HABITAT USE BY TASMAN PARAKEETS (*Cyanoramphus cookii*) AND CRIMSON ROSELLAS (*Platycercus elegans*) ON NORFOLK ISLAND, SOUTH PACIFIC

A thesis submitted in partial fulfilment of the requirements for the degree of

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Figure 0.1. A male Tasman parakeet (*Cyanoramphus cookii*; top) perched at ground level, on a fallen niau (*Rhopalostylis baueri*) frond; and a crimson rosella (*Platycercus elegans*; bottom), perched on a Norfolk pine (*Araucaria heterophylla*) both in the Mount Pitt section of the Norfolk Island National Park. Photos: L. Whitwell and L. Ortiz-Catedral.

DECLARATION

I declare that this thesis is an accurate and original account of my research and that the contents have not previously been submitted for a degree at Massey University, nor any other tertiary institution. Except where acknowledged within, the material contained in this thesis has not been written or published by any other individual and to the extent of my knowledge, does not infringe upon copyright restrictions. The research presented in this thesis is part of larger research project initiated in 2013 by my supervisor Dr. Luis Ortiz-Catedral. Dr Ortiz-Catedral allowed me to execute this project following approved research and animal ethics protocols by the Norfolk Island National Park (Appendix A). Dr Ortiz-Catedral and I coordinated all the logistics for the fieldtrips necessary to collect the data obtained as part of this research. Financial support for this project was obtained from the Disney Conservation Fund, Mohamed bin Zayed Species Conservation Trust, Fonds für bedrohte Papageien and Massey University. The ideas about the components of this thesis were discussed between my supervisor and I prior, during and after fieldtrips. Dr Ortiz-Catedral provided all the supervision necessary for the development of this project, the analysis of results and the elaboration of the final document. I assume all responsibility for mistakes or omissions present in this document.

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The community on Norfolk Island were very welcoming of me which made conducting field work in another country an easy experience. A special thank you to the Norfolk Island National Park staff, including Cassandra Jones, Melinda Wilson, Dids Evans and Joel

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This research has caused me to become enamoured with the Tasman parakeet, and the *Cyanoramphus* genus as a whole, while also confirming to me the type of work that I'd love to be doing. For that reason I must also be thankful for my research and my time in the Master's degree.

ABSTRACT

Islands harbour a disproportionate amount of threatened vertebrate species and remain the focus of intense conservation research and management. Two important components of the ecological restoration of islands include revegetation and control of introduced animal species. The Tasman parakeet (*Cyanoramphus cookii*) endemic to Norfolk Island, is one of the rarest bird species in the South Pacific, with a long history of assisted conservation in particular during the breeding cycle. An introduced parrot, the crimson rosella (*Platycercus elegans*), is thought to compete strongly with Tasman parakeets for nesting and feeding resources, however, the degree of competition for feeding resources has not been quantified. No study has aimed at understanding the selection of available habitats by Tasman parakeets and crimson rosellas, or the relevance of restored vegetation patches for these species for foraging activities. In order to provide information to better manage a growing population of the Tasman parakeet within the Norfolk Island National Park, it is important to understand patterns of habitat use and key resources, as well as the degree of competition with the introduced crimson rosella. I studied the habitat use of Tasman parakeets and crimson rosellas during two seasons, autumn and spring 2017 by surveying 986 vegetation plots. I encountered a total of 80 woody plant species occurring on nine habitat types. The highest plant species richness was in forest edges (70 species), followed by remnant hardwood forest (43 species). The lowest plant species richness was on regenerating vegetation patches (26 species). Tasman parakeets and crimson rosellas used these habitats differently. In autumn and spring, Tasman parakeets preferred remnant hardwood forests (Manly Selectivity Index autumn: 0.50; Chi square 6.86, $P < 0.001$, n = 35; Manly Selectivity Index Spring: 0.32; Chi square 6.86, $P < 0.001$, n = 55). Crimson rosellas preferred forest edge in autumn (Manly Selectivity Index Autumn: 0.34; Chi square

24.51, $P < 0.001$, n = 69) and remnant hardwood in spring (Manly Selectivity Index Spring: 0.28; Chi square 4.56, $P < 0.001$, n = 130). In terms of feeding species, Tasman parakeets and Crimson rosellas exhibited a high degree of overlap in only one food type: ake ake (*Dodonea viscosa*) seeds and fruits. Opportunistic observations during summer, revealed a similar degree of overlap for consumption of seeds and pulp of red guava (*Psidium cattleianum*), although habitat preferences for summer or winter were not quantified in this study. I did not register a single instance of aggressive interactions between Tasman parakeets and crimson rosellas after nearly 300 hours of field observations. My results indicate that Tasman parakeets and crimson rosellas used the available habitats in the Norfolk Island National Park differently. In terms of foraging resources, Tasman parakeets and crimson rosellas do not appear to overlap greatly in food types or feeding species during autumn and spring. Future research should focus on the patterns of habitat use during summer and winter and the degree of competition for feeding resources during these seasons as well. While there has been evidence (prior to this research) of intense competition for nesting cavities between Tasman parakeets and crimson rosellas, my research reveals little inter-seasonal overlap in habitat use and feeding resource. From a management perspective, control of crimson rosellas in an around nest cavities of Tasman parakeets should be favoured over control on foraging areas. Nevertheless, crimson rosellas outnumber Tasman parakeets 3:1, and therefore my results need to be interpreted with caution as it is unclear whether foraging and habitat use patterns consistent with my research would be encountered in the future, as numbers of Tasman parakeets continue to increase.

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CHAPTER 1 : GENERAL INTRODUCTION

Figure 1.1. A male Tasman parakeet (*Cyanoramphus cookii*) feeding on Red Guava (*Psidium cattleianum*) seeds.

Photo: L. Ortiz-Catedral.

ABSTRACT

Habitat loss and fragmentation affect many species worldwide by limiting the availability of critical foraging or habitat for reproduction. For island species, these effects can be compounded by the presence of introduced species in forest remnants that prey or compete with native and endemic species. One way to ameliorate the effects of introduced species, in particular on critical habitat for endangered species, is the large-scale control of introduced species via trapping or via the use of poisoned bait. Understanding how species of conservation interest utilise their managed habitats spatially and temporally can yield important insights into the relative importance of a range of habitats. This information is essential to refine management plans and to increase the efficiency of conservation funds and human-power available to implement and monitor the desired outcomes of a given program. A species that exemplifies the situation outlined above is the Tasman parakeet (Figure 1.1), a critically endangered species of parrot endemic to the last remaining fragment of sub-tropical rainforest on Norfolk Island, in the South Pacific. Norfolk Island has undergone progressive habitat loss and fragmentation since the arrival of the first settlers. This process has been accompanied by the introduction of feral cats (*Felis domesticus*), Pacific rat (*Rattus exulans*) and ship rat (*Rattus rattus)*, known predators of various species, including the Tasman parakeet. Another introduced species, the Crimson rosella (*Platycercus elegans*), competes for nesting sites with Tasman parakeets but the degree of competition for other resources has not been quantified. In this chapter, I provide background information on the Tasman parakeet, challenges to its conservation and outline the general plan of this thesis.

HABITAT LOSS AND FRAGMENTATION

Numerous research articles in the last decade, have highlighted the alarming rate of biodiversity loss in biomes worldwide as a result of human activities (Butchart, Walpole et al. 2010, Cardinale, Duffy et al. 2012, Hooper, Adair et al. 2012, Doherty, Glen et al. 2016). In fact habitat loss and fragmentation in terrestrial and marine environments are considered the chief drivers of biodiversity loss, in particular species extinctions. (Wallenius, Niskanen et al. 2010, Silcock and Fensham 2018, Romero-Muñoz, Torres et al. 2019). Examples of activities that reduce the extent and connectivity of native habitats includes clearing of large tracts for agriculture or urban development (Reside, Beher et al. 2017, Xi Xu, Yujing Xie et al. 2018), expansion of infrastructure for fossil fuel extraction (Moran, Cox et al. 2015), fires (Henderson, Meunier et al. 2018), and overexploitation (Specht, Pinto et al. 2015). As a result of these activities, the majority of terrestrial ecosystems have been anthropogenically altered (Ellis 2013) and non-human species increasingly occupy a fragmented matrix that includes habitat patches of varying size and quality.

Conservation biology, since late 20th century has focused on cataloguing biodiversity on reserves or national parks and lay the ground for conservation work on developing nations, focusing on “species” as the prime unit for conservation (Rojas 1992, Caldecott, Jenkins et al. 1996). The importance of vast tracts of native habitat and their connectivity have since been recognised, thanks to the development of the species area-richness relationship, one of the core concepts in the Theory of Island Biogeography (MacArthur and Wilson 1967). The rapid development of satellite-based assessment of forest fragmentation, in particular on tropical forests has helped conservation biologists assess priority areas to implement conservation programs as well as quantifying patch sizes of key areas for protection on continental areas as well as islands (Skole and Tucker 1993, Kerr and Ostrovsky 2003, Harper, Steininger et al. 2007, Watson, Trueman et al. 2010).

Ongoing improvements in the production of satellite imagery coupled with the fast development of drone technology are revolutionising our ability to map, classify, prioritise and monitor areas for conservation and wildlife management (Glennon and Porter 1999, Koh and Wich 2012). While remote sensing technology helps us understand the scale of habitat fragmentation and habitat loss at local and global scales, the resolution of images and data layers has been criticised as inadequate to unravel significant attributes of biological communities and/or biological interactions (Turner, Spector et al. 2003), particularly if the species of conservation interest uses habitats at smaller scales than can be mapped by remote sensing. For example, in the Azurean Laurel forest of Azores Islands, Portugal an assessment of the extent of invasive plant species using satellite imagery, reports low indices of spectral separability between two aggressive plant invasive species: *Pittosporum undulatum* and *Clehtra arborea*; and between pastures and bare soils (Gil, Yu et al. 2011). This situation can lead to erroneous management recommendations of fragmented habitats because the scenarios obtained by satellite imagery alone can be vastly different from those derived from traditional habitat assessments based on observer-collected data in the field. For small forest remnants on islands, satellite imagery can be useful to characterise “coarse” habitat characteristics, like canopy cover, height of dominant tree species and above-ground biomass (Kennaway, Helmer et al. 2008). But that information needs to be complemented with field information of the patterns of fine-scale habitat use of target species or suite of species of conservation interest (see Chapter 2).

Linking information about the size and characteristics of habitat fragments, and the ways in which species of interest use these can be relatively straightforward. For instance, Beier (1993) created a model that highlighted the need of corridors that allow for immigration between different habitat patches for cougars (*Felis concolor*). For a population of cougars in California, access between habitats fragments via corridors was deemed crucial to lower the extinction risk locally. In addition to models of habitat use as in the previous example, actual estimations of movements of animals in man-modified habitat fragments can be obtained by the use of GPS technology. For instance, Gurarie, Suutarinen et al. (2011) tracked wolves fitted with GPS collars through modified boreal forest fragments in Finland. The authors discovered that the high density of roads within wolves' territories constrained their patterns of habitat use during the pup-rearing season compared to wolves inhabiting less modified forest areas. Due to their large home ranges, cougars and wolves are model organisms that can help us understand animal movements across large habitat tracks. However, for cryptic species at more discrete spatial scales, and for species occurring in low densities or in remote locations, documenting even the most basic aspects of habitat use can be challenging.

SPATIAL AND TEMPORAL VARIATION OF HABITAT USE

The analysis of habitat features at the geographic scale can be complemented with analyses on the temporal variability of resources and how these fluctuations affect the species of interest. Animals utilise areas of different sizes or quality in relation to seasonal changes in availability or suitability of key resources (Blake and Loiselle 2002, Morrant and Petit 2012, Strøm, Thorstad et al. 2018). For example, the grey-cheeked mangabey (*Lophocepbus albigena*) adjusts its diet in response to changes in resource availability between February to December, and switches from a predominantly fruit-based diet to a diet consisting of seeds, leaves and flowers (Poulsen, Clark et al. 2001). Another species that exhibits seasonal changes in response to variation in available feeding resources are Eastern grey kangaroos (*Macropus giganteus*) which adjust their foraging behaviours in response to available biomass and greenness of vegetation, with significant effects in group sizes, levels of vigilance and reproductive output (Favreau, Goldizen et al. 2018). Assessing the movement patterns of animals through their annual cycles can provide valuable understanding of the seasonal importance of different habitats used. Levey (1988) investigated the seasonal variation of the habitat use of Costa Rican fruit-eating birds, and discovered that the abundance of fruit varies through the year, with peak abundance from August to January, during the rainy season. The peak abundance of fruit eating birds was also within the rainy season, from October to January, and has been attributed to fruit availability. Also, during the breeding season for these birds, from February to April, the abundance of insects in the birds diets increases, as indicated by insect remains in faecal samples (Levey 1988). These studies, highlight the importance of understanding seasonal variation in patterns of habitat use on habitat fragments of different sizes, and its effects on the biology of the species.

For species under conservation management, a detailed understanding of patterns of habitat use, seasonal variation in these patterns and maximum carrying capacity of their habitats is paramount to prioritise conservation funds and efforts. For example, for the New Zealand endemic takahe (*Porphyrio hochstetteri*), translocation to predator-free islands of varying size and with different habitat types, has played an important role in protecting the species. Grueber, Maxwell et al. (2012) modelled the population density of takahē at four predator-free island locations: Kapiti Island, Tiritiri Matangi Island, Maud Island, and Mana Island. They found that although the population size of takahē on the islands had been increasing each year, the proportion of breeding individuals, and the number of successfully fledged juveniles, had decreased, directly affecting the viability of the meta-population. They determined that island populations of takahē had reached carrying capacity, and consequently, introducing new individuals would not have a net positive effect on the viability of those populations. A recommendation resulting from this research is removing "excess" individuals from island populations and introduce them to the historical range of the species, the Murchinson Mountains (Grueber, Maxwell et al. 2012).

There are many studies that utilise habitat use and resource availability data to demonstrate the importance of determining the carrying capacity of an environment for effective conservation management and species survival. For example, Plumb, White et al. (2009) acknowledged that with the increase in population size, the bison (*Bison bison*) from within the Yellowstone National Park had been seen moving outside of the parks boundaries, putting nearby livestock at risk of infection of the *Brucella abortus* pathogen. They wanted to investigate if the movements of bison were a response of the park reaching its carrying capacity for this species. Through calculations they found that the upper limit of bison that park could sustain could exist was 6200 individuals. They suggest that maintaining a smaller population than the true carrying capacity, from 2500 to 4500 individuals, would encourage the bison to remain within the park, thus avoiding exposure of livestock to *B. abortus.* Another example comes from research by Iijima and Ueno (2016), where they discovered that there is a spatial component to carrying capacity. They found that the carrying capacity for Japanese sika deer (*Cervus nippon*) varied between 1.34 and 98.4 deer/km^2 across the study site, with altered habitats, such as artificial grassland, having the highest carrying capacities. These examples illustrate the types of management decisions that can be derived from studies that document patterns of habitat use by target species at various spatial scales.

ISLAND BIODIVERSITY AND SPECIES CONSERVATION

An interesting case for the exploration of ideas related to biodiversity at various spatial scales are islands. Two major factors contribute to an island’s biodiversity: size proximity to other landmasses. Small, isolated islands typically exhibit low species richness in contrast to large islands near other landmasses (Paulay 1994, Cody 2006). For example, Madagascar (587, 000 km^2, one of the most important conservation hotspots worldwide) located approximately 400 km off the eastern coast of Africa, has roughly 10,800 species of endemic vascular plants, and more than 700 species of vertebrates. Of these vertebrate species 50% of the birds are endemic and more than 98% of the reptiles, mammals, and amphibians are endemic (Ganzhorn, Lowry et al. 2001). In contrast, Norfolk Island (34.6 km^2), located 1400 km East of Australia has fewer species of flora and fauna: 182 species of native flora, 120 bird species and two native reptiles (Hermes, Evans et al. 1986, Director of National Parks 2018).

The unique species of flora and fauna that are present on islands are often exposed to a greater risk of extinction than those that are found on large, mainland areas (Butchart, Stattersfield et al. 2006). In fact, the majority of extinction since the 1700s have occurred on islands While biological extinctions are common in the geological record of the planet, anthropogenic factors, such as the introduction of pests and predators, and overexploitation, are increasing the rate at which those extinctions occur and do not allow for adaptive changes (Cafaro 2015, McCallum 2015). In a study conducted by Butchart, Stattersfield et al. (2006) it was found that 16 critically endangered bird species had a high probability of becoming extinct during the study period (1994-2004) if human intervention had not occurred. Of those 16 bird species, 63% were island dwelling. There is a consensus that the greatest threats to island birds are from the human impacts of habitat loss and the introduction of invasive species (Johnson and Stattersfield 1990, Blackburn, Cassey et al. 2004, Butchart, Stattersfield et al. 2006).

Birds are not the only insular species that face extinction because of invasive species and habitat loss. Medina and Nogales (2009) investigated the impact that feral cats on endemic animal species in the Canary Islands. Cats were introduced by humans to the Canary Islands in the 15th Century and have since contributed to vertebrate extinctions on the islands. The researchers identified 71 species of prey items, 15 of which were endemic reptiles, 29 endemic or native invertebrates, and 18 endemic or native bird species. The remaining species were introduced, including all of those in the mammalian group. Four of the endemic or native prey species were on the International Union of the Conservation of Nature's Red List of Threatened Species, one endangered bird species, the Canary Island stonechat (*Saxicola dacotiae*), and three critically endangered giant lizards in the genus *Gallotia* (Medina & Nogales, 2009).

Otto, Garzón-Machado et al. (2017) used the Canary Islands to model the effects of human induced habitat loss on endemic species. Since the 15th Century settlement by the Castilians up to 95% of the natural habitat has been lost on the island archipelago. The research conducted by Otto and colleagues found that invertebrates and plants on the Canary Islands experienced a delay between the loss of habitat and extinction, which highlights the need for monitoring of endemic and at risk species after they have experienced habitat loss.

The colonisation of islands by humans has resulted in an increase in the rate of consumption of critical resources due to habitat degradation, habitat loss, and the introduction of pests and predators (Cafaro 2015, McCallum 2015), affecting native and endemic island species, and their likelihood of extinction. In theory, population extinction is inversely proportional to population size, that is, the possibility of extinction increases as population size decreases (Harris 1984, Lande 1993, Kohn and Walsh 1994). Hanski, Moilanen et al. (1996) modelled the minimum number of individuals needed by a metapopulation in order to avoid extinction. They found that while some metapopulations may have the required minimum amount of individuals, they can still be at risk of extinction, unless provided with connected habitats that reduce the impacts of habitat fragmentation and loss. The increased extinction risk of small populations is due, in part, to the decreased genetic variability in small populations resulting in a lowered ability to adapt to changes in an environment (Lande and Barrowclough 1987).

One way to increase a species' population size is to reduce threats to the species such as controlling, and eradicating when possible, introduced predator and pest species. The likelihood of successfully eradicating introduced species from an area is greater when the target area is isolated from potential source populations of introduced species, where they could re-colonise. Island habitats, like Tiritiri Matangi Island in the Hauraki Gulf of New Zealand, provide an example of successful eradication of invasive Pacific rat or “kiore” (*Rattus exulans*) from islands (Graham and Veitch 2002, Simberloff 2002, Miskelly and Powlesland 2013). The nearest population of Pacific rats is approximately 3 km away, a distance greater than the maximum swimming distance for rats (Russell, Towns et al. 2005) One way to reduce the number of predator species that can invade a mainland area is to fence off that area create ‘mainland islands’ or ‘mainland sanctuaries’ (Saunders and Norton 2001, Simberloff 2002). Tawharanui Regional Park in the north of Auckland, New Zealand, is an example of a peninsula that was actively developed to create a mainland island through the use of predator-proof fencing. This has led to an eradication of seven mammalian pests (Butler, Lindsay et al. 2014). The successful eradication of these predators has resulted in population increases of established species within the park as well as the natural recolonization of bellbirds (*Anthornis melura*) (Brunton, Evans et al. 2008). Further, movements of birds into and out of the park has been observed, and the reintroduction of native birds and reptile species is ongoing (Maitland 2011, Butler, Lindsay et al. 2014).

In addition to the management of invasive species, revegetation and reforestation programs can increase the quality of habitats at target locations. Strategic revegetation programs can result in increased food resource abundance and availability (Coyne 2010, Morrison, Lindell et al. 2010, Belder, Pierson et al. 2018). Belder, Pierson et al. (2018) suggest that restoration plantings can increase habitat availability however, restored areas risk becoming ecological traps if they are preferred to remnant areas and they fail to produce adequate resources for the species, and therefore management of post-restoration areas is a key component of species conservation.

