, future studies on the effects of BFDV among New Zealand parrots should include an assessment of humoral immune response.

Although preliminary, the results presented here complement previous studies of BFDV in native and exotic parrots in New Zealand by Ha *et al.* (2007) and Ortiz-Catedral *et al.* (2009b) and strengthen the view of BFDV as a potential further threat for the conservation of New Zealand parrots.

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APPENDIX 8

Nesting sites and nesting success of reintroduced red-crowned parakeets (*Cyanoramphus novaezelandiae*) on Tiritiri Matangi Island, New Zealand

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Nesting sites and nesting success of reintroduced red-crowned parakeets (*Cyanoramphus novaezelandiae*) on Tiritiri Matangi Island, New Zealand

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Abstract We studied red-crowned parakeets (*Cyanoramphus novaezelandiae*) reintroduced onto Tiritiri Matangi Island, New Zealand from 2004 to 2006, in order to provide baseline information regarding nesting sites and nesting success of this population. We found 48 nests both in natural nesting sites and in nest boxes, in all three major habitat types on the island. Clutch size declined as the breeding season progressed, but laying date did not affect nesting success. This means that a breeding pair could fledge at least one young even from a small clutch laid late in the breeding season. Overall nesting success was 60%. Nesting success varied between breeding-seasons. Most of the 17 nesting attempts that failed did so during incubation. Red-crowned parakeets made use of a wide diversity of nesting sites and few sites were re-used, which suggests that suitable nest sites were not limiting. Overall, our results indicate that red-crowned parakeets are good candidates for reintroductions to areas lacking introduced predators, even during the early stages of revegetation.

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Keywords *Cyanoramphus*; kakariki; nesting success; nest sites; New Zealand; parakeets; reintroduction; Tiritiri Matangi; translocation

INTRODUCTION

Reintroduction and translocation are common conservation techniques used for parrots worldwide (Franklin & Steadman 1991; Wiley et al. 1992) and currently are part of the recovery plans of several species (Berry 1998; Hill 2002). In New Zealand, *Cyanoramphus* parakeets (or "kakariki" in Maori) have often been translocated within and outside their historical range during the last 95 years (McHalick 1999; van Hal & Small 2005; Waite 1909). In general these translocations are considered successful (Juniper & Parr 1998; Higgins 1999), but no study has been conducted on the nesting biology, nesting sites and variability in nesting success of any reintroduced population of red-crowned parakeets. Thus, the validity of these conservation techniques for New Zealand *Cyanoramphus* has not been fully evaluated.

Furthermore, it is difficult to implement adequate management decisions based on educated guesses, instead of models developed from an understanding of the temporal changes in nesting success, age structure of the population as well as the regulatory mechanisms operating in translocated populations. (Dimond & Armstrong 2007). Previous studies on New Zealand parakeets have focused on remnant populations on the New Zealand mainland (Elliot et al. 1996) and on a few offshore islands with alien mammalian predators (Greene 2003) that are known to adversely affect nesting birds (O'Donnell 1996). Predation is likely to obscure natural patterns of nest site selection, clutch formation, incubation and the overall nesting success of contemporary New Zealand birds.

Here we describe the nesting sites and nesting success of a population of red-crowned parakeet (*Cyanoramphus novaezelandiae*) reintroduced onto Tiritiri Matangi Island, using data collected over two

consecutive breeding seasons. We also describe nest site re-use and agonistic interactions observed at nest sites. This is the first study of the nesting success of red-crowned parakeets in a site free of introduced predators, and so provides novel information on the reproductive ecology of translocated New Zealand parakeets.

METHODS

Study area and species

Tiritiri Matangi Island (36°36′S, 174°53′E) is a 220 ha island 28 km north-east of Auckland City, in the Hauraki Gulf. The site supports an ongoing habitat restoration programme managed by the New Zealand Department of Conservation. The island's vegetation consists of remnants of broadleaf forest on the north side of the island (19%), areas of grassland (a mixture of several grass species and *Phormium tenax*) (35%) and native trees planted under a re-vegetation programme (46%) (Mitchel 1985; Baber & Craig 2003).

Red-crowned parakeets were once common throughout New Zealand, but human-induced habitat modification, persecution and introduction of alien predators greatly reduced their former range (Higgins 1999). Similar factors might explain their absence from Tiritiri Matangi Island, but there is no record of their disappearance at this location. Prior to the first release in 1974, no red-crowned parakeets were seen on the island (R. Hitchmough pers. comm.). Between 1974 and 1976, i.e., before the eradication of Pacific rats or "kiore" (*Rattus exulans*) in 1993 (Rimmer 2004), approximately 80 captive-bred red-crowned parakeets were reintroduced to Tiritiri Matangi Island (Higgins 1999) from Mount Bruce National Wildlife Centre.

Red-crowned parakeets are medium sized parrots measuring 23–28 cm and weighing 70–100 g. They are sexually monochromatic, but males are slightly larger than females. Sexes can be determined from the morphology of the beak and its dimensions (Sagar 1988). The species is classified as vulnerable by the IUCN (www.iucn.org). Potential breeding pairs were identified by opportunistic observations of pre-nesting behaviours such as cavity inspection, pair roosting, courtship feeding, and aggressive displays towards conspecifics in or around potential nesting sites.

Because most of the replanted vegetation on the island is of relatively homogeneous age with few large, mature trees, approximately 450 wooden nest boxes have been placed around the island since 1984 (Morag Fordham pers. comm.). These nest boxes were installed to provide nest sites for cavity-nesting native passerines such as stitchbird ("hihi") *Notiomystis cincta* (Thorogood 2004) and North Island saddleback ("tieke") *Philesturnus carunculatus* (Stamp et al. 2002), but are also used by red-crowned parakeets and the introduced Myna (*Acridoteres tristis*). In addition to these, we installed another 30 nesting boxes mounted on trees 1–1.5 m above the ground in areas of low nest-box density. The nest-box design is similar to nest boxes used in other parrot studies (Beggs et al. 1984; Krebs 1998).

Nesting sites, nesting habitat and nest monitoring

Data were collected during 220 h of field observations at nests, both in natural nesting sites and nest boxes, during the two breeding seasons from October 2004 to March 2005 and from October 2005 to February 2006. This time interval corresponds to the main stages of the breeding cycle: nest-site selection, egg laying, incubation, nestling and fledging (Higgins 1999).