Many studies have investigated the effect of food abundance and food limitation on population size and individual health. One example is from Hořák, Tószögyová et al. (2015). The researchers demonstrated that the average clutch size of African passerine varies across their geographic range in relation to food availability. They found that when there were more food resources available to the population then more eggs were produced per clutch. A second example is provided by López-Alfaro, Coogan et al. (2015) where they investigated the dietary composition of brown bears (*Ursus arctos*) in North America. They found that bear body size and population size were dictated seasonally by food availability. They also discovered that whilst the bears were usually generalists, their productivity did change in response to the absence of normally available, high quality foods. These examples have shown that increased food resource availability results in increased population numbers, increased body size, and healthier individuals. The aforementioned examples have also demonstrated the importance of understanding how resource availability affects a population across their distribution, and how their behaviour and physiology changes in response to changes across the habitat and over time.

While species that are endemic to islands are evolutionarily and geographically distinct from their mainland relatives, they are also vulnerable to disease, predators and episodic shortages of resources. This vulnerability is increased with the colonisation of island environments by humans (Blackburn, Cassey et al. 2004, Hutton, Parkes et al. 2007, Director of National Parks 2008, Nogales, Vidal et al. 2013).

ISLAND PARROTS: A HIGHLY THREATENED GROUP

Birds are diverse (ca. 10, 000 species) and widespread, occupying a wide range of habitats worldwide (Pough, Janis et al. 2013). Approximately 17% of the world’s bird diversity (1750 species) occurs on islands, yet over 90% of historic avian extinctions involve island species islands (Johnson and Stattersfield 1990). Further, approximately 39% of contemporary threatened bird species, mostly in the South Pacific, are island endemics (Johnson and Stattersfield 1990).

Parrots are birds that can be found in three main geographic regions across the world, the Afro-Asian region, the Neotropical region, and the Australasian region (Forshaw 2010). They are members of the Psittacidae family (order: Psittaciformes) and consist of approximately 356 species. Parrots, as a group, contain more threatened species than any other group of birds, with just over one third (123) of their extant species having the conservation status of near-threatened or above (Collar 2000, Forshaw 2010, Parr and Juniper 2010). The majority of parrot species are forest dwelling animals, with 90% of known species requiring forested habitats, hence deforestation and other forms of habitat destruction contribute highly to the threatened status of parrots (Collar 2000, Forshaw 2010). Consequently, the continual modification and loss of forested habitat can affect parrot populations. Two additional threats to parrots include illegal trading (particularly in South America and South-East Asia) (Herrera and Hennessey 2007, Weston and Memon 2009, Pires 2012) and predation by introduced species (Taylor 1979, Powlesland, Roberts et al. 1995).

New Zealand is an example of an archipelago where, historically, birds had no mammalian predators, however, this ended when Polynesian and European human settlers arrived (Parkes and Murphy 2003). New Zealand has three genera of native and endemic parrots; *Nestor, Strigops* and *Cyanoramphus* with the former two genera in the top 3% of threatened birds worldwide (Jetz, Thomas et al. 2014). Boon, Kearvell et al. (2001) recognise ten full species (three extinct) and four subspecies (one extinct) within the *Cyanoramphus* genus (Boon, Kearvell et al. 2001). Three of these species are found on the main islands of New Zealand. New Zealand examples of conservation techniques that have been successfully used to protect

New Zealand *Cyanoramphus* parrots include pest control, translocations, (Gaze and Cash 2007, Ortiz-Catedral and Brunton 2010, Miskelly and Powlesland 2013) and disease research (Ortiz-Catedral, McInnes et al. 2009). The methodology used on New Zealand *Cyanoramphus* research can be applied to other parrots of this genus that have similar biological and habitat requirements (Ortiz-Catedral and Brunton 2010).

This genus was historically distributed throughout the islands of the South Pacific, from New Caledonia in the north, to the Macquarie Islands in the south. However, due to a number of extinction events, their historic range was greatly reduced (Boon, Daugherty et al. 2001, Boon, Kearvell et al. 2001, Gaze and Cash 2007). There have been four extinctions of this genus, all of which have occurred between in the last 250 years. As described by Forshaw and Knight (2017) all four of the extinctions can be directly attributed to the presence of humans within their environment.

The first in the *Cyanoramphus* genus to go extinct was the Society parakeet (*C. ulietanus*), which was found on Raiatea Island, in the Society Islands. It was discovered in 1774 during Captain Cook’s second voyage of the Pacific Islands, and is assumed have to become extinct shortly thereafter. There are no records of the cause of extinction, however, as with most parrot extinctions on Pacific Islands, and with other of this genus, it is thought that the introduction of mammalian predators, as well as the destruction of natural habitats, contributed to its extinction.

The second parrot within this genus to experience extinction was the black-fronted parakeet (*C. zealandicus*), which was found on Tahiti, in the Society Islands. The last specimen of this species was collected in 1844, with extinction assumed a short time afterwards. The extinction of the black-fronted parakeet had two main causes: they were hunted by humans, for their feathers, and they were also killed by introduced mammalian predators.

The third *Cyanoramphus* species to go extinct was a sub-species of the New Zealand red-crowned parakeet (*C. novaezealandiae*), the Lord Howe Island red-crowned parakeet (*C. n. subflavescens*), that was found on Lord Howe Island. The last known siting of this parrot was in 1869 when it was observed by E.S Hill as being ‘a nuisance to the cultivators’ (Forshaw and Knight 2017). Hill also noted that the birds were once numerous, but only observed a single pair on the 1869 excursion to Lord Howe Island. The damage that the parakeets caused to fruit trees was so bad that the residents of Lord Howe Island considered this bird a pest, hunting them to extinction some time before 1907.

The most recent *Cyanoramphus* extinction was the Macquarie Island red-crowned parakeet (*C. erythrotis*), that was located on Macquarie Island. Most species within the *Cyanoramphus* genus live in established forests, however, due to the absence of trees on their home island, the Macquarie Island red-crowned parakeets were documented as ground-nesting birds that preferred tussock habitats near the coastline. This species was highly prized and was often captured and sent to Sydney for the pet trade. In an 1880 trip to the island the birds were reported as being numerous, however, by 1891 there were none to be found. Predator species on Macquarie Island, feral cats and wekas (*Gallirallus australis*), had low densities as they were limited by their over-winter food species. When rabbits were introduced to the island there was a spike in predator numbers, ultimately leading to the loss of species such as the Macquarie Island landrail (*Gallirallus phillippensis macquariensis*) and the Macquarie Island red-crowned parakeet. While Forshaw and Knight (2017) refer to the Macquarie Island red-crowned parakeet as *Cyanoramphus novaezealandiae erythrotis*, I follow the nomenclature as set out by Boon, Kearvell et al. (2001) where they consider this a full species, hence the scientific name *Cyanoramphus erythrotis*.

The accounts of the *Cyanoramphus* extinctions serve as a reminder that this genus is very sensitive to the impacts of human induced changes to their landscape including hunting, predation by introduced predators, and habitat loss. Forshaw and Knight (2017) consider the Tasman parakeet (*C. cookii*), a parrot that is endemic to Norfolk Island in the South Pacific, to be one of Australia's most endangered parrots, and as such, faces a high risk of extinction from the same threats as the aforementioned extinct birds.

THE PRESENT STUDY

My study aims to contribute to the current knowledge of the biology of one of the world's rarest parrots, the Tasman parakeet, in order to assist its conservation. To date, research on this species have mainly focussed on identifying key food resources and presenting management plans (Hill 2002, Waldmann 2016, Director of National Parks 2018). No study has measured simultaneously the patterns of habitat use of Tasman parakeets and Crimson rosellas, due to the low numbers of Tasman parakeets. Since 1969 it has been suggested that Tasman parakeets and crimson rosellas compete for resources and habitat on Norfolk Island (Smithers and Disney 1969). While there is evidence in support of this for nesting resources (Director of National Parks 2018) little attention has been paid to the degree of overlap (temporal and spatial) of both species on the different habitat types of the Norfolk Island National Park.

In this thesis, I document the seasonal patterns of habitat use of Tasman parakeets and Crimson rosellas within the Mount Pitt section of the Norfolk Island National Park. The overall aim of my study was to provide information about seasonal habitat use and the relative importance of the various habitats on the Mount Pitt section of the Norfolk Island National Park for Tasman parakeets. This information may assist in assessing the carrying capacity of the Norfolk Island National Park, develop targeted plans for control of Crimson rosellas and ultimately advance the conservation of the Tasman parakeet. Initially, this project contemplated the following components:

1) Gross estimation of habitat availability for Tasman parakeets based on records of individual birds, pairs or groups across different habitat types.
2) Quantification of overlap in habitat use by Crimson rosellas and Tasman parakeets via records in summer, autumn, winter and spring.
3) Assessment of dispersal behaviour and critical habitat of recently fledged Tasman parakeets in the Mount Pitt section of the Norfolk Island National Park.
4) Researching the dispersal behaviour and diet of juvenile Tasman parakeets on Phillip Island, as part of the first attempt to reintroduce the species to that site (see Chapter 4, see Appendix A)

Due to unforeseen logistical difficulties that resulted in the suspension of the reintroduction program for Tasman parakeets to Phillip Island (see Chapter 4), I was unable to carry out components three and four, and I could only obtain data for a pilot project in Summer. I was able however, to study the patterns of habitat use of Tasman parakeets and Crimson rosellas in autumn and spring. Also, I developed a preliminary vegetation map of the Mount Pitt section of the Norfolk Island National Park to explore habitat characteristics and plant associations than might prove useful in the management of Tasman parakeets. In spite of these challenges I conducted a study that quantifies for the first time the patterns of habitat use by Tasman parakeets and their competitor, the introduced Crimson rosella. I also characterised the vegetation of the Mount Pitt Section of the Norfolk Island National Park via rapid ground surveys. Taken together, this thesis contributes to the knowledge base for management of the Tasman parakeet in particular and of the Norfolk Island National Park.

Study Species: Tasman Parakeet

The Tasman parakeet, known locally as the Green Parrot, or the *Norfuk Ailen griin paerat* in Norfolk language, is a critically endangered bird endemic to Norfolk Island. Historically, a second subspecies (*flavescens*) occurred on Lord Howe Island, but became extinct there by the late 1800s (Forshaw 2010). The taxonomy of *Cyanoramphus* has been the focus of extensive reviews over the last 30 years, which have seen there have been many taxonomical reviews of this species. Morphological similarities with New Zealand's red-crowned parakeet, or kakariki (*Cyanoramphus novaezealandiae*), saw the Tasman parakeet classed as a sub-species of this, along with the New Caledonian red-crowned parakeet (*Cyanoramphus saisetti*). In 2001 a study conducted a molecular phylogenetic analysis using mitochondrial DNA and found that the two parakeets should each be re-classed as their own species (Boon, Daugherty et al. 2001, Hill 2002, Threatened Species Scientific Committee 2016). Research conducted since the taxonomic change has cited the Tasman parakeet as its own species and given it the threat level of critically endangered. This is despite the persistent use of the sub-species classification by the IUCN (Collar 2000, Parr and Juniper 2010, Szabo, Butchart et al. 2012).

The conservation status of the Tasman parakeet has undergone multiple reviews over time. In 1990, it was listed as critically endangered, which was then downgraded to endangered in 2000, and before being finally upgraded to its current status of critically endangered in 2010 (Snyder 2000, Szabo, Butchart et al. 2012). The population of the Tasman parakeet has experienced large fluctuations since the 1960s (Figure 1.2.). The earliest estimates suggest a population of between 10 and 20 breeding pairs. Between 1978 and 2007 the population increased, peaking in 2007 when the estimated population size was between 200 and 400 individuals (Smithers and Disney 1969, Hermes, Evans et al. 1986, Hill 2002, Butchart, Stattersfield et al. 2006, Brooke, Flower et al. 2010, Director of National Parks 2010). It is unclear if this increase was due to Tasman parakeet population growth, or an inaccurate sampling method. During a 2009 survey of Norfolk Island birds Dutson (2013) experienced difficulty in distinguishing Tasman parakeets from the background vegetation, and so suggested a targeted species survey for the Tasman parakeet. Following this suggestion, an intensive Tasman parakeet bird count was conducted in 2013 and found that the maximum number of individuals to be 96 (Figure 1.2, red data point) (Higgins 1999, Threatened Species Scientific Committee 2016, Ortiz-Catedral, Nias et al. 2018, Department of the Enivronment 2019). The most recent estimate of population size is approximately 438 individuals, with an estimated 27 females of reproduction age (Skirrow 2018). This increase can be largely attributed to the management of rats and feral cats within the park.

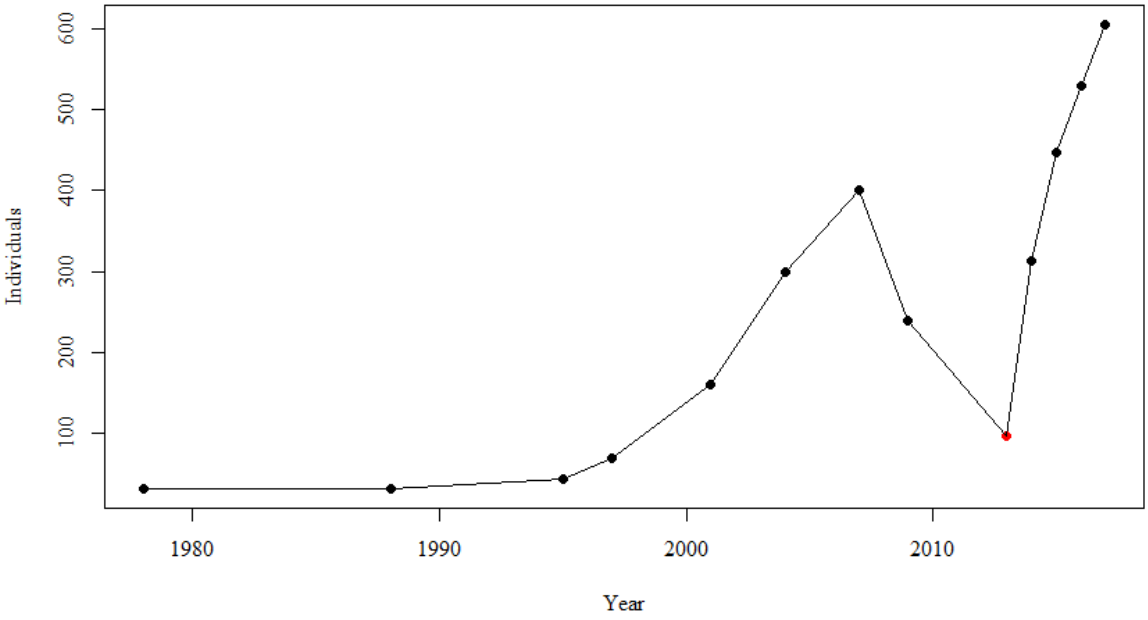


Figure 1.2. Population of Tasman parakeets displaying maximum estimates.

The red point indicates the year 2013, when intensive management began. Graph uses data from Smithers and Disney (1969), Hermes et al. (1986), Butchart et al. (2006), Brooke et al. (2010), Dutson (2013), Ortiz-Catedral et al. (2018), Skirrow (2018).

Prior to the arrival of European settlers the Tasman parakeet occurred commonly throughout Norfolk Island and the nearby Phillip Island (Hill 2002). When European settlers first arrived on Norfolk Island in the late 1700s, they introduced pests such as feral cats (*Felis catus*) and Polynesian rats (*Rattus exulans*), that preyed on the birds and their young and reduced their numbers significantly (Director of National Parks 2010). The first settlers also cleared land for grazing animals (Director of National Parks 2010), which further restricted the habitat of the Tasman parakeet. Another species that has affected the numbers of Tasman parakeets is the introduced crimson rosella (*Platycercus elegans*), which aggressively competes for and destroys parakeet nests (Hill 2002, Dutson 2013, Baker, Harvey et al. 2014, Threatened Species Scientific Committee 2016, Director of National Parks 2018, Skirrow

2018). Parks Australia carries out high levels of pest control within the Norfolk Island National Park and Botanic Gardens, which has given rise to a lower concentration of predators, an abundance of food resources, and a higher availability of nest sites. Because of this the Tasman parakeet is largely restricted to the park, although it is occasionally seen in other areas of the island (Director of National Parks 2010, Threatened Species Scientific Committee 2016).

Both the male and female Tasman parakeets are very similar in appearance, having a bright green plumage, a red crown and lores, red ear-coverts, and blue edging on the wings. The females are slightly smaller in size, with smaller crowns and slimmer beaks. Juveniles appear similar to adults, with a duller red crown and a flesh coloured beak (Hill 2002, Threatened Species Scientific Committee 2016). Nests are typically low to the ground and clutch size varies between one and eight eggs, with incubation lasting 21 days on average. Once hatched, a juvenile will stay in the nest for up to seven weeks, being fed by the father while the mother leaves the nest to incubate a new clutch of eggs (Hill 2002). After fledging, the juvenile will stay near the parents, being fed, for a further three to seven weeks before it becomes independent and sexually mature (Hill 2002, Ortiz-Catedral, Nias et al. 2018). During this time the juveniles are incredibly vulnerable to predation by cats and rats as they feed near the ground, and as a result many do not reach breeding age (Hill 2002).

The diet of adult Tasman parakeets includes seeds, fruit, flowers, and sometimes even the bark and leaves, of both native and introduced species, with studies observing at least thirty different species of flora as part of the diet (Hill 2002, Waldmann 2016). The most common examples of food types include the Norfolk pine (*Araucaria heterophylla*), ake ake (*Dodonaea viscosa*), Norfolk Island palm (*Rhopalostylis bauerri*), African olive (*Olea europaea*) and red guava (*Psidium attleianum*) (Waldmann 2016). Adults of this species exhibit spatial variety in their foraging behaviour and feed on a large variety of vegetation from different forest levels. In comparison, the juveniles tend to feed on the ground almost exclusively on the fallen fruits of the African olive and red guava, while also consuming Norfolk pine seeds and bloodwood (*Baloghia inophylla*) seeds (Waldmann 2016). The Tasman parakeet also exhibits temporal variation to their feeding patterns. In winter, for example, the adult birds will feed mainly on the fallen fruits and seeds of the Norfolk pine, African olive and red guava (Hill 2002, Threatened Species Scientific Committee 2016). The spatial and temporal variation seen in the diet of these birds can be attributed to the variation of food availability in the different seasons (Waldmann 2016).

Management plans for the Tasman parakeet include the "Threatened Species Management Plan" (Director of National Parks 2010), "Approved Conservation Advice" (Threatened Species Scientific Committee 2016), "20 birds by 2020" plan (Australian Government 2015), and the "Norfolk Island National Park and Norfolk Island Botanic Garden Management Plan 2018-2028" (Director of National Parks 2018). The overall goal of these plans is to increase the Tasman parakeet population and the downgrading of its threat status. The common objectives in all of the plans are to increase predator management and control, thereby decreasing the amount of predators in the park, and to increase the protection around nests, ensuring the nesting parakeets are safe from both predators and competitors. However, even if both of these objectives are achieved, and the Tasman parakeet numbers increase, their population may be limited by the resources available within their environment, which is a factor that none of the plans address.

Study Species: Crimson Rosella

The Tasman parakeet and the crimson rosella are classified within the subfamily Platycercinae (Joseph, Toon et al. 2011, Joseph, Toon et al. 2012, Schweizer, Guentert et al.

2013). These two species overlap in their distribution on Norfolk Island, and can be found in using similar habitat types and locations around the park. Crimson rosellas are more numerous than Tasman parakeets and outnumber these by 3:1 ratio (Skirrow 2018). Over the last 50 years there have been multiple observations of the competition between Tasman parakeets and crimson rosellas for nest sites and nesting materials, as presented by Smithers and Disney (1969), Hill (2002), Dutson (2013) and Director of National Parks (2018). Dutson and Director of National Parks also suggest that there may be competition for food resources between the two species. Waldmann (2016) noted some of the food species consumed by the crimson rosellas on Norfolk Island and identified several as key resources that the Tasman parakeet uses, such as red guava, African olive, Norfolk Island pine, and niau. The diet of the crimson rosella, presented by Waldmann, has been the only research that has reported on the crimson rosella diet and how it relates to the diet of the Tasman parakeet. However, the research was based on observations alone, and hence to date, there has been no published studies that have systematically quantified the crimson rosella diet.

The crimson rosella is a medium size parrot that is native to the east and south-east coasts of Australia (Forshaw 2010, Ornithological Society of New Zealand 2010, International 2016). The crimson rosella has also been found in New Zealand after it was introduced to Dunedin in 1910 and separately to Wellington in 1963. Both of these introductions were the outcome of caged pets escaping, and by the late 1990s it was assumed that both populations died out and the species became extinct in the wild (Ornithological Society of New Zealand 2010, Galbraith 2013).

The crimson rosella most likely was introduced to Norfolk Island as a cage bird 1830s (Higgins 1999, Christian 2005, Ornithological Society of New Zealand 2010). The eventual introduced population on Norfolk Island is assumed to be the result of escaped birds establishing and breeding in large numbers by the 1900s (Higgins 1999). Crimson rosellas can be found across Norfolk Island: from the Norfolk Island National Park, to the coast in Kingston (Smithers and Disney 1969, Dutson 2013).

The crimson rosella is known to locals on Norfolk Island as the ‘red parrot’, in reference to its bright crimson plumage. As well as the red colouration, the species also sports a blue chin, throat, and primary wing and tail feathers. Sexes display little sexual dimorphism, with the female exhibiting a duller plumage and a slightly smaller bill (Higgins 1999, Forshaw 2002, Skirrow 2018). The crimson rosella is a larger bird than the Tasman parakeet, ranging from 35cm-38cm in length compared to the Tasman parakeet’s average length of 30cm (Margrath and Lill 1985, Christian 2005, Collar and Kirwan 2018, Skirrow 2018).

The Study Site: Norfolk Island

Norfolk Island (Figure 1.3) is an Australian territory that is located between Australia (1700 kilometres from Sydney), Fiji (1420 kilometres) and New Zealand (1100 kilometres from Auckland), at latitude 29°02’ S and longitude 167° 57’ E, with the closest inhabited landmasses to Norfolk Island being New Caledonia (875 kilometres) and Lord Howe Island (900 kilometres) (Director of National Parks 2008). Norfolk Island is part of a volcanic land mass that was formed between 3.05 and 2.3 million years ago (Jones and McDougall 1973, Anderson and White 2001). The main landmass covers an area of 3455 hectares, while the territory’s two unoccupied islands, Phillip Island (6 kilometres south) and Nepean Island (1 kilometre south), consist of 190 and 10 hectares respectively (Director of National Parks 2008, Director of National Parks 2010).

Both of these nearby islands are important conservation sites for the Norfolk archipelago, as they provide habitat for endemic species, such as the Phillip Island cricket (*Nestitathra philipense*). Some reptile and invertebrate species, such as the Lord Howe gecko (*Christinus guentheri*) (Phillip Island) and the Phillip Island centipede (*Cormocephalus coynei*) (Phillip and Nepean Island), were once also found on Norfolk Island, but they became extinct in this area after the introduction of rats and cockroaches (*Blattella germanica*, *Periplaneta americana* and *P. australasiae*) (Director of National Parks , Director of National Parks 2008).

Norfolk Island is bordered by 32 kilometres tuff and basalt cliffs, due to the islands volcanic history. Both of the island's peaks are located in the north, with Mount Bates sitting at 318 metres above sea level, and Mount Pitt sitting at 316 metres above sea level, (Director of National Parks 2010).

Norfolk Island and Phillip Island are of volcanic origin, while Nepean Island is a limestone formation. While both Norfolk and Phillip Island have soft, easily crumbled soil that is ideal for the root growth of plants, the two islands experience differences in the density of vegetation present. Norfolk Island's soil is nutrient filled and able to support an abundance of vegetation, while Phillip Island has limited top soil that is mainly restricted to tuff and ash beds, leading to very little vegetation. Where vegetation is sparse on Norfolk Island the soil is prone to slips. (Coyne 2010, Director of National Parks 2010). The only freshwater available to the flora and fauna on Phillip Island is rain water, as unlike Norfolk Island, which has three permanent streams and groundwater systems, Phillip Island has no permanent source of freshwater. The temperature range in Norfolk Island can be described as moderate, with lows of down to 11.0^{o}C and highs of up to 26.5^{o}C (Director of National Parks 2010).

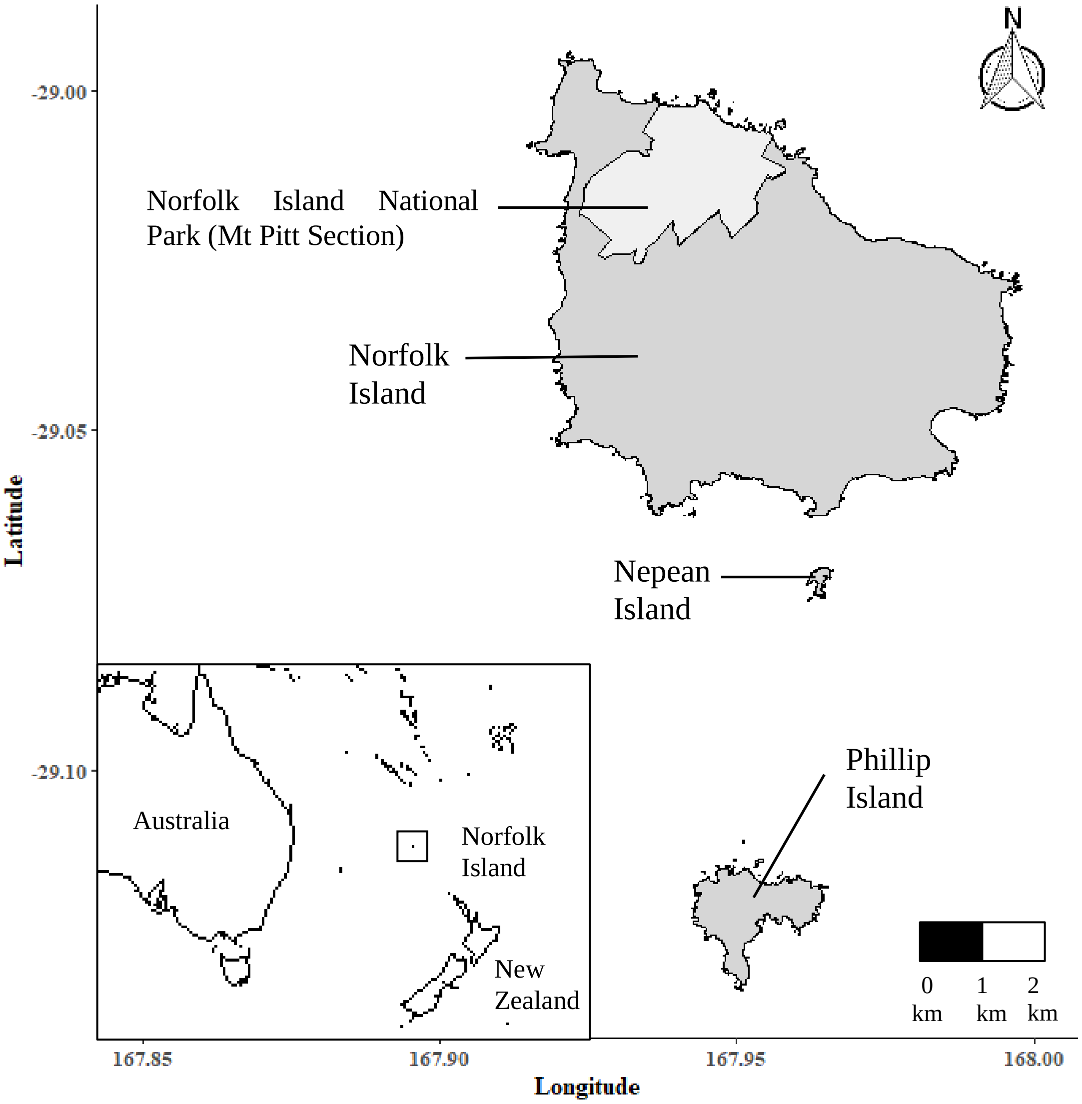


Figure 1.3. Map of Norfolk Island Group showing Norfolk Island, Phillip Island, and Nepean Island.

The Settlement of Norfolk Island by Europeans occurred in three waves, with the first two settlements as penal colonies. In 1774, Captain James Cook visited and named it Norfolk Island, admiring the tall pines and the abundance of flax plants (Coyne 2011). Although uninhabited at the time, evidence was later found of Polynesian settlement in the form of banana (*Musa sp.*) plantations, stone tools, and Pacific rats (*Rattus exulans*) (Anderson 1996, Anderson 2001, Anderson and White 2001). In 1788, the first penal settlement arrived, and the prisoners farmed and cleared the land. This first settlement lasted for 26 years before agricultural breakdown caused an evacuation of the island. The second penal colony began in 1825 in response to overcrowded prisons on mainland Australia, and lasted until 1856, when the prisoners were deported to Hobart. The third settlement began in 1856 with the arrival of the Pitcairn Islanders, the descendants of the *HMAV Bounty* mutineers. All three settlements changed the habitat of Norfolk Island. The first settlement cleared most of the pine and hardwood forest that occupied the island, leaving only a small patch of remnant forest near the peaks towards the north of the island, in what is now the Norfolk Island National Park. The second settlement gave way to historic buildings and structures, and the third settlement was the backbone to the modern day culture on the island with its introduction of tourism, agriculture and recreation (Best 2007).

The vegetation of Norfolk Island varies temporally and spatially (Smithers and Disney 1969). The main land mass has approximately 550 plant species, of which a third are native and approximately 9% are endemic. The island shares 51% of its vegetation with Australia, 39% with Lord Howe Island, and 33% with New Zealand (Mills 2010). The original vegetation on the island has been categorised in to ten groups that occur in different geographic locations and overlap in the type of species they support, for example, seven out of the ten vegetation types contain Norfolk pine trees (Director of National Parks 2010). The vegetation types are comprised of a variety of plants, including invasive species that are either predominant in that vegetation type, or are dispersed amongst the native vegetation. The most common invasive species in Norfolk Island are the red guava and the African olive, both of which are food resources for the Tasman parakeet and other bird species (Director of National Parks 2010). While weed species within the park are actively being managed they are still being spread through invasive fauna such as rats (*Rattus exulans* and *Rattus rattus*.), which are introduced pests (Director of National Parks 2010).

Phillip Island had introduced mammalian pests such as pigs (*Sus scrofa*), goats (*Capra hircus*) and rabbits (*Oryctolagus cuniculus*) (Bomford and O'Brien 1995). The presence of these pests had led to the lack of original vegetation that is seen today. Since the eradication of the pests (pigs and goats in the early 1900s and rabbits in 1986) there has been regeneration of the vegetation on Phillip Island (Coyne 2010). The island is now home to 102 plant species, less than half of which are indigenous, that support both resident and migratory birds, amongst other faune (Director of National Parks 2010).

The Norfolk Island territory is home to 120 bird species (seven endemic), two native reptiles, two native bats, as well as many endemic invertebrate species (Hermes, Evans et al. 1986, Director of National Parks 2018). Also present in the Norfolk Island territory are introduced species, who have negatively impacted native and endemic flora and faune. A few examples of these introduced and damaging species include the crimson rosellas, feral cats, Polynesian and black rats, the house mouse (*Mus musculus*) and the Argentine ant (*Linepithema humile*) (Director of National Parks 2010). One example of at risk species is provided by land snails, invertebrate species that contribute to the native and endemic diversity of flora and fauna on Norfolk Island. There are five critically endangered species of land snail present on Norfolk Island that belong to three genera *Advena*, *Mathewsoconcha*, and *Quintalia*. These species are at risk of extinction due to the presence of rats and introduced snails, along with habitat disturbance.

The effect that the aforementioned invasive species have on the biodiversity of Norfolk Island is negatively impacting a range of species, from birds, to invertebrates, and to plants, and as such, much of the islands biodiversity is confined to the northern region of the island. The Norfolk Island National Park and Botanic Gardens contain most of the remnant native and endemic flora of the island, while covering only 18% of the landmass of the three islands in the Norfolk Group (Smithers and Disney 1969, Director of National Parks 2008, Director of National Parks 2010, Mills 2010). The Botanic Gardens consist of 5.5 hectares of land, the Mount Pitt section of the Norfolk Island National Park consists of 460 hectares of land, and the Phillip Island section of the park consists of 190 hectares of land (Director of National Parks 2018). There are twenty reserves on Norfolk Island, including Nepean Island, that are important areas for conservation (Director of National Parks 2010). The diverse range of vegetation seen in the Norfolk Island National Park and Botanic Gardens is due to them being free of the residential and agricultural land use that is seen outside of the park and garden areas. This means that they are home to many micro-endemic species, making them a target for many conservation management plans that have been introduced to the territory.

The management plans in place for Norfolk Island have been implemented to outline conservation goals, such as maintaining and preserving the biodiversity of island. Some of these plans include the National Park Forestry Zone (Byron 2012), the Threatened Species Recovery Plan (Director of National Parks 2010), the Climate Change Strategy 2011-1016 (Director of National Parks 2011), and the Norfolk Island National Park and Norfolk Island Botanic Garden Management Plan 2018-2028 (Director of National Parks 2018).

THESIS STRUCTURE

Thesis Aims

The overall aim of this thesis is to investigate seasonal activity patterns and habitat use of Tasman parakeets and crimson rosellas within the Mount Pitt Section of the Norfolk Island National Park in order to quantify the degree of seasonal habitat overlap between both species. This information adds to the growing research on the critically endangered Tasman parakeet and fills a significant gap in knowledge for the species. The thesis structure and chapter contents are listed as follows:

Chapter One: Introduction

- In chapter one I provide a general introduction to outline how studies of the spatial and temporal variation of a species habitat preference and use may contribute to the conservation of the species. I also identify the need for researching these concepts for island species as they often face unique threats that mainland species do not. I introduce the critically endangered Tasman parakeet, a competitor species the crimson rosella, and isolate the need for this current study by outlining the gap in the current knowledge. I then provide an outline of the structure and aims of this thesis.

Chapter Two: Vegetation Characterisation of the Last Subtropical Rainforest Fragment on Norfolk Island

- In chapter two I present a characterisation the vegetation in the Mount Pitt section of the Norfolk Island National Park using circular plots and estimating plant species richness. I also present an updated map and estimation of minimum population size for native plant species of conservation significance on Norfolk Island.

Chapter Three: Habitat Preference and Feeding Ecology of the Norfolk Island Parrots

- In chapter three I quantify the spatial and temporal variation of habitat preference of Tasman parakeets and crimson rosellas. This chapter also presents an account of the habitat use of the two species as estimated by the frequency of behavioural states. This chapter examines the degree of niche overlap between the two species. The research in this chapter details and compares the seasonal diets of the Tasman parakeet and the crimson rosella within the Mount Pitt section of the Norfolk Island National Park. Also determined is the degree of overlap of food resources consumed and the habitat type in which they are consumed.

Chapter Four: Future Research Needs

- Chapter four provides a general discussion of the relevance of this thesis for the conservation of the Tasman Parakeet. I also identify the limitations of this research, aspects of this thesis that were unable to occur, and key topics for future research to maintain the survival of this critically endangered species.

CHAPTER 2 : VEGETATION CHARACTERISATION OF THE LAST SUBTROPICAL RAINFOREST FRAGMENT ON NORFOLK ISLAND

Figure 2.1.1. Typical Canopy in a niau (*Rhopalostylis baueri*) forest, Mount Pitt section of the Norfolk Island National Park.

Photo: L. Ortiz-Catedral

ABSTRACT

Islands are home to 37% of the world's critically endangered species and so characterising the habitats on small islands is an important step for setting up conservation priorities and understanding the relative abundance of species on different habitats. In this Chapter I describe a rapid characterisation of woody vegetation, and habitat types, within the Norfolk Island National Park. This was a prerequisite to subsequently analyse the patterns of habitat use by Tasman parakeets and Crimson rosellas (Chapter 3). In this Chapter, I also provide an update on minimum population sizes of threatened woody plants relative to a 2003 baseline. I measured the diversity of woody plant species on 988 plots each with an area of 314 m^2, and identified woody species with at least one individual of fruiting age (DBH > 3 cm). I identified nine habitat types: remnant hardwood, remnant *Araucaria* forest, niau forest, regenerating vegetation, paddock, forestry, forest edge, olive forest, and guava forest. The most common habitat was Forest edge and it was also the habitat with the highest plant diversity (70 species). For native habitats, remnant *Araucaria* and remnant hardwood forests shared nearly half of their woody plant species (Sorenson average: 45.86%), and are thus the most similar habitats in terms of woody species composition. Niau forest and regenerating vegetation shared the lowest number of species, (Sorenson average: 40.40%), and are thus considered the least similar habitats in terms of woody plant species. For non-native habitats, Olive forest and paddocks shared the highest number of species (Sorenson average: 65.31%), while forestry habitat and Guava forest shared the least number of species (Sorenson average: 33.33%). Relative to the 2003 baseline of woody native plants, I found that five species show an 80% larger minimum population size within the area sampled. The rapid characterisation of woody plant species described here represents a useful method to measure similarities between native and non-native habitat types, and to detect temporal changes in woody species of fruiting age.

INTRODUCTION

Habitat loss and fragmentation largely resulting from human activities, in particular agricultural expansion, are processes affecting ecosystem functioning worldwide (Fahrig 2003, Haddad, Brudvig et al. 2015, Yue, Brodie et al. 2015). Recent estimates on remnant global forest cover indicate that 70% of today's forest are in close proximity to forest edges (Haddad, Brudvig et al. 2015). Although edge habitats can harbour higher diversity for certain animal groups (i.e. beetles and neuropterans) (Molnár, Magura et al. 2001, Duelli, Obrist et al. 2002), increased edge habitat resulting from fragmentation can significantly alter species richness and biomass, as well as dynamics of trophic levels (Laurance, Lovejoy et al. 2002). Areas with high levels of fragmentation, have less habitat and space available to organisms, resulting in a loss of species richness and biodiversity (Tilman and Kareiva 2018). The rate of habitat loss worldwide is staggeringly fast: in 2005 it was estimated that 21.8% of the earth's natural habitats were lost to anthropogenic activities, increasing in 2009 to 51.4% (Hoekstra, Boucher et al. 2005, Watson, Jones et al. 2016). Overall, the global loss and increased fragmentation of natural habitats has caused numerous recent extinctions and is a major contributing factor to the current high number of endangered species today (Cafaro 2015).

Islands harbour the largest proportion of endangered species worldwide, with approximately 37% of all critically endangered taxa found in these environments. In addition, most of the recorded land-based extinctions during the last few hundred years have occurred on islands (Tershy, Shen et al. 2015). Further, islands represent just over 5% of the landmass of the planet, yet they harbour over 1000 highly threatened species of vertebrates, and exhibit a higher rate of population decline and species extinction than mainland areas (Spatz, Zilliacus et al. 2017). Numerous conservation efforts worldwide focus on islands, and often involve the control of invasive species, in particular mammals. An analysis of the benefits to local biodiversity following eradications of invasive mammals found a range of biological gains including: recovery of local populations, recolonization to formerly extirpated ranges and new colonisations predominantly on human uninhabited islands (Jones, Holmes et al. 2016). What are the prospects, however, for critically endangered species found on human inhabited islands, with high levels of habitat fragmentation and where the eradication of invasive mammals is not yet feasible? A number of Pacific Islands fall into the latter category.

Pacific Islands represent a unique assemblage of ecosystems with no analogous counterparts on the mainland (Mueller-Dombois and Fosberg 1998). It is therefore important to promote studies on the diversity of plants and plant communities in Pacific Islands. Since the majority of the literature concerning the effects of habitat loss and fragmentation has focused on mainland forest ranges (Montejo-Kovacevich, Hethcoat et al. 2018, Taubert, Fischer et al. 2018, Vijay, Reid et al. 2018), the generalisation of these patterns to island ecosystems has been questioned. For instance, the scale of isolation between fragments is at the landscape level on mainland ranges (hundreds or thousands of kilometres), while on islands it occurs at the patch level (dozens to hundreds of kilometres) ((Martin-Queller, Albert et al. 2017). Thus, the effects at the species level resulting from habitat fragmentation and isolation operate at more discrete scales than mainland environments. Therefore, the conservation of species inhabiting habitat fragments on Pacific Islands requires an understanding of the types and composition of current habitats and their distribution to assess the potential effects of isolation between habitat patches. For a range of small Pacific Islands however, very little information exists on the range of current habitats, their composition, and dynamics. Therefore, a first step towards understanding how species of conservation interest use the different habitats on an island, is to characterise the range of habitats and the vegetation associations within them.

There is a disparity in the literature regarding the methodologies used on mainland and island habitats for vegetation diversity sampling (Fan, Fei et al. 2011, Shafie, Amiri et al. 2011, Peña and Ulloa 2017). Whilst most methods can be applied at both location types, the level of detail required and the constraining factors of the focal environment must be taken into account when regarding appropriate methodology. Methodology choice will also impact the type of data produced by the study, hence care must be made during planning to select a sampling process that will produce relevant data.