Natural nests were located by inspection of tree cavities, rock crevices, vegetation clusters, trunks and burrows for signs of parakeet activity (i.e., droppings, feathers, egg shells, nestlings). Our analysis is restricted to nests that were accessible from the ground. The following parameters were recorded for every natural nest found: location, plant species, nest height (cm), internal height of cavity (cm), length and width of entrance (cm), and depth from entrance to nest chamber (cm). Habitat type was categorised as remnant forest, grassland, or replanted bush. Nest site re-use and nest usurpation (the take-over of the nest by conspecific or heterospecific breeding pairs between years), were also recorded. Nesting site re-use refers only to nests successively active in 2004–05 and 2005–06.

In the breeding season of 2004–05, nests were checked once a week until egg laying began. After the first egg had been laid nests were visited daily to determine the laying sequence. During incubation, nests were visited once a week. After hatching, nests were visited every second day to collect data on nestling survival.

In 2005–06, nests were visited once a week for the duration of the nesting cycle. Laying dates for this breeding season were estimated either by back-dating partially laid clutches, assuming an interval

of 2 days between consecutive eggs (mean for all known egg laying intervals = 1.74 ± 0.06 (SE), n = 87), or by back-dating nestlings of known age. The age of chicks was assigned retrospectively using a regression equation for wing length versus weight, together with an examination of feather development (Ortiz-Catedral 2006).

Observations at nest sites were made 10–20 m from the nest entrance and from behind native vegetation to minimise disturbance of breeding pairs. Nest contents were inspected only after females flew out of the cavity to be fed by males. In both seasons, survival of embryos and nestlings was recorded to calculate nesting success per breeding pair. Nests were checked from the ground using an extendable mirror and a hand torch. Manipulation of eggs was done using disposable latex gloves. Fertility of eggs was determined by shinning a flashlight through each egg. We considered fertile eggs to be those that showed a clear net of blood vessels 4 days after the start of incubation. By contrast, we classified eggs as infertile if these failed to develop blood vessels 1 week after beginning of incubation.

Nests were found at different stages of the nesting cycle (i.e., clutch formation or fledglings), so different nests were included in different analyses depending on the amount of information we could obtain. Consequently, sample sizes differ between analyses. For some nests we could not determine the exact number of hatchlings or fledglings produced. We considered a nesting attempt successful if at least one fledgling was produced, and to have failed if no fledglings were produced.

Statistical analyses

We limit our analysis to the outcome of each nesting attempt per breeding pair (i.e., success or failure). In some natural nests, especially those in clusters among vegetation, it was not always clear if the female was away or sitting at the back. Also, natural nesting chambers were very fragile structures, and nestlings from 15 days old would scramble away amongst leaves and branches during handling. Consequently, most data were collected from nest-boxes, because it was much easier to monitor nests in boxes without disturbing nesting birds and nestlings.

Nesting success was determined using Stanley's method for estimating stage-specific daily survival probabilities (Stanley 2000). We chose this method because it allows the incorporation into the dataset of nests checked at irregular intervals and nests found at different stages of the nesting cycle. Stanley's program is available in the SAS© programming language from Ecological Archives (http://www.esapubs.org/archive/ecol/E081/021).

Following Armstrong et al. (2002), we changed the starting P values during the iterative phase of the program from $P = 0.90$ to $P = 0.99$ to avoid convergence into incorrect estimates of P values (i.e., a P value greater than 1 for any given nest stage) (Armstrong et al. 2002). Similarly, following Stanley (2000) and Armstrong et al. (2002) we used the Delta method to calculate confidence intervals. Survival during the laying stage was not included in the analysis because most nests in 2005–06 were found during incubation or in the early nestling stages. This did not affect the overall estimation of nest success, as only one nest failed during laying over the two breeding seasons of study. Accordingly, equations to calculate survival during egg laying were deleted from Stanley's program. Nest success rate was calculated as: $P_1^{\wedge t1} \times P_2^{\wedge t2}$ where P^1 and P^2 are estimated survival probabilities for the incubation and nesting stage respectively, and t_1 and t_2 represent mean duration of incubation (1) and nesting (2) (Stanley 2000; but see Armstrong et al. 2002).

We performed a Chi-square test of heterogeneity to check for differences in distribution of nests among the three different habitat types. We also conducted a series of Fisher's exact tests to determine association between: habitat type versus nesting outcome (i.e., success or failure); nest type versus nest re-use; nest re-use versus nesting outcome; and finally nest type versus nesting outcome. We used linear regression to model the relationship between laying date and clutch size, and logistic regression to model the effect of laying date on nesting outcome. For both regressions we pooled clutches from both seasons to increase sample size.

Given the potential influence of the nest-monitoring regime on nest outcome, we classified nests as having been observed at either "high" or "low" monitoring intensity. We considered nests that were followed from laying to fledgling (and therefore were visited more often) to be in the high monitoring intensity group, and those that were found at advanced stages of the nesting cycle (i.e., with nestlings or fledglings) to be in the low monitoring intensity group. We tested whether the frequency of researcher visits and nest checks could explain the failure or success of nests analysed by conducting a Fisher's exact test on monitoring intensity versus nesting outcome. We recognise two problems with this approach: our classification of nests by monitoring intensity could create bias towards nests surviving longer during our study, and

we could not assign an appropriate control group of nests because of the low density of active nests found per breeding season. However, we consider this analysis a useful approximation to understand the effects of researcher visits on nesting outcome. All analyses were performed in SAS Version 8© and StatView Version 5.01.

RESULTS

Natural nest sites, nesting habitat and nest site re-use

Altogether, 48 nests were found (30 in nesting boxes, 18 in natural nests), representing 60 nesting attempts over two breeding seasons. Of these 40 (66%) nesting attempts were in nesting boxes and the other 20 (33%) were in natural nest sites. Of the natural nests, seven were found in remnant forest; four in replanted areas and seven in grassland including tree cavities, tunnels in vegetation clusters and ground burrows. Four species of trees were used by red-crowned parakeets for nesting, but a single species (*Metrosideros excelsa*) accounted for six of the nine nests found in trees (Table 1). Likewise, one species (*Phormium tenax*) accounted for six of seven nests found in non-woody plant species (Table 1). Most natural nest sites had a horizontal entrance. Internal cavity height and entrance width showed the least variation between nests, while height from the ground was most variable (Table 2). The only cavity with a non-horizontal entrance was a skyward facing hollow in a cabbage tree (*Cordyline australis*).