Two common approaches to vegetation sampling are remote sensory methods, such as satellite imagery (Lu and Weng 2007), and ground-based methods, such as relevés sampling (Alcántara, Garrido et al. 2019). Where only qualitative, broad-scale data are required, the use of aerial photography and satellite imagery are appropriate as they provide a time sensitive approach by capturing the whole sample site in one image (Kim 2016). This type of sampling technique is also used on larger islands, or islands where access is limited as a result of difficult and dangerous terrain, as remote images may be accessed from anywhere in the world (Wangchuk, Bolch et al. 2019). Further, images produced by satellites are stored on a database that may be accessed for comparisons in temporal patterns (Ford 2013).

Conversely, ground-based methods require a larger input of time, and often occur at a greater cost, as many sample sites are needed to create an effective assessment of the vegetation present. However, the benefit of this sampling method is that vegetation can characterised at finer scales, yielding quantitative data on the diversity of strata within habitats (Zhou, Robson et al. 1998, Ruiz, Fandiño et al. 2005, Zegeye, Teketay et al. 2006). The information produced via this method can be used as a benchmark for studies that quantify the spatial and temporal patterns of a species' preferred habitat use within fragmented habitats, and as a baseline of the vegetation available for the species of interest.

When time constraints prevent a thorough measurement of several aspects of the plant community structure, a rapid characterisation of the presence/absence of woody plant species may be an ideal alternative that will still produce quantitative data for use in habitat preference studies (see Chapter 4). This broad-scale sampling was practical in this thesis, for characterising the vegetation composition in the Mt Pitt section of the Norfolk Island National Park (henceforth referred to as NINP), as this data would subsequently be used to compare patterns of habitat use between two competing parrots that are found primarily within stands of woody plant species (see Chapter 2). Tasman parakeets (*Cyanoramphus cookii*) and crimson rosellas (*Platycercus elegans*) feed predominantly on fruits, flowers, leaves and seeds of woody plants (Waldmann 2016). Therefore, analyses of patterns of habitat use in woody vegetation can reveal the degree of competition or overlap across habitat types within NINP (see Chapter 3).

Norfolk Island Vegetation

Norfolk Island harbours a high diversity of flora and fauna, with numerous endemic species (Coyne 2011). There are a number of publications describing the vegetation composition on Norfolk Island (Smithers and Disney 1969, Mueller-Dombois 2002, Coyne 2011), however, prior to this research there has not been a large-scale characterisation of habitat types and local species richness of woody plant species within the NINP. Historically, the vegetation of Norfolk Island prior to the arrival of the first Europeans comprised primarily of sub-tropical rainforest, with obvious stands of tall Norfolk pines along the ridges, ferns and palms throughout the gullies, and flax (*Phormium tenax*) bushes along cliff edges (Smithers and Disney 1969, Mueller-Dombois 2002, Coyne 2011). Major changes to the vegetation composition since the 1770s included the clearing native bush for agriculture (Coyne 2011) and the planting of Eucalyptus species and other hard wood trees for construction (Smithers and Disney 1969, Byron 2012).

Today the vegetation of Norfolk Island is highly fragmented, with the majority of the islands’ 182 native plant species confined to the NINP and Botanic Gardens, two areas that occupy approximately 13% of the islands landmass (Director of National Parks 2018). The restricted distribution of these endemics can be attributed to the lack of urbanisation and agriculture within these areas, as well as intense pest management of both animals and plants within them, making NINP and the Botanic Gardens the last strongholds for these species (Director of National Parks 2018). Three general habitat types had been identified within the park: Araucaria stands, fern and palm gullies, and mixed hardwood forest (Coyne 2011). In general, native forest fragments are interspersed between patches of invasive plant species. While Norfolk pines continue to be a prominent feature of the park, several changes over the course of 200 years have altered the profile of the landscape. Soil-stabilising flax bushes have been lost from cliff edges, white oak stands across exposed lower slopes have been replaced by African olive (Figure 2.2), and hardwood forests are now less prevalent throughout the park, replaced by guava on foot slopes, and shrubbery and grass invasive types on mountain summits (Mueller-Dombois 2002).

Figure 2.2. Cliff edges and low slopes with African olive, where once would have stood flax and white oak.

Photos: L. Ortiz-Catedral.

The prevalence of invasive plants on Norfolk Island was largely made possible by the clearance of native vegetation by early settlers, giving way for the establishment of species such as red guava (*Psidium cattleianum*), one of the worst vegetative pests in Hawaii, and

African olive (*Olea europaea*) (Coyne 2011). Red guava was introduced to Norfolk Island as a fruiting plant, however, the dense bush thickets and wide ranging root systems of this species that restrict the growth of any native plants around them, allowed the guava to quickly spread throughout the island. The fruits also have a negative impact on the environment as they alter the chemical composition of downstream soil (Lowe, Browne et al. 2000, Director of National Parks 2010). The African olive is another prominent invasive species that has become established, not only on the main island, but also nearby Phillip Island, where it has developed monoculture forests as a characteristic of the plants ability to survive in low light levels (Cuneo and Leishman 2006, Director of National Parks 2010, Cuneo and Leishman 2013).

Current management action for invasive plants aims to limit spread and distribution African olive and red guava via mechanical removal (Director of National Parks 2018). However, while these actions may result in an eventual reduction of these invasive species, the seedbank can be very persistent and affect moisture levels of soil surrounding native plants' root systems. For instance, African olive seeds can remain viable for over two years ((Cuneo, Offord et al. 2010). Changes in soil moisture dynamics can prevent native plant species, such as ferns, from regenerating, furthering the fragmentation of native vegetation (Hill 2002, Director of National Parks 2010, Coyne 2011).

While the available literature on vegetation of Norfolk Island attempts to calssify the diversity of habitats on the islands, no measures of association and similarity have been calculated for the invasive and native species and habitat types within the NINP. These measures of plant community structure can provide valuable information into patters of association or dissimilarity of forest stands helpful to prioritize weed control at various spatial levels. This type of information can also be used to understand temporal and spatial patterns of habitat use of animal species of interest (Chapter 3).

Rare species within the Norfolk Island National Park

Norfolk Island is home to 45 species of rare plants that fall into three categories: threatened, endangered, and critically endangered (Coyne 2011). As of 2003 11 of those species were identified as having less than 50 individuals (Table 2.7). Before the present there had not been an update on the location or abundance of individuals of fruiting age of these rare species since their initial identification in 2003. A key task in the conservation management of the threatened species on Norfolk Island is the monitoring and risk assessment of these species (Director of National Parks 2018). Taking into consideration the effect invasive species may have on native populations, and the limited population size of some of these highly threatened species, it was proposed that this study would provide a baseline assessment of the location of these species within the NINP.

Tasman parakeet diet

Tasman parakeets are distributed within NINP and forage on a range of food types including the seeds, fruits, bark and leaves of both native and introduced species (Hill 2002, Waldmann 2016). Plant species associations for feeding resources of the Tasman parakeet are currently unknown, however, previous research into the utilisation of plant species by this parrot have identified five key food resources that are a mix of native and invasive species: Norfolk pine (*Araucaria heterophylla*), ake ake (*Dodonea viscosa*), African olive (*Olea europaea*), niau (*Rhopalostylis baueri*), and red guava (*Psidium cattlieanum*) (Waldmann 2016) (Figure 2.3). While these food species contributed to a large proportion of the Tasman parakeet diet (82%), the total diet of the Tasman parakeet only includes 15% of the total plant species present on Norfolk Island.

Figure 2.3. Tasman parakeets feeding on unripe red guava (top left), niau fruits (top right), Norfolk pine seeds (bottom left) and ake ake fruits (bottom right).

Photos: L. Ortiz-Catedral.

Aims

In order to investigate the patterns of habitat use of Tasman parakeets and Crimson rosellas, and to better understand the relative importance of habitats across a spectrum of restoration from weedy edges to mature forest remnants, I conducted a vegetation classification focusing on plants of fruiting age, using a systematic sampling of radial plots of fixed diameter (relevés). My aim was to produce an updated vegetation map that can be used to understand areas of greater seasonal activity by Tasman parakeets. Also, I aimed at comparing the diversity of different habitat types within the Mount Pitt section of the Norfolk Island National Park and the fine scale associations of species to investigate the relationships between habitat characteristics and patterns of habitat use by Tasman parakeets and Crimson rosellas (Chapter 3). The results presented in this chapter can also be used as a baseline to assess changes in habitat distribution over time and to inform decisions regarding restoration efforts in a range of habitat types. The specific aims of this chapter are as follows:

1. Create a detailed map that characterises the composition of the vegetation within the Norfolk Island National Park
2. Provide associative measures of key food species of the Tasman Parakeet and the Crimson Rosella.
3. Provide an updated account of the location of rare plants of fruiting age within NINP.

METHODS

Data Collection

Relevés (sample plots of vegetation) were selected for sampling from an existing network of rat bait stations (henceforth bait stations that follow established transect lines throughout the NINP, provided by the Parks Australia staff. The actual bait station was used as the center for the vegetation plot. Previous research on the Tasman parakeet (Skirrow 2018) has used the same bait station grid to monitor population numbers (Figure 2.4). I visited 988 bait stations out of the total 1800 (55%). Due to logistical constraints, such as risk levels and accessibility, I was not able to sample the remaining stations but the locations visited constitute a representative sample of the main areas where Tasman parakeets occur, and across all habitat types of woody vegetation (Waldmann 2016). A team of two people surveyed vegetation independently at each of the stations and registered each woody plant species of fruiting age: plants with a stem of at least 3 cm DBH within a 10 m radius (314 m^2) of the bait station. This plant size class was chosen based on a pilot study in 2014-2016 (Ortiz-Catedral pers. comm.). I registered the presence of plant species of fruiting age but did not estimate the density or absolute number of individual plants within the plots. This is because during a pilot conducted early in this study, I determined that it would take roughly one to two hours per plot to characterise the vegetation in detail, which would require over 200 field-days to complete.

Instead observers and I registered the presence of woody plant species (species richness per plot) as this measure allowed me to compare richness between plots and vegetation types. No herbaceous plants, shrubs, non-woody ferns, or mosses were recorded, however, at sample sites located in open areas where grass was the only plant in the area ‘grass sp’ was recorded for the vegetation composition. Registering the vegetation per plot required approximately 15 minutes on average. Most plant species were easily identified by their flowers, fruits and leaves, however at sites with high canopy or low light levels the bark and buttresses of the tree were used to assist the identification process.

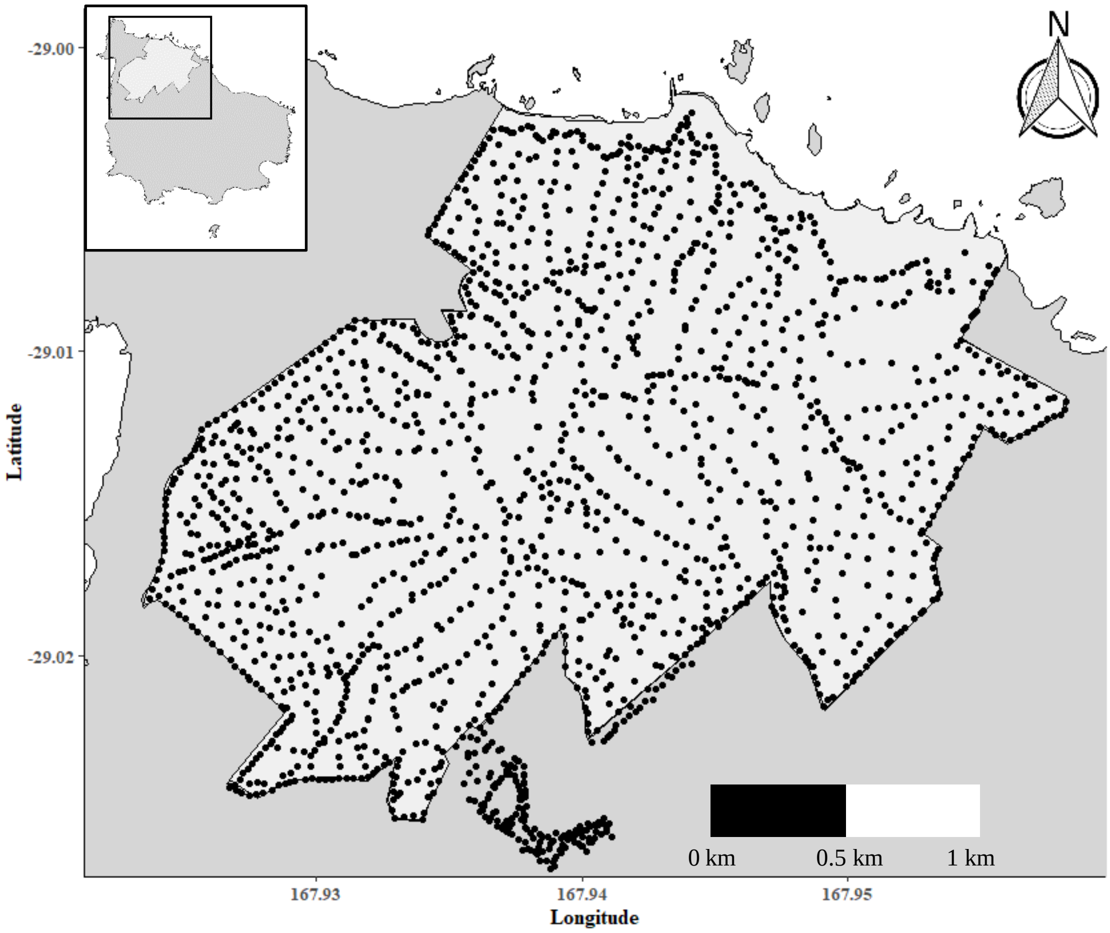


Figure 2.4. Map of all bait stations present in the Mt Pitt Section of the Norfolk Island National Park and Botanic Gardens.

Each plot was also assigned to a habitat type based on the dominant species (canopy cover of 50% or more). These habitat types are: niau forest, foresty, remnant *Araucaria* forest, remnant hardwood forest, paddock, guava forest, olive forest, forest edge, regenerating vegetation less than five years old, and regenerating vegetation more than five years old (Figure 2.5). The last two categories were identified based on feedback from staff of the Norfolk Island National Park in relation to the number of years elapsed since removal of weeds and replanting of native woody plant species. Any plot classified as "forest edge" was further subdivided into subtypes according to the dominant canopy species. That is, a forest edge could have the subtype *Auracaria* remnant, niau forest, and so on.

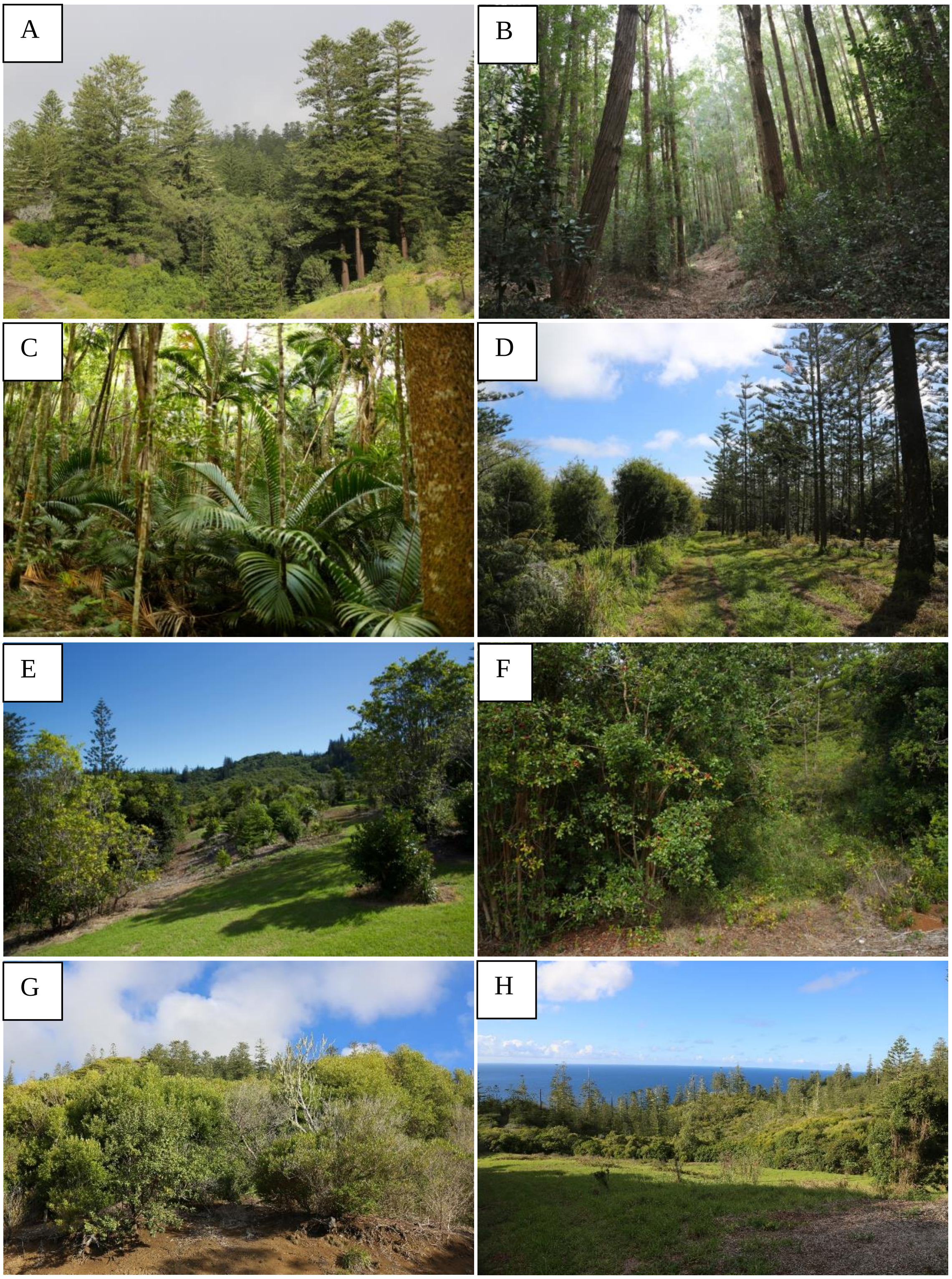


Figure 2.5. Habitat types within the Mt Pitt section of the Norfolk Island National Park Remnant *Araucaria* (A), remnant hardwood (B), niau forest (C), forestry and forest edge (D), regenerating vegetation (E), guava forest (F), olive forest (G) and paddock (H).

The total area surveyed during this researched was 31.04ha (6.75% Mt Pitt NINP). Most bait stations were between 25m and 50m apart, meaning that 5m-30m between each station was not surveyed (Figure 2.6). An estimated 181 hours was spent on the field component of this chapter.

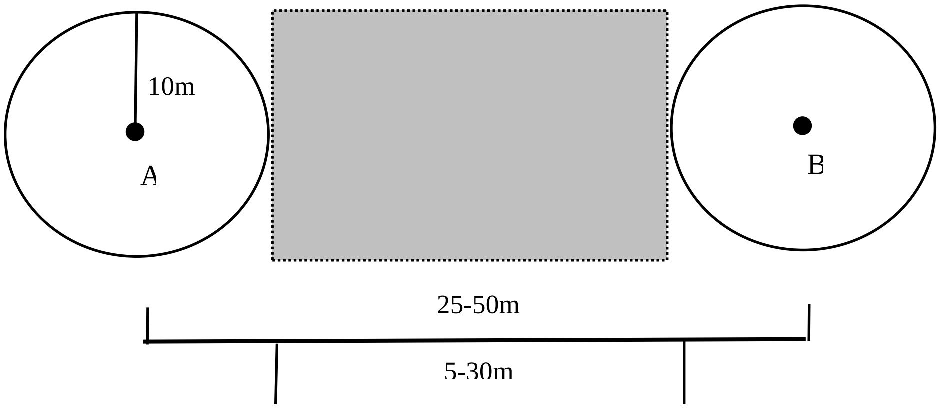


Figure 2.6. Line diagram showing bait station set up.

A and B represent bait stations. The grey area between them represents the non-surveyed, continuous habitat between stations.

Statistical Analysis

Five maps were created in R Studio (Version 1.1.463). The first map displays the distribution of the nine identified habitat types across the NINP. The remaining four maps present the distribution of five rare plant species that have demonstrated an increase in the minimum number of mature individuals per hectare of 80% or greater between the 2003 survey and the 2017 survey. There are five species displayed across four maps due to the high level of overlap between locations of individuals.

Simple, descriptive statistical analyses were undertaken for this chapter as the data collected consisted of presence and absence observations. The descriptive analyses allow for the identification of patterns in the community structure of the NINP.