There was no significant difference in the number of nesting attempts found in different habitat types ($\chi^2_2 = 1.69$, $P = 0.42$, $n = 60$ nests: 28 in replanted vegetation, 14 in grassland and 18 in remnant forest). The distribution of successful nesting attempts was 22 (45%) in replanted areas, 12 (24%) in grassland and 15 (30%) in remnant forest, but successful nesting attempts (i.e., nests producing at least one fledgling) were not more common in replanted areas than other habitat types (Fisher's exact test $P = 0.915$; $n = 60$). Only 13 (32%) of nest sites were active in both seasons. Nest boxes were not re-used more often than natural nests (10 nesting boxes re-used: 16% of total; three natural nests re-used: 5% of total; Fisher's exact test $P = 0.66$, $n = 60$). Nests from which at least one young fledged were not re-used more often than those that failed over both seasons (11 (27%) successful nests re-used; 2 (5%) non-successful nests re-used; Fisher's exact test $P = 0.45$, $n = 40$). There was no significant relationship between nest type and nesting outcome (27 (45%) successful nests in nesting boxes; 7 (14%) successful nests in natural nests; Fisher's exact test $P = 0.41$, $n = 50$). Monitoring intensity had no effect on nesting success (17 (39%) successful "high monitoring" nests, and 17 (39%) successful "low monitoring" nests; Fisher's exact test, $P = 0.26$, $n = 43$).

Agonistic behaviour

Two cases of interspecific conflicts for cavities were noticed, both concerning a North Island saddleback and a parakeet pair displaying aggressive behaviours around the cavity entrance about 3 weeks before the first egg of the season was laid. These behaviours included chases, alarm calls and wing flapping. In both cases, the female parakeet reacted more actively than the male towards the saddleback. However, both conflicts were short (<5 min) and the disputed cavities were left unused.

Nest usurpation was noticed in only two cases. The first was when a little spotted kiwi ("Pukupuku", *Apteryx owenii*) roosted in a ground level cavity at the base of a *Metrosideros* tree, which had previously been a parakeet nest site. The second was a saddleback constructing a nest in a nest box that had previously been used by parakeets. Agonistic interactions in these two cases were not observed.

Intraspecific conflicts between parakeets were common throughout the breeding season, but were short (<5 min) and of low intensity. When the intruders moved 20–25 m from the nesting site the residents stopped behaving aggressively.

Egg laying period

In 2004–05 the first egg was laid on 4 December and the last on 23 January 2005, a total duration of 51 days ($n = 30$ clutches). In 2005–06, laying started 32 days earlier, extending from 31 October to 6 February; a total of 99 days ($n = 30$ clutches). Red-crowned parakeets laid 6.82 ± 1.6 eggs per clutch ($n = 50$, range 4–9) with an overall fertility of 92.82 ± 2.24% ($n = 50$, range 57.14–100%) over both breeding seasons. Clutch size declined as the laying period progressed (mean clutch size ± SE 2004–05 = 6.36 ± 0.34; 2005–06 = 7.19 ± 0.27; $F_{1,46} = 10.65$; $P < 0.01$, $n = 47$), but laying date was not a significant predictor of nesting success (logistic regression, *Wald* $X^2 = 1.48$; $P = 0.22$, $n = 47$).

Nesting success

Of the 60 nests found, only the 50 from which we obtained enough data were included in Stanley's analysis of nesting success. Of these, 17 failed and

33 fledged at least one young. This figure gives an apparent nest success of 66% over two breeding seasons. Stanley's daily survival probability model provides a lower estimate of 60.5% based on a mean incubation period of 21 days and a mean nestling period of 40 days (average for 64 hatched eggs and 83 fledglings; Ortiz-Catedral 2006). In both years, the incubation stage presented a lower daily survival probability than the nestling stage. Estimated survival probability during incubation for 2004–05 was lower than in 2005–06 (Table 2).

DISCUSSION

Nesting sites and nest site re-use

Most Psittaciformes are secondary cavity-nesters (Mawson & Long 1994; Marsden & Pilgrim 2003; Brightsmith 2005b) that prefer a consistent nest type throughout their geographical range (e.g., palm cockatoos *Probosciger atterrimus*) (Murphy et al. 2003) whilst others display local nest type preferences (i.e., Bahama parrots *Amazona leucocephala* (Snyder et al. 1982). By contrast, we found a high diversity

Table 1 Natural nest cavities used by red-crowned parakeet on Tiritiri Matangi Island between 2004 and 2006. HS = herbaceous shrub; T = tree; V = Twining vine. Data are presented as mean ± SD.

Plant species	No. of nests	Nest height (cm)	Entrance length (cm)	Entrance width (cm)	Distance to nest chamber (cm)	Internal height (cm)
Metrosideros excelsa (T)	6	85.66 ± 48.62	19.96 ± 7.60	15.36 ± 7.45	56.83 ± 17.70	30.83 ± 32.60
Phormium tenax (HS)	6	0	35.33 ± 19.90	33 ± 12.50	58.83 ± 33.64	20 ± 3.52
Melycitus ramiflorus (T)	1	65	13	13	101	14
Muehlenbeckia complexa (V)	1	160	18.5	15.7	85	18.5
Beilschmedia tarairi (T)	1	0	11	17	64	11
Cordyline australis (T)	1	95	60	16	60	60
Fallen log	1	55	38	12	70	9
Ground burrow	1	0	16	24	53	16
Total	18	49.38 ± 13.26	27.13 ± 3.98	21.55 ± 2.76	62.11 ± 5.38	24.08 ± 4.5
Coefficient of variation		113.92	62.19	54.34	36.77	88.01

Table 2 Estimates of daily survival probability for the incubation and nestling stages, and overall nesting success rates for the nesting period (incubation + nestling) for red-crowned parakeet on Tiritiri Matangi Island.