The proportion of each habitat type was calculated, along with the area that the habitat occupied. Simpson's Diversity Index (D) (Kent 2011) is an index that calculates the probability that two observations will belong to the same species. The complement of this index (1-D) is used to calculate the diversity between multiple areas (Kent 2011, Morris, Caruso et al. 2014). Simpson's Diversity Index uses abundance measurements to assess the diversity of different plots (Kent, 2011). As this study did not record abundance, the observations across each habitat type were combined, to provide as an estimation of the 'relative abundance' between habitat types. The complement of Simpson's Diversity Index was used to calculate the diversity between three main habitat types in NINP: 'Native', 'Invasive', and 'Forest Edge'. The 'Native' type was a combination of all of the observations recorded in the remnant araucaria, remnant hardwood, regenerating vegetation, and niau forest habitat types, while the 'invasive' type was comprised of all of the observations recorded in the paddock, olive forest, guava forest, and forestry habitat types. The 'forest edge' type consisted only of the observations made within the forest edge habitat type. The square proportion of species richness (p_i^2) was calculated for each habitat type, and then combined for each overall type, to give the Simpson's Diversity Index per overall habitat type. The complement for each overall habitat type was then calculated.

Simpson Diversity Index was calculated using the formula:

$$D = \Sigma p_i^2$$

where D= Simpson's Diversity Index, and p_i^2= proportion of *i* species within the habitat. The complement of Simpson's Diversity Index was calculated using the formula:

$$1-D$$

The complement of Simpson's Diversity Index ranges from 0-1 where 0 represents low diversity and 1 represents high diversity.

The Sorensen-Dice coefficient is a method of calculating the similarity of the species present within two areas or habitat types (Kent 2011). The purpose of using this statistical tool was to both provide a descriptive measure of vegetative composition within the park and to identify potential explanations for the variation of bird presence within the park. That is, if the habitat preference of a specific bird was high for one habitat type, then it would be expected to be high for a habitat type with a similar assemblage of species. The Sorensen-Dice coefficient between pairings of habitat types was calculated using the formula:

$$S_s=2a/(2a+b+c)$$

where S_s= Sorensen's similarity, a= number of species in common, b= number of species in habitat type 1 and c= number of species in habitat 2. The Sorensen-Dice coefficient ranges from 0-1, where 0 is no similarity and 1 is complete similarity. A percentage of similarity was obtained for each habitat type pairing.

Researchers have identified the five plant species that have the highest contribution to the Tasman parakeet diet (Hill 2002, Waldmann 2016). These species are Norfolk pine, red guava, African olive, ake ake, and niau. The association between each species was calculated using a chi-square test for association, corrected using Yates correction for small cell frequencies (Kent 2011). Chi-square associations were calculated for these species to identify areas where the focal bird species may be present, that is, a bird may be found more times in an area where two feeding resources are found, as compared to one feeding resource. Also, this information may be of importance in the continued management of invasive plant species within the park as it will identify if key native species are found in association with invasives. A contingency table was created for each species pairing, and the association was then calculated using the formula:

$$X^2= ((|ad-bc|- 0.5N^2)*N)/(a+b)(c+d)(a+c)(b+d)$$

where X^2= the association between species x and species y, a= number of locations where both species are together, b= number of locations of species x only, c=number of locations of species y only, d= the number of locations where neither species are found, and N= the total number of locations. |ad-bc|= is the absolute difference between ad and bc, regardless of the sign (Kent 2011).

The contingency table had one degree of freedom, and so for an association between two species to be significant the value of X^2 must be greater than 3.84 at significance level of 0.05 (or $X^2>6.64$ at $p=0.01$) (Kent 2011). For significant associations the direction (positive or negative) of the association was calculated by comparing the observed frequency (both species occurring together, a) and the expected frequency. The expected frequency was calculated using the formula:

$$E=(a+b)(a+c)/N$$

There is a positive association between the two species if the observed frequency is greater than the expected frequency, and the association is negative if the observed frequency is lower than the expected frequency (Kent 2011).

RESULTS

I sampled a total of 988 relevés during this research after approximately 181 hours of sampling. This effort totalled to an area of approximately 31.04 hectares. If I account for continuity between sample sites the total area sampled amounts to approximately 90 hectares. 5422 individual plants of fruiting age were identified in this research that belonged to 80 plant species. Each habitat type had between 15 - 70 plant species present, and occupied an area between 0.41ha and 4.59ha, with the exception of forest edge, which occupied nearly half of the sample area (area=14.61ha) (Table 2.1). A location in the park was left without survey, in the northern section (Figure 2.7), due to the dangerous steep mountainside and the dense thicket of olive forest.

Distribution and species composition of habitat types

Forest Edge

The forest edge habitat type could be found all across the park, but is concentrated most densely around the park edges. This was the most common habitat type, with its presence identified at 465 sample locations. This habitat type also had the highest species richness of any of the nine habitat types (richness=70).

Remnant Araucaria

This was the second most common habitat type found within the park as it was identified at 146 of the sample locations. This type was dispersed across the park, however, it was less common on the northern and western edges of the park. There were 43 species found within remnant *Araucaria.*

Forestry

This habitat type was found clustered around the south-western edge of the park. This habitat type was identified at 92 sample locations, and had 20 plant species within it.

Guava Forest

This habitat type was the fourth most common habitat type, with 88 sample locations being of this type. Guava forest was mostly found on the eastern and south-eastern edges of the park, having a total of 32 species.

Remnant Hardwood

The remnant hardwood habitat type was found throughout the centre of the park, more so towards the eastern edge. While this habitat type was the fifth most common, identified at 79 sample sites, it had the second highest species richness, with 43 species identified within it.

Niau Forest

Niau forest was present at 53 sample locations. This type had present 25 plant species, and was found clustered around the centre and southern sections of the park.

Olive Forest

There are 33 sample locations in which olive forest was found. Within this type was found 19 species. This type was located around the edges of the park and less so in the centre.

Paddock

The paddock habitat type was found at 19 sample locations, and had present only 15 plant species. This type was found primarily in the north-west section of the park.

Regenerating Vegetation

Regenerating vegetation was the least common of the nine habitat types found within the NINP during this research, found at only 13 sample locations, which represent only 1.32% of the total sample locations surveyed. This type has present 26 species of plants, and could be found across the east and central parts of the park.

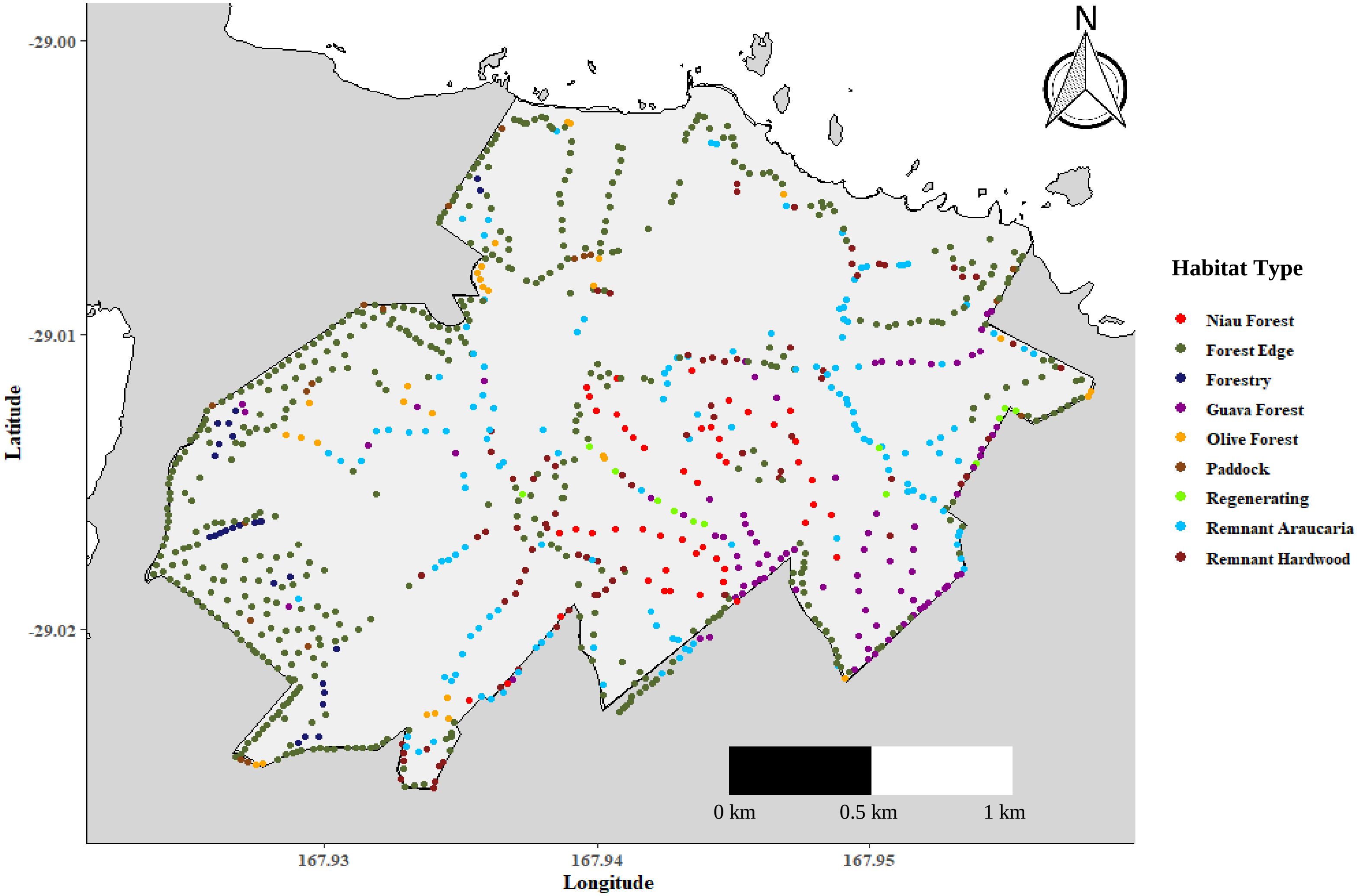


Figure 2.7. Distribution of habitat types across the Norfolk Island National Park for each relevé (sample location)

Table 2.1. Diversity of species with each habitat type.

The diversity index, p_i^2, indicates how similar the species are within each habitat type. This value ranges from 0-1, where 0 is a high diversity and 1 is a low diversity. Habitat types are RV= regenerating vegetation, NF= niau forest, RA= remnant *Araucaria*, RH= remnant hardwood, F= forestry, GF= guava forest, OF= olive forest, P= paddock, FE= Forest edge.

	Habitat type	Obs	Area (ha)	Area %	Species richness	p_i	p_i^2
Native	*RV*	13	0.41	1.32	26	0.33	0.10
	NF	53	1.67	5.36	33	0.41	0.17
	RA	146	4.59	14.78	42	0.53	0.28
	RH	79	2.48	8.00	43	0.54	0.29
Invasive	*F*	92	2.89	9.31	20	0.25	0.06
	GF	88	2.76	8.91	32	0.40	0.16
	OF	33	1.04	3.34	19	0.24	0.06
	P	19	0.60	1.92	15	0.19	0.04
Forest Edge	*FE*	465	14.61	47.07	70	0.88	0.77
Total		988	31.04	100			

Table 2.2. Simpson's Diversity Index (D) for native, invasive and forest edge habitat types.

Simpson’s Complement (1-D) is a measure of diversity between the species found at each habitat type ranging from 0-1, where 0 is low diversity and 1 is high diversity.

Habitat Type	Obs (n)	Area %	Total Richness	D	1-D
Native	291	29.46	50	0.84	0.16
Invasive	232	23.48	45	0.31	0.69
Forest Edge	465	47.07	70	0.77	0.23
Total	988				

Diversity of habitat types

The ‘Invasive’ habitat type had the highest Simpson’s complement (1-D=0.69) while the ‘Native’ habitat type had the lowest (1-D=0.16). This means that the ‘Invasive’ habitat type has a higher diversity of species than the ‘Forest Edge’ and ‘Native’ habitat types (Table 2.2). One relevés had no recorded plant species of fruiting age within the 10 metre radius of the station. This sample location was found in the forest edge habitat in a young, regenerating forest and represented 0.1% of the total relevés surveyed. It was noted that outside of the 10 metre survey radius were *Araucaria heterophylla* and *Elaeodenderon curtipendulum* trees.

Measures of similarity between habitat types

The measures of similarity between habitat types ranged from 27.50% (olive forest - paddock) to 65.31%. (paddock - remnant hardwood). The ‘Native’ habitat type pairings ($x^{n,}$,Table 2.3) had high similarities of species found within them, ranging from 40.40%-45.86%. The ‘Invasive’ habitat type pairings (x^{i} Table 2.3) were over a larger range than the ‘Native’ types, ranging from 33.33%-65.31%.

Table 2.3. Sorensen-Dice coefficients for each habitat type pairing.

Number of shared species (a) is top-right. Sorensen-Dice coefficients are the measure of how similar the species are between two habitat types, expressed as a percentage and located bottom-left (S_{S}). Habitat types are RV= regenerating vegetation, NF= niau forest, RA= remnant *Araucaria*, RH= remnant hardwood, F= forestry, GF= guava forest, OF= olive forest, P= paddock, FE= Forest edge.

Habitat Type	*F*	*GF*	*OF*	*P*	*NF*	*RV*	*RA*	*RH*
F		13	13	10	10	12	16	13
GF	33.33^{i}		13	14	22	21	28	29
OF	40.00^{i}	33.77^{i}		32	10	13	18	15
P	36.36^{i}	37.33^{i}	65.31^{i}		8	10	11	11
NF	29.33	42.48	33.33	25.00		18	25	25
RV	34.29	42.00	36.62	32.79	40.40^{n}		25	25
RA	34.04	43.08	37.11	27.85	44.44^{n}	42.37^{n}		36
RH	29.21	43.61	32.61	27.50	44.93^{n}	42.02^{n}	45.86^{n}	

Tasman parakeet feeding species

The most commonly occurring species from the previously identified five key food resources for the Tasman parakeet was the Norfolk pine, which was found at 619 sample locations. The next two species that were most commonly occurring were the African olive, found at 430 sample locations, and the red guava, which was found at 417 sample locations. The fourth species was niau, which was found at 207 surveyed sample locations, and the least common out of the five was the ake ake which was found at 149 sample locations (Table 2.4).

Table 2.4. All plant species with a DBH of 3cm or greater identified within the Mt Pitt section of the Norfolk Island National Park.

* Species found in 5% or more of the total relevés, ^ Known food species that are also found on Phillip Island, + Key Tasman parakeet food resource.

Species	Sample size	Percentage
Achyranthes arborescens	5	0.51
Achyranthes margaretum	3	0.30
Alyxia gymopogon *	54	5.47
Araucaria heterophylla * ^ +	619	62.65
Asplenium australasicum	1	0.10
Baloghia inophylla *	218	22.06
Banana sp.	1	0.10
Boehmeria australis	13	1.32
Caesalpinia bonduc	2	0.20
Capparis nobilis	6	0.61
Cedrella sinesis	1	0.10

Celtis paniculata	20	2.02
Citrus jambhiri	46	4.66
Coprosma baueri	1	0.10
Coprosma pilosa	6	0.61
Cordyline fruticosa	1	0.10
Cordyline obtecta * ^	308	31.17
Cyathea australis	11	1.11
Cyathea brownii *	141	14.27
Delarbrea paradoxa	2	0.20
Dodonaea viscosa * +	149	15.08
Dracaena sp.	1	0.10
Dysoxylum bijugum *	76	7.69
Elaeodendron curtipendulum *	280	28.34
Eriobotrya japonica	3	0.30
Eucalyptus sp. *	118	11.94
Exocarpos phyllanthoides *	81	8.20
Fabacea sp.	21	2.13
Freycinettia baueriana	48	4.86
Grass sp.	24	2.43
Hakea salicifolia *	94	9.51
Hibiscus sp.	1	0.10
Hibiscus tiliaceus	9	0.91
Homalanthus populifolius	1	0.10
Howea forsteriana	2	0.20

Lagunaria patersonia * ^	216	21.86
Lantana camara ^	42	4.25
Macademia sp.	3	0.30
Macropiper excelsum	32	3.24
Melia azedarach	2	0.20
Melicope littoralis	26	2.63
Melicytus latifolius	18	1.82
Melicytus ramiflorus	12	1.21
Meryta angustifolia *	170	17.21
Meryta latifolia	42	4.25
Metrosideros excelsa	2	0.20
Milletia australis	4	0.40
Muehlenbeckia australis	2	0.20
Musa acuminate	1	0.10
Myoporum obscurum	1	0.10
Myrsine ralstoniae *	387	39.17
Nerium oleander	1	0.10
Nestegis apetala *	355	35.93
Nisperus japonica	1	0.10
Ochna serrulata	1	0.10
Olea europaea * ^ +	430	43.52
Passiflora sp.	1	0.10
Pennantia endlicheri *	52	5.26
Persea americana	1	0.10

Pinus sp.	2	0.20
Pisonia brunoniana	17	1.72
Pittosporum bracteolatum *	219	22.17
Pittosporum undulatum	7	0.71
Plumeria sp.	1	0.10
Pouteria costata	4	0.40
Prunus persica	1	0.10
Psidium cattleianum * +	417	42.21
Psidium guajava	5	0.51
Rhopalostylis baueri * ^ +	207	20.95
Ricinus communis	1	0.10
Sarcomelicope simplicifolia	20	2.02
Schinus terebinthifolius *	230	23.28
Solanum mauritianum * ^	63	6.38
Streblus pendulinus	16	1.62
Ungeria floribunda	45	4.55
Washingtonia robusta	1	0.10
Leucaena leucocephala	2	0.20
Wikstroemia australis	1	0.10
Zanthoxylum pinnatum	13	1.32
Total	5442	

There are ten pairings between the five key food resources. Six pairings exhibited high associations, while the other four showed very low associations (Table 2.5). The strongest association was between niau and African olive (X^2=172.11, p<0.01). Niau also had a strong association with Norfolk pine (X^2=35.17, p<0.01), and a weaker association with red guava (X^2=3.67, p<0.1). Red guava also had a strong association with African olive (X^2=271.2, p<0.01). The association between ake ake and red guava, and ake ake and Norfolk pine, were very similar (X^2=18.46, X^2=18.00, respectively. Both p<0.01).

Table 2.5. Associations (X^2) between key food species.

The greater the value the more likely they are to be found at the same location.

Species	Norfolk pine	Ake ake	Red guava	African olive	Niau
Norfolk pine					
Ake ake	18.00**				
Red guava	1.86	18.46**			
African olive	1.49	0.03	27.12**		
Niau	35.17**	0.08	3.67*	172.11**	

Note: df=1

*p<0.1 ** p<0.01

There were only two associations in a positive direction, and none were between invasive and native pairings (Table 2.6). African olive and red guava had a positive association, as well

Table 2.6. Direction of association for significant pairings.

Pairings are listed from high to low association.

Species pairs	Expected frequency	Observed frequency	Association
African olive-niau	89.40	6	Negative
Norfolk pine-niau	129.12	92	Negative
Red guava-African olive	275.77	317	Positive
Ake ake-red guava	62.29	38	Negative
Norfolk pine-ake ake	92.46	116	Positive
Niau-red guava	90.73	78	Negative

as Norfolk pine and ake ake. All of the species that niau was associated with were negative associations.

Distribution of rare plants

Forty-five species of plants had been identified as rare in 2003, including woody plants, ferns, and shrubs. During the surveys of vegetation plots that were conducted as a part of my research, 23 of those threatened species were identified. As the results from my research only indicated the presence or absence of mature individuals at each relevés surveyed, the number of each species that was reported represented the minimum number of mature individuals of that species.

There were fifteen species which demonstrated an increase in the minimum number of mature individuals per hectare located within the NINP (Table 2.7). Only five species saw an increase in individuals per hectare of 80% or more: *Cordyline obtecta* (increase=95.60%), *Melicytus latifolius* (increase=93.64%), *Myrsine ralstoniae* (increase=90.22%), *Boehmeria australis* (increase=82.90%), and *Meryta angustifolia* (increase=81.02%) (Figure 2.8).