Breeding season	2004–05	2005–06	Overall
No. of nests	25	25	50
Incubation stage	0.9773	0.9913	0.9833
Nestling stage	0.9915	0.9989	0.996
Estimated survival (%) (Incubation)	61.74 (61.73–61.75)	83.235 (83.23–83.24)	70.81 (70.20–70.81)
Estimated survival (%) (Nestling)	71.07 (71.07–71.07)	95.69 (95.69–95.69)	85.52 (85.18–85.52)
Estimated survival (%) (Incubation-nestling)	43.88 (43.87–43.88)	79.65 (38.81–96.02)	60.56 (26.83–86.54)

of natural red-crowned parakeet nest types within a single area on Tiritiri Matangi Island, at various vertical heights: tree cavities, vegetation clusters, fallen logs and ground burrows excavated by grey faced petrels ("oi", *Pterodroma macroptera*) from 0 to 1.83 m above the ground. Outside the period of this study we have also noticed red-crowned parakeets nesting in rock crevices and nests excavated by kotare (sacred kingfishers *Halcyon sancta*). Varied nest sites have already been documented for the red-crowned parakeet across its geographic range (Higgins 1999), but to the best of our knowledge our data show the greatest diversity of nest sites documented for a single population of red-crowned parakeets, and the greatest for any parrot population occupying such a small area (220 ha).

Nest re-use by red-crowned parakeets on Tiritiri Matangi Island was low, both in natural nesting sites and in nesting boxes. Because some nests were not found until the second year of study, inter-annual nest use is biased towards nests found in the 2004–05 breeding season. Like other cavity nesters, parakeets commonly cover egg-shell remains, or other evidence of previous use, with loosened nest floor substrate, consequently it was not always possible to determine if the nest sites found in 2005–06 had been used previously. Thus, actual nest re-use may be higher than we estimated, but if correct, our observed low incidence of nest re-use does not reflect competition with other species for nest sites, as most nest sites remained vacant for the duration of the breeding cycle, despite the presence of other cavity nesters on Tiritiri Matangi (i.e., hihi and tieke).

Many authors have stressed the importance of competition as a driving force behind nest site selection by parrots (Pell & Tidemann 1997; Heinsohn & Legge 2003). More importantly, there is evidence for predation as a crucial factor determining nest selection and nest niche diversification for parrots (Eberhard 1997; Brightsmith 2005a; White et al. 2006). Consequently, there is great emphasis on management of nest sites for parrot conservation worldwide (Monterrubio-Rico & Enkerlin-Hoeflich 2004; Walker et al. 2005; Pizo 2008). In the red-crowned parakeet, it seems that competition for cavities is low, at least on Tiritiri Matangi Island. For example, we noticed considerable variability in nest types, cavity characteristics, apparent low cavity re-use, and low-intensity agonistic interactions near the cavity. A low incidence of nest site re-use has also been recorded in the closely related Norfolk Island green parrot (*Cyanoramphus cookii*) (Hill 2002).

In our study, nesting success was not related to nest type or location across habitats. These findings contrast with observations of red-crowned parakeet on Little Barrier Island, where agonistic interactions around nest sites were common, particularly at the beginning of the breeding season (Greene 2003). Little Barrier Island supports natural populations of both red and yellow-crowned parakeets (*Cyanoramphus auriceps*) and it is possible that overlap in nesting site requirements between these closely related species result in a higher occurrence of agonistic interactions.

Other studies have reported more high intensity interactions attributed to nest defence and territoriality, as the breeding season progresses (Beissinger et al. 1998; Renton 2004) but we did not observe this despite extensive observations of the nests we found. It has also been suggested that low cavity re-use by parrots is a mechanism to avoid predators (Renton & Salinas-Melgoza 1999), however, we did not observe predation events over 2 years despite the presence of potential native predators such as ruru (morepork *Ninox novaezelandiae*). It is possible that nest-site selection by parakeets on Tiritiri Matangi Island is driven by causes other than competition or predation, such as nest microclimate characteristics or previous breeding experience of pairs.

Nesting success between breeding seasons

Variability in nesting success between breeding seasons is a common feature in parrot studies (Krebs 1998; Koenig 2001) and it is generally explained by predation of eggs and nestlings (Garnett et al. 1999) or climatic variability (Walker et al. 2005). In this study, variability between years resulted from changes in survival during the incubation and nestling stages. Between 2004 and 2006, estimated survival during these stages increased nearly 20% despite negligible changes in fertility. It is of particular interest that estimated survival was lower during incubation than the nestling stage, in both years of our study. In general, parrot nests tend to fail most often during the nestling stage, due to predation of nestlings or poaching (Waltman & Beissinger 1992; Wright et al. 2001). Losses also occur during incubation in parrots but the proximate causes are not always clear (Fernandes Seixas & de Miranda Mouráo 2002; Heinsohn et al. 2003). Most commonly, losses during the incubation stage are due to un-hatched infertile eggs (Saunders 1986; Eberhard 1998; Holdsworth 2006). By contrast, we found high clutch fertility and variable embryo survival between breeding seasons.

Human visitation to nests, social interference from conspecifics (Beissinger et al. 1998) and suboptimal incubation performance due to poor body condition (Gorman et al. 2005) can affect survival during the incubation period by reducing the hatchability of eggs. Handling of eggs could affect hatchability by increasing the likelihood of trans-shell infection by pathogens, by disturbing the normal incubation behaviour of females or by killing embryos due to over-vigorous, or prolonged, handling. Because we used disposable sterilised gloves to handle eggs, transferring pathogens to them by handling was unlikely. Furthermore, our egg-handling protocol was identical in both breeding seasons but a high incidence of nesting failure during incubation was only observed in 2004–05. Un-hatched eggs were collected for sex determination of embryos, and none showed signs of pathogen infection. It is also improbable that our visits to nests altered the incubation behaviour of females, since we recorded numerous successful nesting attempts even under our high intensity-monitoring regime, and not a single instance of abandonment.

Inter and intraspecific interactions (social interference) were uncommon during this study, and are unlikely to explain changes in embryo survival during incubation. Furthermore, we found no signs of aggressive intrusions from conspecifics (e.g., broken eggs). Red-crowned parakeets breed well in captivity, where nesting success and food abundance have been repeatedly linked (Forshaw 1989). For the closely related yellow-crowned parakeet (*Cyanoramphus auriceps*), increased nesting success has been documented in years of fruit abundance, and observations of captive red-crowned and orange-fronted parakeets (*C. malherbi*) suggest a similar pattern (Jack van Hal pers. comm.). Our finding of second clutches during 2005–06 on Tiritiri Matangi is consistent with these reports. The potential link between food supply, body condition and improved incubation performance has not been explicitly tested in wild New Zealand parakeets, but many New Zealand plants stage mass flowering (masting events) (Connor 1966; Brockie 1986; Webb & Kelly 1993; Schauber et al. 2002), including some of the plants eaten by red-crowned parakeets on Tiritiri Matangi Island. A close relationship between masting events and breeding performance has been reported for many New Zealand forest birds (Beggs & Wilson 1991; Moorhouse 1991; Clout et al. 1995). Red-crowned parakeets may be among them, so future studies should test this hypothesis.

Conservation implications

Recovery plans for *Cyanoramphus* parakeets often emphasise nest management, since lack of safe nest sites is seen as the main factor limiting nesting success. Consequently, parakeet recovery plans often recommend providing nest boxes (Miskelly 1998; Greene 2000). Our results indicate that red-crowned parakeets are very flexible in choice of both nesting habitat and nest sites, and that nest site re-use and laying date seem to have little influence on nesting outcome. Breeding pairs laying small clutches late in the breeding season, either in a nest box or a natural site, can usually produce at least one fledgling, even when the density of active breeding pairs is high. This is particularly relevant for the conservation via translocation of this vulnerable species since availability of nesting sites is one of the criteria for selection of suitable release sites. Our study suggests that nest sites are currently not limiting for kakariki on Tiritiri Matangi Island.

Nest boxes can be an important monitoring tool, but reasons for their use and establishment must be clearly identified and evaluated against other management priorities. The idea of "boosting" the productivity of translocated parakeets by providing nesting boxes appears unrealistic since, at least in the absence of mammalian predators, nesting success seems unrelated to nest site characteristics. Thus, establishing nest boxes in habitats free of mammalian predators is probably both unnecessary and wasteful if nesting success in such habitats is primarily driven by the availability of food resources before and during the breeding season.

We recommend future research on parakeets on islands free of mammalian predators should focus on identifying the spatial and temporal distribution of the foods that determine nesting success.

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APPENDIX 9

Clutch parameters and reproductive success of a translocated population of red-crowned parakeet (*Cyanoramphus novaezelandiae*)

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Clutch parameters and reproductive success of a translocated population of red-crowned parakeet (*Cyanoramphus novaezelandiae*)

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Abstract. At least four populations of the red-crowned parakeet (*Cyanoramphus novaezelandiae*) have been established via translocation within New Zealand over the last 40 years, but reproductive parameters of these populations have not been documented. We quantified differences in clutch parameters and reproductive success for a translocated population of this species on Tiritiri Matangi Island over two breeding seasons. Overall clutch parameters and estimates of reproductive success were consistent with reported values from natural populations. However, we found previously unreported differences in clutch size, hatching success and brood size between breeding seasons. The number of fledglings produced per breeding pair increased significantly from 1.4 to 3.4 fledglings during our two-year study. In contrast, egg volume and fertility per clutch did not vary during the same period. Overall, 7 eggs were laid per breeding pair but only 2.22 nestlings fledged, representing a 63.8% loss of initial reproductive potential. Losses during the incubation stage were caused by partial and total hatching failure, whereas starvation of nestlings caused all losses during the brood-rearing stage. Hatching success during our study was lower than that reported for wild populations of this and other parrot species, and remained lower even during the most productive breeding season. We found no cases of predation on eggs or nestlings during our study despite the presence of native and exotic avian predators on Tiritiri Matangi Island. We show that clutch size, brood size and changes in loss between breeding seasons are determinants of reproductive output in translocated red-crowned parakeet and also that reproductive output can vary greatly between breeding seasons. Finally, if reduced hatching success is the result of small founder size, management of parakeets should consider the movement of larger and more genetically diverse flocks.

Introduction

The red-crowned parakeet (*Cyanoramphus novaezelandiae*, henceforth 'parakeet') is a New Zealand parrot listed as Vulnerable (V) by the IUCN (www.iucn.org). Formerly widespread, the species has experienced an ongoing decline attributed to exotic mammalian predators brought into the archipelago by humans (Higgins 1999). In an attempt to establish viable populations within the species' historical range, parakeets have been translocated to mainland sites and offshore islands since 1968 (Juniper and Parr 1998; McHalick 1999). Currently, at least four populations have been established on islands: Tiritiri Matangi, Cuvier, Whale (Higgins 1999) and Matiu-Somes (Montoya and Burns 2007). Unfortunately, there are no published data on post-release monitoring or even basic reproductive parameters for these populations. Such information is necessary not only as a reference to compare the relative success of other translocations of this species and its close relatives, but also to determine whether strategic management intervention on already established populations is needed to ensure their long-term persistence. For instance, translocated populations of takahe (*Porphyrio hochstetteri*) show higher egg infertility and lower fledgling success than a population in its natural range, possibly resulting from increased genetic load (Jamieson 2003; Jamieson *et al*. 2003). Furthermore, hatching success of translocated South Island robins (*Petroica australis*) is only one-third of that reported for mainland populations, purportedly due to inbreeding depression (Mackintosh and Briskie 2005). Finally, it has been shown that populations of both native and exotic New Zealand birds passing through bottlenecks of less than 150 individuals show an increase in hatching failure (Briskie and Mackintosh 2004). Thus, a detailed account of founder flock size and reproductive parameters can serve as an initial step in conservation planning for translocated populations.

On Tiritiri Matangi Island, a total of 84 parakeets were reintroduced from captive stock between 1974 and 1976 (Higgins 1999). At present the species is common on the island and numerous nests in nesting boxes and natural nesting sites are accessible for observations during spring and summer (Ortiz-Catedral and Brunton 2009), making this site ideal to study in detail multiple aspects of the reproductive biology of translocated parakeets.