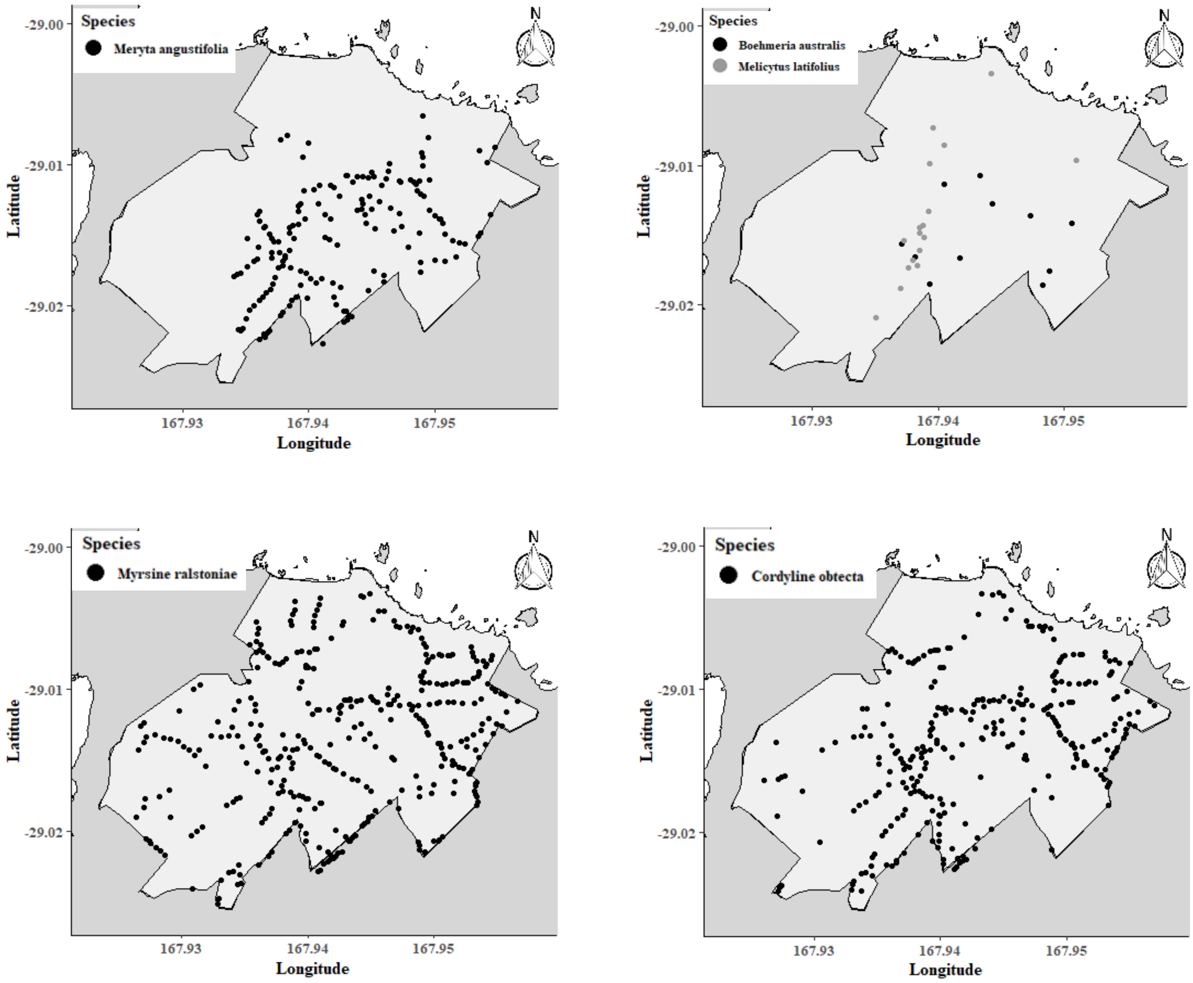


Figure 2.8. Distribution of rare plants.

Threatened plants showing an increase of individuals per hectare of 80% or greater from the 2003 survey to the 2017 survey.

Table 2.7. Minimum number of individuals of fruiting age per hectare of rare plants.

Plant species identified as threatened in 2003 (Coyne 2011) and the associated 2017 values. The 2003 study counted all individuals within the Mt Pitt section of the Norfolk Island National Park (NINP) (area surveyed=460 ha), while the 2017 study noted only one mature individual at each bait station the species was present, at within the confines of the NINP (area surveyed=30.98 ha). '+' :percentage increase; '-' :percentage decrease. CR: Critically Endangered, E: Endangered, V: Vulnerable.

Species	Status	2003	2017	Difference (%)
Achyranthes arborescens	CR	0.12	0.16	+23.22
Achyranthes margaretum	CR	0.04	0.10	+55.10
Boehmeria australis	CR	0.07	0.42	+82.90
Coprosma baueri	E	0.50	0.03	-93.49
Coprosma pilosa	E	0.41	0.19	-52.36
Cordyline obtecta	V	0.43	9.88	+95.60
Dysoxylum bijugum	V	1.89	2.45	+22.90
Melicope littoralis	V	0.59	0.84	+29.28
Melicytus latifolius	CR	0.04	0.58	+93.64

Melicytus ramiflorus	V	0.95	0.39	-59.13
Meryta angustifolia	V	1.04	5.49	+81.02
Meryta latifolia	CR	0.32	1.36	+76.11
Muehlenbeckia australis	E	0.22	0.06	-70.30
Myoporum obscurum	CR	0.01	0.03	+66.33
Myrsine ralstoniae	V	1.22	12.49	+90.22
Pennantia endlicheri	E	0.37	1.68	+78.24
Pittosporum bracteolatum	V	2.00	7.07	+71.68
Pouteria costata	E	0.38	0.13	-66.25
Streblus pendulinus	E	0.41	0.52	+21.29
Ungeria floribunda	V	1.09	1.45	+24.87
Wikstroemia australis	CR	0.34	0.03	-90.42

DISCUSSION

Due to logistical constraints only 55% of the total bait station grid within the NINP in 2017 was surveyed (n=988). The data that has been presented in this chapter will be used in Chapter 3 as a baseline for the comparison of patterns of habitat use between the Tasman parakeet and the crimson rosella, two parrot sympatric parrot species that are known to compete for other resources, such as nesting materials (Director of National Parks 2018). The map of habitat types that has been created in this chapter will be used to determine the habitat types for parrot observations, as well as providing an estimate of the habitat types available to these bird species.

Composition

The data that I gathered for this chapter has been used to create the first fine-scale map of habitat types and woody vegetation associations that are present within the NINP (Figure 2.7). The *Norfolk Island National Park and Norfolk Island Botanic Gardens Management Plan 2018-2028* (Director of National Parks 2018) lists African olive and red guava as the top priority weeds to control within the park, and so the vegetation map created in this chapter can assist park management in the undertaking of invasive plant control through the identification of areas of invasive species presence. We were also able to identify which rare plants have increased in numbers (individuals of fruiting age) between 2003 and 2017 (Table 2.7). While this study did not account for abundance, this information can provide park management with a baseline estimate on how the populations of rare and endangered plants have changed over time. In assessing the rare plants we also discovered certain plant species that seemed to experience a decrease density of mature individuals, with *Wikstroemia australis* experiencing a decrease of 90.42%. These results may be an outcome of our sampling methodology, as not all possible sample locations in the NINP were surveyed. Identifying the presence of these rare plant species can allow managers within the park to tailor developments and upgrades of paths, recreation, and facilities around these species.

I identified nine main habitat types within the NINP. During the analysis stage, I discovered that the two regenerating habitat types consisted of similar plant species and were both represented by small sample sizes, so I combined these two types into a single one. Forest edge was the predominant habitat type, as can be expected in an area affected by habitat fragmentation and loss (Fagan, Cantrell et al. 1999). Forest edge sub-types were disregarded for analytical purposes as only a broad-scale identification of habitat types was required. Forest edges within the NINP are characterised by a lack of canopy, and often occupy road sides and the edges of visitor and maintenance tracks. Many of the forest edges found within the park are the cause of anthropogenic modification, and as such, the behaviours expressed within this habitat type may be a result of habitat modification. Much of the plant life that comprises the edge habitat is that of younger individuals, as many of these trees have been replanted (self-seeded) since the creation of the tracks. Edges can have impacts on the dispersal of organisms who use that habitat (Chapter 3), but they can also have an effect on the composition of the plants present, through the dispersal of the seeds of those plants, changes in the behaviours of pollinators, and changes to the soil (Fagan, Cantrell et al. 1999, Harper, Macdonald et al. 2005).

Diversity

I grouped the habitat types into three main sections, native, invasive, and forest edges. Invasive habitat types had the highest plant diversity (1-D=0.69), even though they account for the lowest area of the park that we surveyed (23.48%). Forest edge was comprised of the largest area of the park (47.07%), however, this type had a medium level of diversity (1-D=0.23). Native habitat type was the second most common habitat (29.46%), but it had the lowest diversity out of the three types (1-D=0.16). The invasive group was formed of forestry, guava forest, olive forest, and paddock, many of which were found along road edges and in forestry areas. These areas are ideal growing sites for a variety of pest plants, which could be a leading cause of the high diversity found in these areas.

Similarities

Measures of similarity between habitat types identified that all of the native types were within close to 5% similarity of each other (40.40% - 45.86%). The remnant hardwood and remnant *Araucaria* habitat types shared the highest amount of plant species within the native groupings (45.86%), while the olive forest and paddock habitat types shared the highest number of plant species within the invasive groupings (65.31%). The two habitat types that shared the highest amount of plant species between the native and invasive groupings was the remnant hardwood and guava forest types (43.615%). Due to the invasive nature of such plants, areas of predominantly red guava and African olive do not allow for the growth of new plant species, however, if there are mature trees that established prior the introduction of the invasive species, then those pre-existing species may survive, hence the high association between these two types.

Key feeding resources

From previous research I identified five key food resources, Norfolk pine, ake ake, African olive, red guava, and niau (Waldmann 2016). During this research I identified 5442 individual plants of 80 different species. The five key resources accounted for 33.48% (n=1822) of those individuals identified, with one third of those feeding resources consisting of Norfolk pine (n=619). A chi-square analyses was conducted on the association between each plant species and I found that only two pairings were positively associated with each other, African olive and red guava (X^2=27.12, p<0.01), and Norfolk pine and ake ake (X^2=18.00, p<0.01). All other significant pairing were negative associations, meaning that there was a strong likelihood that the two species were not found in the same location. Niau and Norfolk pine had a strong negative association (X^2=35.17, p<0.01), even though they are both native species. This is likely due to the preference of Norfolk pine for ridge lines, and niau for deep soils found in valley areas. These associations may account for the preference of Tasman parakeets and crimson rosellas towards certain habitat types, as is mentioned in Chapter 3.

Track use

Due to its popularity as a tourist destination the visitor tracks within the park often experience a high volume of foot traffic as compared to facility and maintenance tracks, which are only visited by Parks Australia staff. A review of the literature finds that non-motorised tourist activities can have negative impacts on bird behaviour, physiology, breeding, and population levels (Steven, Pickering et al. 2011). The presence and behaviour of parrots along the visitor tracks may therefore be affected by the number of visitors present upon these, and hence behaviours recorded in Chapter 3 may not be an accurate reflection of their natural behaviours at those locations. Having the vegetation characterised at more sample locations may have provided us with a more accurate account of the habitat use of the Tasman parakeets and crimson rosellas in Chapter 3.

Alternative methodology

The decision to sample the presence/absence of woody plants only in the present Chapter is justified as we only compared broad-scale differences in habitat use for the analyses Chapter 3, however, there have been instances of Tasman parakeets feeding on non-vascular plants, grasses, and ferns that may call for a fine-scale study. The patterns of habitat use that derive from the data presented in Chapter 2 are not conclusive of the total dietary behaviours of the parrot species, and as such, conducting a study with the inclusion of non-woody plants, may expose new patterns in the habitat use and dietary behaviours of these birds.

Studies of New Zealand parrots indicate just how extensive and informative vegetation studies can be. One such example is provided by Joyce (2008) in which they presented an in depth vegetation analysis that comprised of aerial photographic maps, quadrat sampling during which vegetation cover was established, and presence/absence sampling. The vegetation data collected was used to quantify habitat preference of the kakapo, a critically endangered parrot. This study was able to provide a clear understanding of how kakapo utilise their habitat across the whole study island with the application of mixed sampling methods. Where one method may have lacked detail or precision, other methods ensured this detail was not lost.

To provide weight to the presence of plant species within the NINP the abundance of woody plant species, along with the abundance of fruiting resources, should be quantified. As the availability of resources often follows seasonal trends, assessing the temporal fruit abundance may provide another layer of detail in understanding habitat use of the two parrot species. Pavey, Nano et al. (2014) were able to correlate the decrease in Princess parrot (*Polytelis alexandrae*) population to the decrease in the abundance and availability of feeding resources, in particular, flowering plants, through the use of extensive ground-based abundance sampling.

The detail provided by these examples demonstrates the importance of this level of research for the conservation of critically endangered species, particularly when extinction risk is amplified by the presence of that species in only one location. A more thorough undertaking of vegetation assessment, focussing on non-visitor areas, may provide a level of detail that time did not allow for in my research. Applying mixed methods of aerial and ground-based sampling may allow for a more discrete level of detail to be obtained from the sample site, consequently leading to a clear depiction of the total habitat available to Norfolk Island species, in particular, the Tasman parakeet.

CHAPTER 3 : HABITAT PREFERENCE AND FEEDING ECOLOGY OF THE NORFOLK ISLAND PARROTS

Figure 3.1. Tasman parakeet feeding on unripe peach fruit.

Photo: L. Ortiz-Catedral.

ABSTRACT

Resource availability and competition pressure are both factors that contribute to patterns of habitat use. Determining the proportion of available *vs*. used habitats may highlight the relative importance of habitat types in fragmented environments where species of conservation concern occur. Tasman parakeet and crimson rosella coexist in the Mount Pitt section of the Norfolk Island National Park (NINP). Evidence suggests nesting competition between both species but there is limited information on the degree of competition for other resources. I conducted a temporal analysis of habitat use patterns of Tasman parakeets and crimson rosellas in autumn and spring, 2017. I compared the spatial location of individual birds of each species in a matrix of nine habitat types on sections of NINP open to the public and sections closed to the public, during targeted surveys (on-survey transects) as well as opportunistic encounters (off-survey transects). These observations, and the data on habitat availability within the NINP prepared in Chapter 2, were used to identify patterns of habitat use for the two species. I also examined the dietary composition between species and season. During autumn Tasman parakeets displayed significantly higher selection for remnant hardwood ($B_i = 0.51$, $X^2 = 6.86$, $p < 0.01$), and the crimson rosella displayed significantly higher selection for forest edge ($B_i = 0.34$, $X^2 = 24.51$, $p < 0.001$). During spring the Tasman parakeet displayed significantly higher selection for remnant hardwood ($B_i = 0.32$, $X^2 = 8.92$, $p < 0.001$), and the crimson rosella displayed significantly higher selection for Forest Edge ($B_i = 0.25$, $X^2 = 23.89$, $p < 0.001$). During spring on-survey transects the crimson rosella and the Tasman parakeet overlapped in feeding species, predominantly feeding on fruits of ake ake (*Dodonea viscosa*) (73% and 54%, respectively). During autumn on-survey transects there was no overlap between feeding species. My results indicate that during spring and autumn crimson rosellas used a wider variety of habitats than Tasman parakeets within NINP.

INTRODUCTION

Worldwide conservation projects often focus on areas with a high abundance of threatened species. Successful management of these species often involves understanding how they interact with other taxa, including introduced or invasive species, in a matrix of fragmented habitats (Lindenmayer, Cunningham et al. 2002, Ni, Liang et al. 2018). The increase of human activity in an area decreases the availability of suitable habitat (Andren 1994), hence, many species may experience a reduction in the size of their home ranges and territories (Prugh, Hodges et al. 2008). Population size is negatively associated with the proportion of suitable habitats in a landscape (Andren 1994). As a result, island endemic species will feel the effects of fragmentation greater than migratory, or mainland species, as islands have a limited range of suitable habitats available.

Often, species will avoid areas of anthropogenic development, however, during periods of low food availability some species might forage in human-occupied habitats to some degree (Matuzak, Bezy et al. 2008). Researchers have found that when foraging away from disturbed habitats animals appear to feel safer, as evidenced by an increase in foraging effort and a decrease in observation of surroundings. Conversely, when forced to forage near areas of disturbed habitat it has been shown that animals are increasingly vigilant and may be at risk of a lowered foraging efficiency (Speziale, Lambertucci et al. 2008). Consequently, an increase of species mortality as a result of lowered food consumption can be compounded by the isolation of populations within fragment patches (Reed 2004). Identifying the processes underlying habitat choice can contribute to the active conservation of endangered species, while also providing valuable information on the relative importance of various available habitats by the target species.

Habitat use and availability

Species often occur in more than one habitat type, and different habitats are used for different purposes, often as a reflection of the resources available within them (Manly, McDonald et al. 2004). Some examples of habitat use include feeding (Hatase, Sato et al. 2006), passage (Recio, Seddon et al. 2015, Berg, Bergman et al. 2016), resting (Tyne, Johnston et al. 2015), and nesting (Hart, Zawada et al. 2016). Research regarding habitat use can provide insight into the relative importance of each habitat type for the focal species, and can illustrate the preference for various habitat compositions, such as if the species prefers native or invasive vegetation, if the species prefers older or younger vegetation, or, if the species prefers deep forest or forest edges (Gurarie, Suutarinen et al. 2011, Centeno-Cuadros, Hulva et al. 2017, Ni, Liang et al. 2018).

The relative importance an organism places upon certain habitat types can be measured on a scale of preference, ranging from low preference, indicating that the habitat is less desirable, to high preference, indicating that the habitat that is more desirable (Manly, McDonald et al. 2004). For many animal species preference is often low for habitats that have experienced some degree of human alteration, as seen in the preference for winter foraging habitats of lesser kestrels *(Falco naumanni*) (Tella and Forero 2000). While forest margins (the natural habitat) were the least available habitat type to the kestrels (area=0.8% of total space), the birds exhibited the greatest selection for this type (selection index=14.22, preference=very high). Contrastingly, modified habitats were more abundant than natural habitats (area=82.3% of total space), and yet only one modified habitat was selected for (selection index=3.05, preference=low), whilst all other modified habitats were avoided (selection index <1, preference= very low).

The connectivity between habitat patches has been demonstrated to be of importance to the survival of individuals within a population, more so in areas of anthropogenic modification and fragmentation (Ni, Liang et al. 2018). Some species, with narrow niche requirements, are at a higher risk of extinction if their area of occupancy is small (Slatyer, Hirst et al. 2013), however, the area of occupancy can be greater if there are corridors that connect suitable habitat patches, as they allow for the movement of individuals between areas of low and high abundance of resources (Andren 1994). Conversely, if the fragmentation is so great that there is a disconnection between habitat patches then individuals in a population are at risk of a disproportionate amount of time being spent searching for resources as they move through areas of unsuitable habitat (Ni, Liang et al. 2018).

Habitats that are suitable for herbivores are those with a high abundance of plant species (Scherber, Eisenhauer et al. 2010), and habitats that are suitable for carnivores are those with a large number of prey species (Carbone and Gittleman 2002). The suitability of habitat types may change in response to seasonal resource abundance, such as during the annual reproductive cycle of plants. As plants progress through their reproductive cycle, the types of food available from these plants, such as flowers, fruits, and seeds, will vary in their availability throughout the year (Kudo, Ida et al. 2008), and so as a reflection of diet preference many animal species will utilise other habitat types within their home range. Monthly fruiting phenology transects found that food resources of the lilac-crowned parrot (*Amazona finschi*) exhibited seasonal changes to their food resource output, that is, the amount of seeds, fruits, and flowers that they produced (Renton 2001). It was found that the seasonal patterns of habitat use for this parrot species could be attributed to the availability of resources, as the parrots had shown almost no overlap of dietary items between seasons.

Competition and niche choice

Factors affecting the survival of a population not only include the abundance of resources or the degree of fragmentation of their habitat, but also competition for limited resources within that habitat. Competition exists within all environments, for both plants and animals, with the most common resources fought over being food, mates, and territories (Dvoretsky and Dvoretsky 2011, Hawkins and Crawford 2018). Competition comes in two forms that can be distinguished based upon the species that are competing: intraspecific if the two organisms are of the same species, and interspecific if the two organisms are of separate species.

Species often exhibit generalist or specialist feeding strategies, with specialists tending to show preference for a narrow range of resources, and generalists consuming resources from within a wider range (Mihuc 1997). Generalist feeders experience will experience a lower number of interspecific interactions as there is less direct competition for the same resources (Mihuc 1997). When food resources are low the range of resources utilised will increase for many species as the number of preferred feeding species decreases. As a consequence of diminishing resources, many species will occupy a greater range than normal, furthering the number of interspecific interactions between those species that may now experience an overlap of habitats. In some areas, such as in fragmented forests within Thailand, species with similar habitat requirements may alter their spatial and temporal distributions during seasons of low resources in order to avoid the potentially harmful interactions (Petersen, Savini et al. 2018). Animals may also avoid competitive interactions by exploiting physical traits, as is the case of the common noctule bat (*Nyctalus noctula*), which avoids interspecific competition with Nathusius's pipistrelle (*Pipistrellus nathusii*) when hunting prey through the use of different echolocation frequencies (Roeleke, Johannsen et al. 2018).

However, not all interactions may be avoided, resulting in competition that may prove fatal to one or both of the species involved. As noted by Palomares and Caro (1999), up 68% of the deaths of mammalian carnivores studied could be attributed to interspecific competition. While some outcomes of these interactions are directly fatal, others can induce stress, which may lead to an increase in mortality over time. For example, a study found that one species of goby, the tidewater goby (*Eucyclogobius newberryi*), experienced its highest stress levels during its juvenile phase, when in the presence of the threespine stickleback (*Gasterosteus aculeatus*), as evidenced by an increase in cortisol levels (Chase, Flynn et al. 2016). The researchers found that the increased stress levels as a result of the abundance of competitors coupled with a low number of food resources may lead to a high mortality, through limited metabolism and lowered bodily functions, such as, the development from the juvenile to the adult life stage.

When two heterospecific species compete for finite resources, one is likely to outcompete the other unless there is some distinguishable difference between the realised niches of two species (Hardin 1960, Michielsen 1966). This concept known as the competitive exclusion theory and states that for the co-existence of two species with similar habitat requires within the same geographic location there must be some way in which they utilise their habitats that offers an avoidance of complete competition (Hardin 1960, McLean, Hölzer et al. 1994).

Often the resources that an organisms utilises within its environment are not an accurate reflection of the resources it is physically able to use. The fundamental niche of an organism is described by Kearney and Porter (2004) as ‘a set of conditions and resources that allow a given organism to survive and reproduce in the absence of biotic interactions’. The realised niche of an organism refers to the actual resources and conditions that the organism has access to, in the presence of such biotic interactions as resource competition (Chase and Leibold 2003). Research has found that an organisms realised niche is not fixed, rather, species are able to shift their occupancy to new habitats if competitors are removed and the new habitat falls within the species' fundamental niche (Alatalo, Gustafsson et al. 1985).

While the idea that a fluid realised niche may allow for species survival is of conservation benefit, this idea relies on connectivity between habitat patches, and may not apply on islands where the available habitat is already limited by the islands size. Losos and Ricklefs (2009) propose a theory regarding why insular species with similar resource requirements may be able to coexist in the same geographic space. They theorise that as shared resources are used over time their abundance decreases, with the patches of resources becoming increasingly further apart. Consequently, interspecific competition will lessen over time as species disperse in search of resources, while intraspecific competition is likely to increase within patches. While this may be true of islands large enough to allow for such dispersal of species, some islands are small and only offer limited suitable habitat. How, then, do species with similar patterns of habitat use avoid competition? The literature suggests that sympatric species in areas with limited foraging resources, such as islands, are able to avoid interspecific competition through the partitioning of available resources within chosen habitats (Arlettaz 1999, Comte, Cucherousset et al. 2016), that is to say, that when resource portioning is high, the level of interspecific competition will be low (Pacala and Roughgarden 1982).

The parrots of Norfolk Island and their competition for resources

Parrots experience both intraspecific and interspecific competition due to the overlap of territories, and the similarities between species in both physical and behavioural characteristics. Interspecific interactions can lead to population decline, hybridisation with closely related species, such as between the Forbes' parakeet (*Cyanoramphus forbesi*) and the Chatham Island red-crowned parakeet (*C. novaezelandiae chathamensis*) (Chan, Ballantyne et al. 2006), and an overall reduction in reproductive output, as is the outcome of competition between glossy-black cockatoos (*Calyptorhynchus lathami*), galahs (*Eolophus roseicapilla*) and little corellas (*Cacatua sanguinea*) (Garnett, Pedler et al. 1999). Interspecific interactions are highest when species are competing for the same resources, such as nesting sites and materials. Three sympatric parrot species, the sulphur-crested cockatoo (*Cacatua galerita*), the palm cockatoo (*Probosciger aterrimus*) and the eclectus parrot (*Eclectus roratus*), share similarities in breeding behaviours. While all three species nest in tree cavities, differences in the habitat chosen and the physical properties of the nests allow for competition avoidance. However, where there was a high similarity between nesting habits competition was also high. This competition had the potential for reproductive failure, in one instance, the eclectus parrot lost 25.8% of its nests to the sulphur-crested cockatoo (Heinsohn, Murphy et al. 2003).

When two species are competing the one that faces extinction is the one with the lower breeding potential (Hardin 1960). There are two parrot species in residence on Norfolk Island, the Tasman parakeet (endemic) and the crimson rosella (invasive), both of which are known to compete for nesting sites (Director of National Parks 2018). There is evidence that out of the two species, the Tasman parakeet has the lower breeding potential, and therefore faces extinction as a result of competition with the invasive parrot (Dutson 2013). Due to the threat posed by the crimson rosella to the Tasman parakeet Parks Australia, the leading government body on Norfolk Island protecting the native and endemic flora and fauna, actively attempts to control the crimson rosella population by destroying any active nests when found, and conducting shootings of individual rosellas within the park (Hill 2002, Director of National Parks 2018, Skirrow 2018).

The Tasman parakeet and the crimson rosella share many behavioural and physical characteristics, for example, both are cavity nesters (Director of National Parks 2018). A cavity is formed when a tree limb falls off of a mature tree, leaving behind a small hole that eventually hollows out to become a cavity (Edworthy, Trzcinski et al. 2018). Early land clearance on

Norfolk Island reduced the abundance of mature forest trees around the island, with their current range restricted to the Mount Pitt section of the Norfolk Island National Park, hereafter referred to as the NINP. Anthropogenic modification of native habitats has many impacts on local wildlife, including restricting species to areas of habitat suitability (Saunders, Smith et al. 1982, Gurarie, Suutarinen et al. 2011, Centeno-Cuadros, Hulva et al. 2017). Consequently, Tasman parakeets are similarly restricted, as are the majority of the reproductive age crimson rosellas (Hill 2002, Director of National Parks 2018).

Tasman parakeets and crimson rosellas interact in a competitive manner for available resources, with the crimson rosella often displaying aggressive tendencies towards the native parrot (Director of National Parks 2010, Dutson 2013). The Tasman parakeet is a territorial species, with the males holding the territories and calling to attract females (Hill 2002). The species will breed all year round, however, breeding will peak between December and March, and slow between September and November (Hill 2002, Director of National Parks 2018). This loss of breeding potential during these months has been attributed to the peak in the crimson rosella breeding at this time (Hill 2002). During these months the crimson rosella will behave aggressively during interactions with the Tasman parakeet, expelling adults from their territories, and even going as far as to remove Tasman parakeet chicks and eggs from natural, protected, and artificial nests (Hill 2002, Director of National Parks 2018).

On mainland Australia the crimson rosella will often win in aggressive interactions with other parrots, such as the eastern rosella (*Platycercus eximius*) (Pell and Tidemann 1997). The crimson rosella is approximately 120g-150g and the eastern rosella is between 100g and 110g (Magrath and Lill 1983, Higgins 1999, Galbraith 2013, Galbraith 2013). The size difference between the two birds may be influencing the outcome of those interactions, and therefore size may be a contributing factor to the aggression displayed by crimson rosellas towards Tasman parakeets on Norfolk Island.

Since its introduction to Norfolk Island the crimson rosella has established itself as a pest that affects not only the Tasman parakeet, but other birds as well, such as the Norfolk boobook (*Ninox novaeseelandiae undulata*) with which it is also a nest competitor (Higgins 1999, Director of National Parks 2010, Baker, Harvey et al. 2014). Crimson rosellas have also had a negative impact on the local community, as large numbers of these birds have been seen to eat and destroy fruit from private fruit trees, and are also known to nest in chimneys (Smithers and Disney 1969).

While crimson rosellas are seen all over the island Tasman parakeet range of occupancy has been restricted to the NINP by the presence of humans in their environment. The habitat of the Tasman parakeet was described by Higgins (1999) as mature native forests, mainly comprised of *Araucaria stands.* Higgins also recorded Tasman parakeets as occasionally being present in *Eucalyptus* forest. More recent research into the habitat of the Tasman parakeet observed that the species exhibits variation in their habitat preference as a reflection of the seasonal abundance of resources (Waldmann 2016). In winter the Tasman parakeet was identified as primarily feeding on fallen pine seeds along the ridges within the park, while in summer the birds were found in areas such as Palm Glen and along the exposed, northern coasts that contain of high densities of invasive species, like red guava and African olive.

While minimal research has been published regarding the foraging patterns of crimson rosellas on Norfolk Island, there is literature that describes the species preferred habitat types on mainland Australia. The fundamental niche of crimson rosellas encompasses a wide array of habitat types, as detailed by Higgins (1999). In their native habitat on the eastern coasts of Australia crimson rosellas can be found at almost any altitude from subalpine forests down to sea level. Habitat types this species occupies include pristine woodlands and forests, human-altered environments (such as logged areas), riparian forests, and regenerating spaces. The habitat types with the highest occupancy of rosellas, as identified by Higgins, were older and wetter forests.

Published works that have documented the habitat types preferred by the crimson rosellas on Norfolk Island have mostly come from observational reports. The birds have been observed in almost all habitat types on Norfolk Island, and while they are most abundant inside of the park, they can also be found amongst houses and farmland, along the southern coast of the island, and on small islets close to the shore (Smithers and Disney 1969). Dutson (2013) conducted a study of Norfolk Island forest birds and found that higher rates of crimson rosellas were found in invasive, rather than native patches (Figure 3.2). Within the invasive vegetation Dutson had encountered no crimson rosellas in African olive (encounter rate=0, measured as records per point count), and only small numbers of rosellas in red guava (encounter rate=0.13).

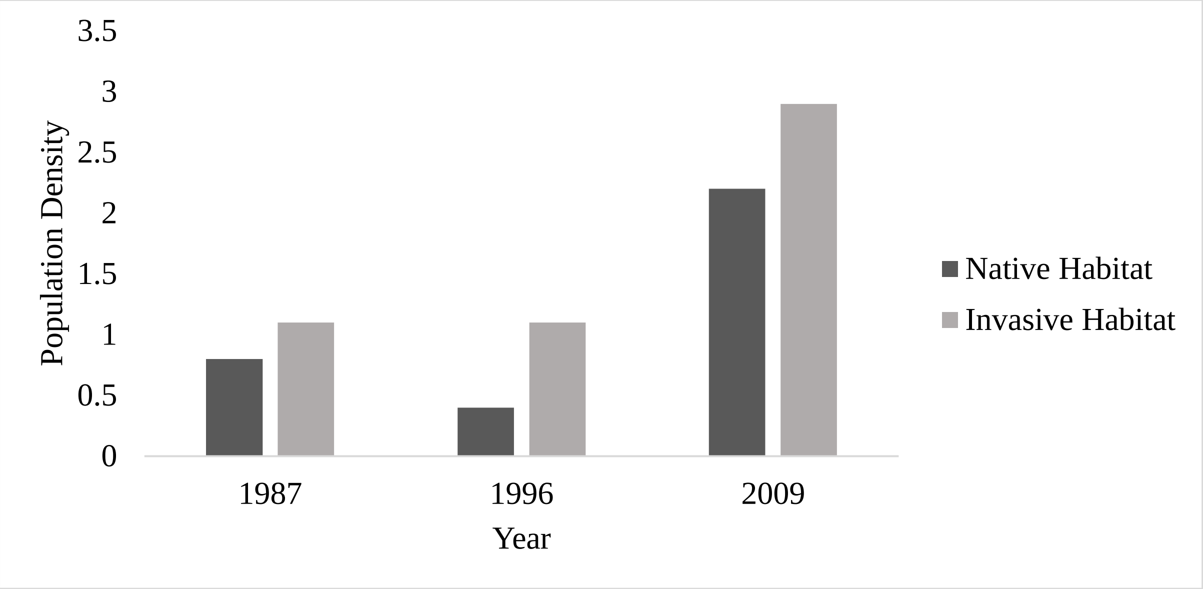


Figure 3.2. Population Density of Crimson Rosella in different vegetation types.

Data obtained from (Dutson, 2013).

Many of the dietary records of the crimson rosella are from mainland reports from the late 1970s to the 1990s. The records include data from a variety of habitat types, and provide information on plant species composition and what part of the plant that is eaten, such as leaves, sori, and bark (Magrath and Lill 1983, Recher, Holmes et al. 1985, Osborne and Green 1992). Eucalyptus has been recorded as the main component of the crimson rosella diet, along with the gall insect larvae found on *Eucalyptus* sp., *Acacia* sp. seeds, and *Dicksonia* fern sori (Bridgewater 1934, Magrath and Lill 1983). This research also demonstrates that there are seasonal changes to the diet of mainland crimson rosellas, with *Dicksonia antarctica* sori the key species in autumn (30.5%) and gall insect larvae and buds the key food resource in Winter (45.9%) (Magrath and Lill 1983). Seasonal changes in the diet of mainland birds have also been observed by Osborne and Green (1992) where the found that crimson rosellas will adjust their feeding habits response to the amount of snow present. To date there has been no published research that details the dietary composition or seasonal feeding behaviours of the crimson rosella on Norfolk Island.

By comparison, the Tasman parakeet has a dietary profile that is documented in both published articles and books (Forshaw and Cooper 1981, De la Motte and Hall 1988, Hicks and Preece 1991, Davidson 1997, Higgins 1999, Hill 2002, Waldmann 2016). Hill (2002) compiled the dietary research from Forshaw and Cooper (1981), Hicks and Preece (1991), and Davidson (1997) to create a list of the key items of an adult Tasman parakeet diet. These key food items were Norfolk pine, ironwood, Ti tree, niau, bloodwood and Norfolk Island hibiscus. Research has stated that while adults only occasionally consume African olive and red guava (Hill 2002) almost half the diet of juvenile Tasman parakeets comprised of the fallen seeds of African guava and red olive (Davidson 1997).

More recent research conducted by Waldmann (2016) found 30 species of plants comprised the diet of the Tasman parakeet, including nine invasive species (Figure 3.3). The five key food species that were identified during that research were Norfolk pine, African olive, niau, red guava, and ake ake. These plants comprised 88% of the feeding observations of this study (Waldmann 2016).

Figure 3.3. Some examples of Tasman parakeets feeding on invasive plant species, tobacco (*Solanum mauritianum*) (top), and wattle (*Leucaena leucocephala*) (bottom)

Gap in the knowledge

Assessing the degree of overlap in food resources and habitat use between the Tasman parakeet and the crimson rosella has important conservation implications as the former species exists in only one population and has a significantly low population size in comparison to the latter (Director of National Parks 2018, Skirrow 2018). While interactions regarding nest competition are well documented there is a gap in the current knowledge regarding the extent to which the Tasman parakeet and the crimson rosella share, and compete for, food resources in a limited space (Director of National Parks 2018).

The habitat data presented by Waldmann (2016) on the Tasman parakeet were from incidental observations and were limited to areas of public access only. The research highlighted the need for a systematic study to quantify the seasonal movements of this species across a wider range of their habitat. The aforementioned study conducted by Dutson (2013) is the only published research that describes the vegetation that the crimson rosellas inhabits on Norfolk Island. All other descriptions of their habitat are from observations only. To date there has been no published record of feeding species for the crimson rosella on Norfolk Island.

Most of the research on the Tasman parakeet has been on the composition of diet and population size (Dutson 2013, Waldmann 2016, Skirrow 2018). There is currently no published research that has quantified the degree of seasonal habitat preference for the Tasman parakeet across the Mount Pitt section of the Norfolk Island National Park, nor has there been any research that has compared the dietary requirements of the Tasman parakeet and the crimson rosella. The seasonal preference of habitat also remains undefined for the crimson rosella. Also currently unknown is the degree to which the seasonal movements of Tasman parakeets and crimson rosellas overlap and the similarity of habitat use between the two species.

Aims

According to the competitive exclusion theory (Hardin 1960), for the Tasman parakeet and the crimson rosella to co-exist in the same environment there must be some spatial or temporal measurable difference in the niche of the two species, whether it is the foods they consume, the food parts consumed, or how and when they use their habitat. The research presented in this chapter aims to provide the first assessment of interspecific competition for food resources between the Tasman parakeet and the crimson rosella. This research will also provide the first account of habitat preference and habitat use of both the Tasman parakeet and the crimson rosella. This research will aid in understanding if the habitat chosen by Tasman parakeets is by its own choice, or if it is a reflection of competitive avoidance with crimson rosellas. The specific objectives of this chapter are:

1. Quantify the seasonal variability, and the degree of overlap, of the diet of the Tasman parakeet and the crimson rosella
2. Quantify changes in inter-seasonal habitat preference and habitat use of Tasman parakeets and crimson rosellas
3. Determine if there is a significant overlap between Tasman parakeet niche and Crimson rosella niche

METHODS

This research was conducted across three seasons in 2017: summer, autumn, and spring. The summer collection was in March and was conducted over a two week period, the autumn collection was in May and was conducted over a three week period, and the spring collection was in October and November and was conducted over a two week period. The autumn and spring surveys followed systematic sampling methods (detailed below), while the data collected during summer was from incidental observations only whilst collecting data for Chapter 2. Data collected outside of the systematic survey periods was labelled 'non-survey' and was not used for statistical analysis.

Study site

While the Tasman parakeet has been observed in areas outside the NINP (Parr and Juniper 2010) we chose to limit our surveys to the park as that is where most of this parrots breeding and foraging occurs. The Forestry section of the NINP was included in this sample area as the eucalyptus stands have been observed providing habitat to the Tasman parakeet (Director of National Parks 2018).

The surveys were conducted across different transects within the park, which comprised of all visitor tracks, some bait lines, and some maintenance access paths. Access paths and bait lines that were located off of the visitor tracks were labelled as 'non-visitor transects'. A total of 27.8km of transects were chosen for this research (Figure 3.4), with 13.69km of those being visitor transects (Figure 3.4, dark grey) and 14.11km of those being non-visitor transects (Figure 3.4, light grey). There were 10 visitor transects that ranged from 0.47km to 2.5km in length and 11 non-visitor transects that ranged from 0.82km to 1.9km in length.

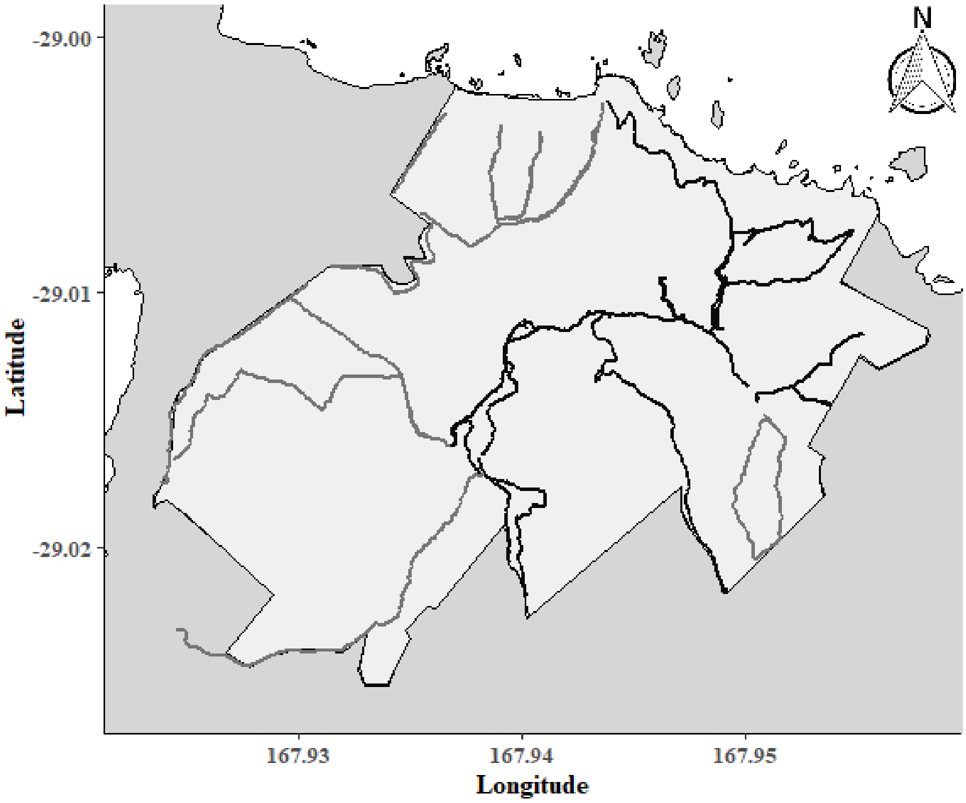


Figure 3.4. Norfolk Island National Park showing the visitor (dark grey) and non-visitor (light grey) tracks that were surveyed.

The paths that were chosen as transects passed through a representative of each of the nine habitat types that were identified in Chapter 2 and met safety and access requirements. The planning stage of this chapter identified that some of the potential transect lines that were too close to private property, were by cliff edges, or passed through other dangerous obstacles such as gullies, and so were excluded from the observation study.