In this paper we present an analysis of differences in clutch parameters and reproductive success between two consecutive breeding seasons for this population. We also identify and analyse stage-specific mortality during the nesting period. Our study represents a first approach to understanding the effects of

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variability in clutch size, egg volume and fertility between breeding pairs of parakeets, and their relationship to hatching success, nestling mortality and fledgling success between breeding seasons in a translocated population of parakeets.

Methods

Tiritiri Matangi Island (36°36′S, 174°53′E), is a 220-ha sanctuary 28 km north-east of Auckland City managed by the Department of Conservation, New Zealand. The vegetation consists of mixed broadleaf coastal forest, grasslands and revegetated patches (Rimmer 2004). Nearly 50% of the island's vegetation cover consists of native shrubs and trees planted between 1984 and 1994 as part of a community-led revegetation project (Mitchel 1985; Rimmer 2004). We collected data from natural nests and nesting boxes. Nests were searched at least once a week from October to February during the breeding seasons of 2004–05 and 2005–06. During this period there were ~300 nesting boxes scattered throughout the island (M. Fordham, pers. comm.) used by parakeets and other cavity-nesting species including hihi (*Notiomystis cincta*) and saddleback (*Philesturnus carunculatus*) (Rimmer 2004). We searched for parakeet nests using behavioural cues of nesting pairs. These are highly stereotypical and exhibited by parakeets only during their breeding season (Higgins 1999). We limited our analysis to 43 nests found in nesting boxes and 7 nests found in accessible natural sites. Although nests in natural sites (i.e. tree cavities, vegetation clusters, etc.) are common on Tiritiri Matangi Island (Ortiz-Catedral and Brunton 2009), these were often too fragile to inspect on a regular basis without significant disturbance to the nest structure or intrusion to incubating females or nestlings. Study nests were visited at least once per week to document changes in clutch size, hatching success and nestling mortality. Monitoring continued until fledging of chicks (~50 days after hatching).

Incubating females regularly exit nesting cavities to be fed by males (Greene 2003). Eggs were measured during these brief incubation absences. Length and width of eggs were measured to the nearest 0.1 mm with a stainless steel vernier calliper. The volume (V) of eggs was determined following the formula of Tatum (1975):

$$V = \pi LB^2/6$$

where L is length and B is maximum width. This formula was used because measurements could be taken easily in the field with minimal disturbance to eggs, and rapidly enough to place the eggs back in the nest before incubating females returned. Fertility was determined in the field by candling with a small hand torch. The egg shell is almost translucent and embryos could be seen clearly when light was shone through the eggs. Fertility was calculated as the number of fertile eggs divided by the total number of eggs laid in a clutch. Hatching success was determined as the proportion of hatched eggs divided by the total number of fertile eggs in the clutch. Infertile eggs were not included in the analysis of hatching success. Nests were found at different stages of the nesting cycle (i.e. egg laying, incubation, hatching, and brood rearing); thus information was necessarily incomplete for some nests (e.g. only nests found during egg laying or incubation could be used for analysis of clutch parameters, etc.). As a result, sample sizes differ between analyses.

All breeding pairs were unbanded and thus clutches and broods were assumed to be independent between breeding seasons. Normality of data was tested using the Shapiro–Wilks test. When the data did not fulfil assumptions of parametric tests, non-parametric alternative tests were applied. All statistical analyses were performed in SAS Version 8© and StatView Version 5.01©.

Differences in mean egg volume and mean fertility per clutch between breeding seasons were contrasted by two-sample t-tests on a total of 30 clutches. To estimate differences in clutch size, hatching success, fledgling success and number of hatchlings and nestlings, 50 nests were considered and the differences compared using a Wilcoxon–Mann–Whitney test. A further analysis was performed to test for differences associated with clutch and brood sizes. The variables considered were: hatching success, number of hatchlings, degree of brood reduction, number of dead nestlings and number of fledglings. Mean values for these variables were compared using one-way ANOVA. When significant results were found, we used *a posteriori* comparisons to distinguish differences between pairs of categories. For comparisons, clutches were classified as small (4–5 eggs), medium (6–7 eggs) or large (8–9 eggs). Similarly, broods were categorised as small (1–3 nestlings), medium (4–6 nestlings) or large (7–9 nestlings).

Nest losses were classified either as partial or total losses. 'Partial loss' includes (1) clutches from which at least one egg failed to hatch (partial hatching failure) and (2) clutches that showed partial brood failure (i.e. at least one young died during the brood-rearing stage). 'Total loss' considers (1) total nest failure (i.e. clutches lost owing to environmental causes, abandonment during incubation or unknown causes); (2) total hatching failure (no eggs hatched in a clutch but females remained sitting on eggs for a period equivalent to, or longer than, normal incubation); and (3) total brood failure (all hatched young died before fledging owing to starvation or environmental causes).

Results

Clutch parameters and reproductive success

Parakeet clutches had the following overall values: a mean clutch size of 6.82 ± 1.60 (s.e.) eggs; an egg volume of 5.40 ± 0.11 cm^3 and 92.82 ± 2.24% fertility. Only clutch size varied significantly between breeding seasons (Table 1). Overall hatching success was 53.14 ± 4.66%, brood size was 3.80 ± 0.36 nestlings and number of fledglings was 2.22 ± 0.29. These three measures of reproductive success varied significantly during our study (Table 1). Overall, fertility and hatching success values in a clutch were similar between different clutch-size categories (ANOVA for fertility: $F_{2,47} = 0.72$, $P = 0.49$; ANOVA for hatching success: $F_{2,47} = 2.62$, $P = 0.08$) (Fig. 1). Likewise, brood reduction and fledging success did not vary between brood categories (ANOVA for brood reduction: $F_{2,40} = 0.72$, $P = 0.49$; ANOVA for fledging success: $F_{2,40} = 0.72$, $P = 0.49$) (Fig. 1). However, the number of nestlings hatching per nest was significantly positively related to initial clutch size (Spearman rank correlation: $r_s = 0.61$, $P < 0.01$). Similarly, the number of dead nestlings in a brood was significantly positively correlated with brood size (Spearman rank correlation: $r_s = 0.59$, $P < 0.01$), with large broods having more dead nestlings than other brood categories (number of dead

Table 1. Variability in clutch parameters and reproductive success of red-crowned parakeets on Tiritiri Matangi Island, New Zealand, between the 2004–05 and 2005–06 breeding seasons

Values represent means ± s.e. Sample sizes (number of clutches or broods) are given in parentheses. Z = Statistic for Wilcoxon–Mann–Whitney test; t = two sample t-test. *, $P<0.05$; **, $P<0.01$

	2004–2005	2005–2006	Statistic
Clutch parameters			
Clutch size	6.29 ± 0.33 (24)	7.31 ± 0.26 (26)	$Z_2 = -2.31$*
Egg volume (cm^3)	5.46 ± 0.18 (15)	5.23 ± 0.12 (15)	$t_{28} = 1.04$
Fertility (%)	91.35 ± 2.87 (24)	91.59 ± 3.04 (26)	$Z_2 = -0.30$
Reproductive success			
Hatching success (%)	41.22 ± 6.77 (24)	64.15 ± 5.73 (26)	$Z_2 = -2.54$*
Brood size	2.75 ± 0.49 (24)	4.77 ± 0.44 (26)	$Z_2 = -2.94$**
No. of fledglings	1.04 ± 0.27 (24)	3.27 ± 0.41 (26)	$Z_2 = -3.80$**

nestlings in small broods, 0.93 ± 0.20; medium broods, 3.19 ± 0.39; large broods, 3.86 ± 0.86; ANOVA: $F_{2,40} = 7.82$, $P<0.01$; Tukey test = 3.23, $P=0.05$). Although more nestlings died in large broods, the number of chicks successfully fledging per brood was significantly positively correlated with initial clutch size (Spearman rank correlation: $r_s = 0.44$, $P=0.02$) and initial brood size (Spearman rank correlation: $r_s = 0.71$, $P<0.01$). Overall, large broods produced more fledglings than small broods but medium and large broods produced similar numbers of fledglings (number of fledglings in small broods, 1.07 ± 0.25; medium broods, 1.86 ± 0.42; large broods, 3.86 ± 0.88; ANOVA: $F_{2,40} = 9$, $P<0.01$; Tukey test = 3.44, $P=0.05$). Our analysis of stage-specific losses through the nesting cycle showed similar losses during the incubation and brood-rearing stages (18% and 16% respectively).

Causes of partial and total nest losses

Twenty-six nests experienced partial losses through the nesting cycle during our study. These included partial hatching failure and brood reduction. In general, partial hatching failure was followed by brood reduction due to starvation of nestlings. In 2004–05, 34% of clutches presented partial hatching failure and 34% of broods suffered partial brood reduction (Fig. 2). In 2005–06, partial hatching failure affected 62% of clutches and partial brood reduction was recorded in 70% of broods. Although partial hatching failure and partial brood reduction were more common during the second breeding season of study, the proportion of successful nests was greater (Fig. 2). Total losses varied considerably between seasons. In 2004–05, 57% of clutches failed completely; these included clutches failing to hatch any young (23%), total brood failure (27%), and two instances of total nest failure (7%) (Fig. 2): one nest was flooded and another was deserted soon after completion of the clutch due to unknown causes. The clutch was left intact with no signs of predation.

Total losses in 2005–06 occurred only in 8% of clutches and included one case of total hatching failure (4%) and one case of total brood failure (4%). No instances of total nest failure were observed. The only case of total brood failure was due to flooding of the nest close to fledging of most nestlings. No instances of total brood failure due to starvation of nestlings were recorded. Although partial losses were more common during the second breeding season of our study, 91% of clutches produced at least one fledgling. In contrast to 2005–06, the previous breeding season had only 42% of clutches resulting in at least one fledgling (Fig. 2).

Discussion

Our analyses indicate that clutch size, brood size and changes in loss during the nesting cycle of translocated parakeets are determinants of reproductive output between breeding seasons; variation in egg size and fertility had no detectable effect on reproductive output during our study period. The clutch size of translocated parakeets is similar to that reported for a natural population on Little Barrier Island (Greene 2003) and falls within

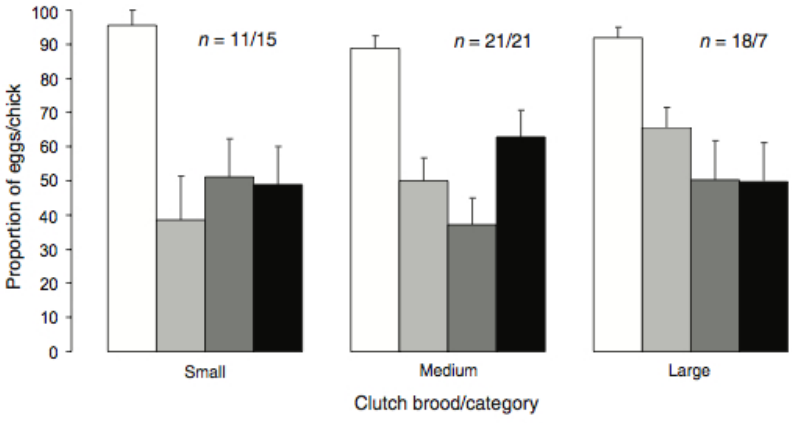

Fig. 1. The relationship between parameters of reproductive success and clutch and brood size categories of the red-crowned parakeet during two breeding seasons on Tiritiri Matangi Island, New Zealand. Values are means ± s.e. Bars represent fertility (white), hatching success (light grey), brood reduction (dark grey) and fledgings success (black). Sample sizes are given above bars (n = number of clutch or broods analysed). *Note*: Clutch/brood size category (from left to right) small, medium and large.

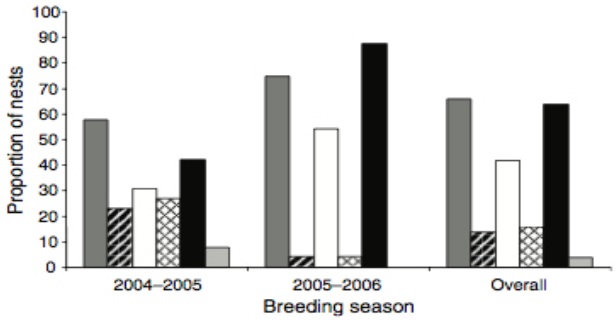

Fig. 2. Proportion of nests showing partial and total losses during the nesting cycle of the red-crowned parakeet on Tiritiri Matangi Island, New Zealand. Partial hatching failure (dark grey bars); total hatching failure (hatched bars); partial brood failure (white bars); total brood failure (crisscrossed bars); successful nests (black bars); total nest failure (light grey bars).

the clutch size range of a natural mainland population of the smaller yellow-crowned parakeet (*Cyanoramphus auriceps*) in Fiordland National Park (Elliott *et al.* 1996). Likewise, the egg volume of parakeets on Tiritiri Matangi Island is similar to that reported from Little Barrier Island (Higgins 1999; Greene 2003) and the fertility appears standard when compared with natural populations of this (Greene 2003) and other (Renton 1998; Garnett *et al.* 1999) parrot species.

Overall, the hatching success for translocated parakeets was lower than the 74.6% average reported from 22 studies in wild parrot populations (Masello and Quildfeldt 2002) and 83.6% reported for wild parakeets on Little Barrier Island (Greene 2003). Hatching success remained lower than these two reference values even during the second, more productive, breeding season. Wild bird populations have an approximate hatching success of 90% (Koenig 1982) and reductions from this threshold are commonly used as a proxy for assessing inbreeding depression (Keller and Waller 2002; Briskie and Mackintosh 2004). Between 1974 and 1976, 84 parakeets were reintroduced to Tiritiri Matangi Island (Higgins 1999). This founder number is lower than the minimum of 150 individuals estimated by Briskie and Mackintosh (2004) as necessary to avoid increased hatching failure. However, it is unclear if our hatching success estimate is the result of inbreeding depression resulting from a small founder flock. One possible alternative explanation is that clutches laid in nesting boxes have lower hatching success than natural nesting sites. Parakeets do not bring plant material to nesting sites. Instead, females chew debris already present in cavities to a fine powder and lay their eggs on top of this loosened substrate (Greene 2003). Nest boxes on Tiritiri Matangi Island are made of solid plywood and during our nest inspections we noticed that the only cushioning material was a thin layer of wood chips and a few parakeet feathers, presumably a less stable substrate than that of natural nesting sites. Also, we encountered several eggs with fine cracks shortly after being laid. Finally, the interior walls of the nest boxes are smooth and do not have climbing structures. Thus, potentially regular movements of incubating females may cause excessive vibration on unstable clutches and subsequent embryo death. In our analysis, natural nesting sites are underrepresented (only 10% of study nests) and thus it is difficult to make statistical comparisons of hatching levels between nest types.

Another possible explanation is that low hatching success can be the result of seasonal effects. Wild crimson rosella (*Platycercus elegans*) nesting in boxes with a thick layer of wood chips, showed variable hatching success over four years and the lowest hatching success recorded (50%) coincided with the driest year (Krebs 1998). Despite these two alternative explanations, the possibility still exists that reduced hatching success is the result of inbreeding depression on translocated parakeets in accordance to other studies of New Zealand birds (Briskie and Mackintosh 2004; Mackintosh and Briskie 2005).

Overall fledging success during our study was comparable to that of available parrot studies in the wild (fledging success for 23 studies, 58.22%: Masello and Quildfeldt 2002), but higher than estimates for wild parakeets on Little Barrier Island (fledging success, 39.3%: Greene 2003). This could be explained by lower predation in nesting boxes and the absence of mammalian predators on Tiritiri Matangi Island. On Little Barrier Island, Pacific rats (*Rattus exulans*) prey on parakeet nestlings and morepork (*Ninox novaeseelandiae*) prey on parakeet fledgings (Greene 2003). Pacific rats were eradicated from Tiritiri Matangi Island in 1993 (Rimmer 2004) and from Little Barrier Island in 2004 (Rayner *et al.* 2007) via aerial poison drops. Although morepork and potential exotic predatos such as common myna (*Acridoteres tristis*) and Australasian harrier (*Circus approximans*) are present, the nesting boxes on Tiritiri Matangi Island have a narrow entrance that might prevent them from reaching broods.

In contrast to that on Little Barrier Island, fledging success on Tiritiri Matangi Island varied considerably between breeding seasons. The dramatic decrease in total brood failure during the second breeding season and the predominance of starvation as a cause of death among nestlings during our two-year study suggests that food availability is most likely to play a role in determining the observed differences in reproductive success. *Cyanoramphus* parakeets are known to boost breeding success when food supply is abundant (Elliott *et al.* 1996) and a similar link between food availability and reproductive success has been suggested for other New Zealand parrots, including kaka (*Nestor meridionalis*) (Beggs and Wilson 1991; Moorhouse 1991), kakapo (*Strigops habroptilus*) (Powlesland and Lloyd 1994; Elliott *et al.* 2001) and kea (*N. notabilis*) (Diamond and Bond 1999).

Conservation relevance

Research on other New Zealand birds has shown that new populations can be established with founder flock sizes as low as 15 individuals (Taylor *et al.* 2005), but bottlenecks of fewer than 150 individuals cause increased hatching failure (Briskie and Mackintosh 2004) and can compromise immunocompetence of translocated populations (Hale and Briskie 2007). Thus, during translocations genetic diversity could be compromised in the short term in favour of a more manageable founder flock size (i.e. 15 individuals versus 150) to establish new populations. However, the option of translocating additional genetically diverse individuals to compensate for the detrimental effects on fitness resulting from genetic isolation (Westemeier *et al.* 1998)

should still be considered as a management measure in the medium to long term.

Although our study population was established with a relatively small founder flock 34 years ago, it has persisted and increased in numbers without direct management and exhibits overall clutch parameters comparable to those of wild parakeets. However, measures of hatching success on Tiritiri Matangi Island parakeets highlight the need for management actions to remediate potential underlying genetic problems that might compromise the long-term viability of this and other translocated parakeet populations. In particular, it is necessary to conduct further research to determine whether low hatching success is the result of inadequate nest box design or inbreeding depression. If the latter is the case, surplus translocations of more genetically diverse individuals should be considered for existing translocated populations of parakeets.

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