All transects were surveyed between one and four times each season. To limit observing the same bird twice within a search session (and therefore collecting the same information twice) each transect was only surveyed once during each morning or afternoon session of the same day.

Data collection

Transects were surveyed at a slow walking speed (Approx. 3 km $^{\text{hour}}$) to ensure work effort was consistent across all transects and seasons. One to three observers walked the transects between 06:00-12:00 hours and 14:00 to 18:00 hours, corresponding with the peak activity time of the Tasman parakeets (Hill 2002, Waldmann 2016). In heavy rain and high winds no surveying was conducted due to low parrot activity, low visibility, and the safety of observers.

The visibility along each transect was dependent on the degree of thickness of the vegetation present. In areas that were predominantly comprised of invasive vegetation, such as red guava and African olive, the visibility was up to 5m. Visibility extended to approximately 15m-20m in hardwood, niau and fern patches, and up to 100m in open areas. If the bird was more than 1m from the edge of the path a range finder was used to accurately estimate the distance from the observer.

Surveys were conducted for both the Tasman parakeets and crimson rosellas concurrently to maximise the limited field time available. For each observation, regardless of species, the observer noted the GPS location using a Garmin GPS unit, transect name, time of day, and weather conditions. The observer also noted the species being observed, the size of the flock, and the bird’s state, that is, if they were flying, perching or on the ground, or feeding. To avoid psuedoreplication data that was collected during each observation was of the individual (or group) as it was first sighted. If the birds were flying the flight direction, and the distance and direction from the observer were recorded and if they were perching then height and perch species were identified. The behaviour of each individual upon sighting was noted, however this information was not used for subsequent analyses. If the individual was feeding upon first being observed, then the plant species, the part of the plant eaten (seeds, fruits, or leaves), and the approximate height they were feeding at, were all recorded.

The Tasman parakeets exhibit cryptic colouration (Figure 3.5, top), making them a difficult species to distinguish from a background of predominantly green vegetation in forest habitats. A combination of watching for movement, listening for calls, and listening for the cracking sounds of seeds were used to locate the birds. Contrastingly, crimson rosellas were easily distinguishable from the background as they have bright colours that contrast with their surrounds (Figure 3.5, bottom). Whilst easily observed at a distance, the flighty nature of the crimson rosella often resulted in the birds flying away if disturbed. Crimson rosellas were only approached if the feeding item was unable to be identified from a distance, with the observer moving slowly and quietly as to not disturb the birds.

Only visual observations were used for the analyses component of this research as feeding species and locations needed to be identified. Therefore audio observations were only used as a method for locating birds.

Figure 3.5. A male Tasman parakeet (top) feeds on fruits of the introduced tobacco (*Solanum mauritianum*) on the side of a road on Norfolk Island. A crimson rosella (bottom) perched on Norfolk pine (*Araucaria heterophylla*).

Photo: L. Ortiz-Catedral

Statistical analysis

Habitat use and selection preference

Observations made of birds in flight were not included in the analysis of habitat selectivity as the selection of birds within the habitat, not those passing through, was to be quantified.

To determine which habitat types that the Tasman parakeets and crimson rosellas were using we overlaid the GPS data of locations for both species with the habitat type data from Chapter 2. Each bird observation was assigned the habitat type of the closest relevé, as habitats were assumed continuous between sample locations (maximum distance of 50m), due to observations of vegetation cover in the field.

The design for the research presented in this chapter follows design 1, sampling protocol A (SPA) as laid out by Manly, McDonald et al. (2004). Design 1 details that habitat use shall be assessed for the population as a whole, as opposed to identifying individual animals. Sampling protocol A involves comparing a sample or census of available habitat to the used units of that resource. This design has the assumptions that no data is associated with individual animals, the proportions of available units are known for different resource categories, and the used resource units that are sampled are random.

Savage's selectivity index was used to quantify the relative selection and avoidance for the nine habitat types presented in Chapter 2, for the Tasman parakeet and the crimson rosella in autumn and spring, 2017 (Manly, McDonald et al. 2004). This index was calculated using the formula:

$$w_i=U_i/p_i$$

where w_i= the Savage selectivity index for the *i*th species, U_i= the proportion of observations recorded in the *i*th habitat, and p_i= the proportion of the *i*th habitat against the total available habitat. U_i is the number of units of category *i* in a sample of used units divided by the size of a sample of used resource units, while p_i is the number of available units in category *i* in a sample of available units divided by the size of a sample available resource units (Tella and Forero 2000). This index ranges from 0 to infinity, where 0 represents maximum avoidance, 1 represents no selection, and infinity represents maximum selection (Tella and Forero 2000).

The results of the selectivity index were standardised using Manly's Standardised Selection Index (B_i) in order for selection to be compared between seasons and bird species (Manly, McDonald et al. 2004). Manly's standardised selection index calculates the probability that the selected used resource is from the same category, assuming all categories are equally available with the same frequency. B_i was calculated using the formula:

$$B_i=w_i/\Sigma w_i$$

where B_i= Manly's standardised selection index, w_i= Savage's selectivity index, Σw_i= the sum of w_i across all values of n, where n=number of habitats available. A B_i of (1/*n*) represents no preference, with values below and above this representing avoidance or preference respectively (Manly, McDonald et al. 2004, Lardeux, Loayza et al. 2007).

The frequency of observations for each bird state (on the ground, perching, flying from a perch, or flying overhead) was quantified for both autumn and spring, for the Tasman parakeets and crimson rosellas.

Feeding ecology

For the statistical analyses of feeding observations, only those where the feeding species and feeding part were positively identified were use. Feeding species identified during on-survey sampling were compared between season and bird species. Feeding species identified during non-survey (summer, spring, and autumn) sampling were presented for both species to indicate further feeding species, however, these were not used for analysis purposes. The frequency of the part of the plant eaten (bark, fruit pulp, or seeds) was quantified for the autumn and spring seasons for both the Tasman parakeet and the crimson rosella.

The seasonal diversity of feeding species for Tasman parakeets and crimson rosellas was calculated using the complement of Simpson’s diversity. The Simpson’s complement (1-D) represents the probability that two individuals taken from within the same data set are different species. The Simpson’s complement was calculated using the formula:

$$1\text{-}D = 1 - \sum p_i^2$$

where $\sum p_i^2$ = the sum of the square proportions of feeding plants within that data set. A measure of evenness (E) was also obtained for the Tasman parakeet and the crimson rosella in autumn and spring, using the formula:

$$E = D/n$$

where D= Simpson’s diversity index, and n= the number of plant species fed on, also known as the D_{max}. The value of evenness ranges from $1/D_{max}$ to 1, where $1/ D_{max}$ indicates an unequal representation of feeding species within the sample, and 1 indicates a sample with an equal representation of feeding species within a sample.

The frequency of foraging height and flock size for each species within each season was quantified. As foraging height is an aspect of habitat use a t-test was conducted to determine if there was a significant difference between the foraging heights of each bird species, in the two sampling seasons. A t-test was also conducted between the two seasons for each bird species to determine if there was a significant difference in the seasonal foraging heights of the two bird species.

The variability of foraging height was determined for the Tasman parakeet and the crimson rosella in each season by calculating the coefficient of variation using the formula:

$$\hat{c}_v = \sigma / \mu$$

where σ= sample standard deviation, and μ= sample mean. This value was then expressed as a percentage.

RESULTS

In autumn the total length of visitor transects that were surveyed was 33.13km, and the total length of non-visitor transects that were surveyed was 24.19km. In spring the total length of visitor transects that were surveyed was 49.71km and the total length of non-visitor transects that were surveyed was 41.99km (Table 3.1).

Table 3.1. Transect lengths per season for on-survey observations only. Summer is excluded. V= visitor tracks, N= non-visitor tracks.

	Autumn		Spring	
	V (km)	N (km)	V (km)	N (km)
AM	26.81	12.98	29.43	19.6
PM	6.32	11.21	20.28	22.39
Total	*33.13*	*24.19*	*49.71*	*41.99*
Seasonal Total	*57.32*		*91.7*	
On- (*off-)* survey observations	122 (*132*)		210 (130)	

Non-survey observations were those made while moving between survey transects, and those made outside of research hours while moving about the park. During the summer survey there were 51 Tasman parakeet and 51 crimson rosella observations, all of which were non-survey. The autumn season consisted of 61 non-survey and 37 on-survey observations for the Tasman parakeet, and 71 non-survey and 85 on-survey observations for the crimson rosella.

The spring season consisted of 63 non-survey and 56 on-survey observations for the Tasman parakeet, and 67 non-survey and 154 on-survey observations for the crimson rosella.

Habitat preference

There were 35 observations of the Tasman parakeet during the autumn survey for which there was habitat data collected (Table 3.2). These observations were in three habitat types, forest edge, remnant *Araucaria*, and remnant hardwood. Tasman parakeet observations were highest in forest edge (n = 23), and lowest for remnant *Araucaria* (n = 5). For the autumn survey of the Tasman parakeet the threshold for preference was $B_i = 0.33$. The Tasman parakeet displayed a significant relative selection for remnant hardwood ($B_i = 0.51$, $X^2 = 6.86$, $p < 0.01$), and a significant relative avoidance for forest edge ($B_i = 0.29$, $X^2 = 4.89$, $p < 0.05$).

During the spring survey a total of 52 observations were made of the Tasman parakeet for which there were habitat data collected (Table 3.3). These observations were made within five habitat types, forest edge, olive forest, regenerating vegetation, remnant A*raucaria*, and remnant hardwood. As with the autumn survey, the majority of observations made were in the forest edge habitat type (n = 30). For the spring survey of the Tasman parakeet the threshold for preference was $B_i = 0.2$. Manly's standardised forage ratios indicated significant relative preference for remnant hardwood habitat ($B_i = 0.32$, $X^2 = 8.92$, $p < 0.001$).

During the autumn survey there were a total of 69 observations of the crimson rosella recorded for which habitat data was collected (Table 3.4). The crimson rosellas were observed in six habitat types: forest edge, forestry, niau forest, paddock, remnant A*raucaria*, and remnant hardwood. The majority of these observations were in the forest edge habitat (n = 53), with the remaining habitats having between 1 and 6 observations. For the autumn survey of crimson rosellas a Manly Index of B_i=0.17 indicated the threshold for preference. The results for the autumn survey indicated a significant relative preference for forest edge ($B_i = 0.34$, X^2

= 24.51, $p < 0.001$). Relative avoidance for forestry (B_i=0.06, X^2=3.36, p<0.1) and remnant *Araucaria* (B_i=0.10, X^2=3.11, p<0.1) were significant to an alpha level of 0.1.

During the spring survey there were a total of 130 observations of the crimson rosella (Table 3.5). The crimson rosellas were observed in all nine habitat types in spring, with the majority of observations in the forest edge habitat (n=89). The second most common habitat type for crimson rosellas was in remnant hardwood (n=17), followed by remnant *Araucaria* (n=15). The other habitat types had observations that ranged between one and three observations. The preference threshold for the spring survey of crimson rosellas was 0.11. The crimson rosella displayed significant selection for forest edge ($B_i = 0.25$, $X^2 = 23.89$, $p < 0.001$), remnant hardwood ($B_i = 0.28$, $X^2 = 4.56$, $p < 0.05$). The crimson rosella displayed significant relative avoidance for guava forest ($B_i = 0.03$, $X^2 = 8.70$, $p < 0.01$) and forestry ($B_i = 0.01$, $X^2 = 11.23$, $p < 0.001$).

In both autumn and spring the crimson rosella occupied more habitat types than the Tasman parakeet. In all overlapping habitat types in autumn, apart from forest edge, the Tasman parakeet displayed higher preference for those sites (Figure 3.6).

Table 3.2. Habitat selection for the Tasman parakeet for autumn.

m_i = available habitat, u_i= used habitat, π_i= proportion of available habitats, o_i= proportion of used habitats, w_i= Savage selectivity index, B_i= Manly selectivity index, X^2= chi-square. Preference threshold: B_i=0.33 (above= relative preference, below= relative avoidance).

Habitat type	m_i	u_i	π_i	o_i	w_i	B_i	SE	X^2
Forest edge	465	23	0.47	0.66	1.40	0.29*	0.18	4.89
Remnant *Araucaria*	146	5	0.15	0.14	0.97	0.20	0.41	0.01
Remnant hardwood	79	7	0.08	0.20	2.50	0.51**	0.57	6.86
Total	988	35			4.86	1.00		

Preference is significant when X^2 is greater than the critical value for X^2 at df=1

At α level of *0.05 X^2 = 3.84, **0.01 X^2 = 6.64, ***0.001 X^2 = 10.83

Table 3.3. Habitat selection for the Tasman parakeet for spring.

m_i = available habitat, u_i= used habitat, π_i= proportion of available habitats, o_i= proportion of used habitats, w_i= Savage selectivity index, B_i= Manly selectivity index, X^2= chi-square. Preference threshold: B_i=0.20 (above= relative preference, below= relative avoidance).

Habitat type	m_i	u_i	p_i	o_i	w_i	B_i	X^2
Forest edge	465	30	0.47	0.58	1.23	0.17	2.36
Olive forest	33	2	0.03	0.04	1.15	0.16	0.04
Regenerating	13	1	0.01	0.02	1.46	0.20	0.15
Remnant *Araucaria*	146	9	0.15	0.17	1.17	0.16	0.26
Remnant hardwood	79	10	0.08	0.19	2.41	0.32**	8.92
Total	988	52			7.42	1.00	

Preference is significant when X^2 is greater than the critical value for X^2 at df=1

At α level of *0.05 X^2 = 3.84, **0.01 X^2 = 6.64, ***0.001 X^2 = 10.83

Table 3.4. Habitat selection preference for the Crimson rosella in autumn.

m_i = available habitat, u_i= used habitat, π_i= proportion of available habitats, o_i= proportion of used habitats, w_i= Savage selectivity index, B_i= Manly selectivity index, X^2= chi-square. Preference threshold: B_i=0.17 (above= relative preference, below= relative avoidance).

Habitat type	m_i	u_i	p_i	o_i	w_i	B_i	X^2
Forest edge	465	53	0.47	0.77	1.63	0.34***	24.51
Forestry	92	2	0.09	0.03	0.31	0.06	3.36
Niau forest	53	2	0.05	0.03	0.54	0.11	0.83
Paddock	19	1	0.02	0.01	0.75	0.16	0.08
Remnant *Araucaria*	146	5	0.15	0.07	0.49	0.10	3.11
Remnant hardwood	79	6	0.08	0.09	1.09	0.23	0.05
Total	988	69			4.82	1.00	

Preference is significant when X^2 is greater than the critical value for X^2 at df=1

At α level of *0.05 X^2 = 3.84, **0.01 X^2 = 6.64, ***0.001 X^2 = 10.83

Table 3.5. Habitat Selection preference for the Crimson rosella in spring.

m_{i} = available habitat, u_i= used habitat, π_i= proportion of available habitats, o_i= proportion of used habitats, w_i= Savage selectivity index,

B_i= Manly selectivity index, X^2= chi-square. Preference threshold: B_i=0.11 (above= relative preference, below= relative avoidance).

Habitat type	m_i	u_i	p_i	o_i	w_i	B_i	X^2
Forest edge	465	89	0.47	0.68	1.45	0.25***	23.89
Forestry	92	1	0.09	0.01	0.08	0.01***	11.23
Guava forest	88	2	0.09	0.02	0.17	0.03**	8.70
Niau forest	53	3	0.05	0.02	0.43	0.07	2.39
Olive forest	33	1	0.03	0.01	0.23	0.04	2.66
Paddock	19	1	0.02	0.01	0.40	0.07	0.92
Regenerating	13	1	0.01	0.01	0.58	0.10	0.30
Remnant *Araucaria*	146	15	0.15	0.12	0.78	0.14	1.08
Remnant hardwood	79	17	0.08	0.13	1.64	0.28*	4.56
Total	988	130			5.77	1.00	

Preference is significant when X^2 is greater than the critical value for X^2 at df=1

At α level of *0.05 X^2 = 3.84, **0.01 X^2 = 6.64, ***0.001 X^2 = 10.83

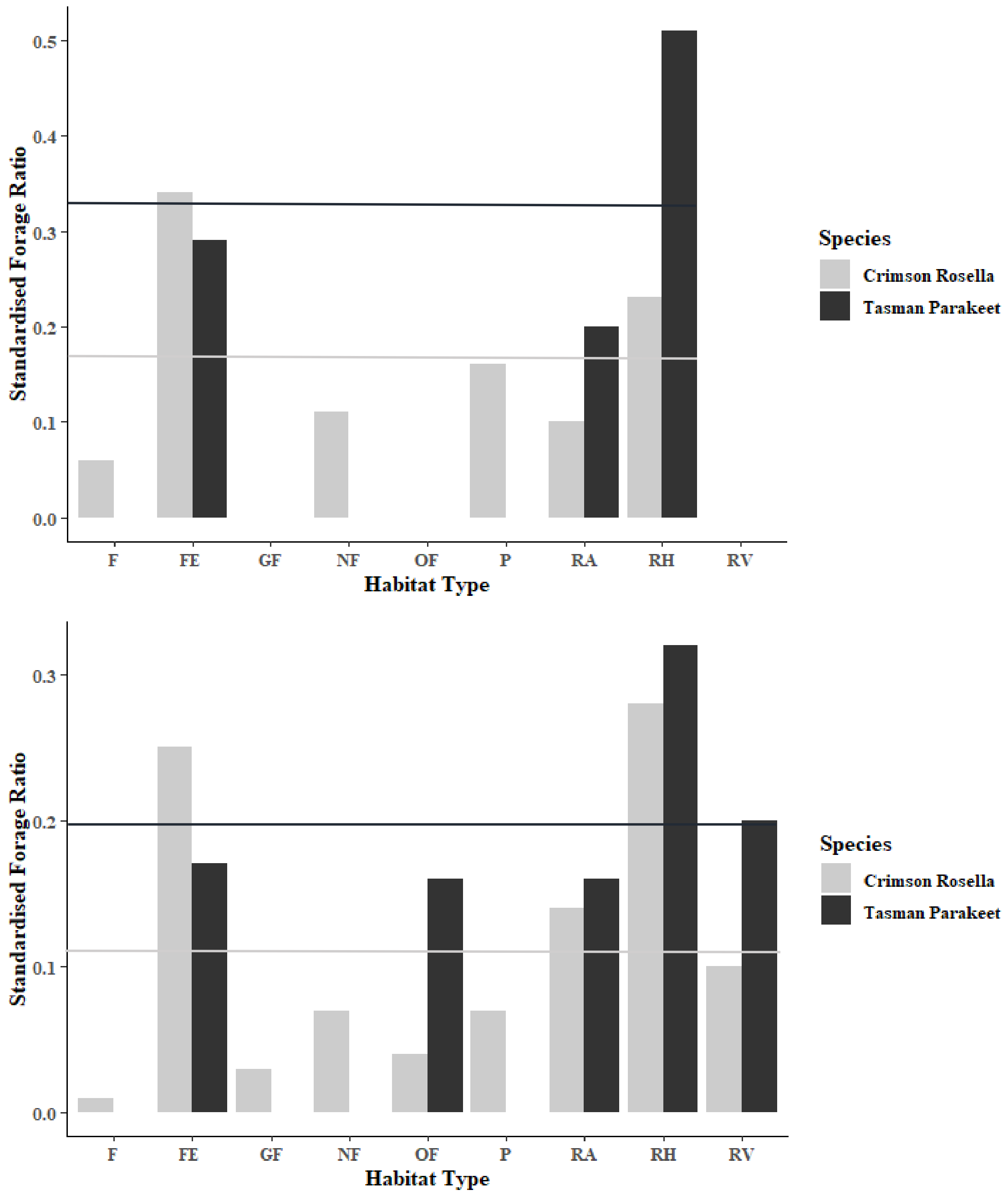


Figure 3.6. Habitat preference of the Tasman parakeet and crimson rosella in autumn (top) and spring (bottom).

Forage Ratio indicates relative preference for each habitat type. F= forestry, FE= forest edge, GE= guava forest, NF= niau forest, OF= olive forest, P= paddock, RA= remnant araucaria, RH= remnant hardwood, and RV= regenerating vegetation. The lines represent no preference for each species, above the line is relative selection, and below the line is relative avoidance.

Bird state

Tasman parakeets were observed perching more than any other state in both autumn (62%) and spring (75%). Crimson rosellas were observed flying overhead more than any other state in both seasons (60% autumn, 48% spring). Crimson rosellas would fly from their perch and fly overhead more than the Tasman parakeet in both seasons (Figure 3.7). In autumn, the Tasman parakeet was found on the ground more than the crimson rosella (TP=8%, CR=1%), however, in spring, the Tasman parakeets were not found on the ground at all (TP=0%, CR=3%).

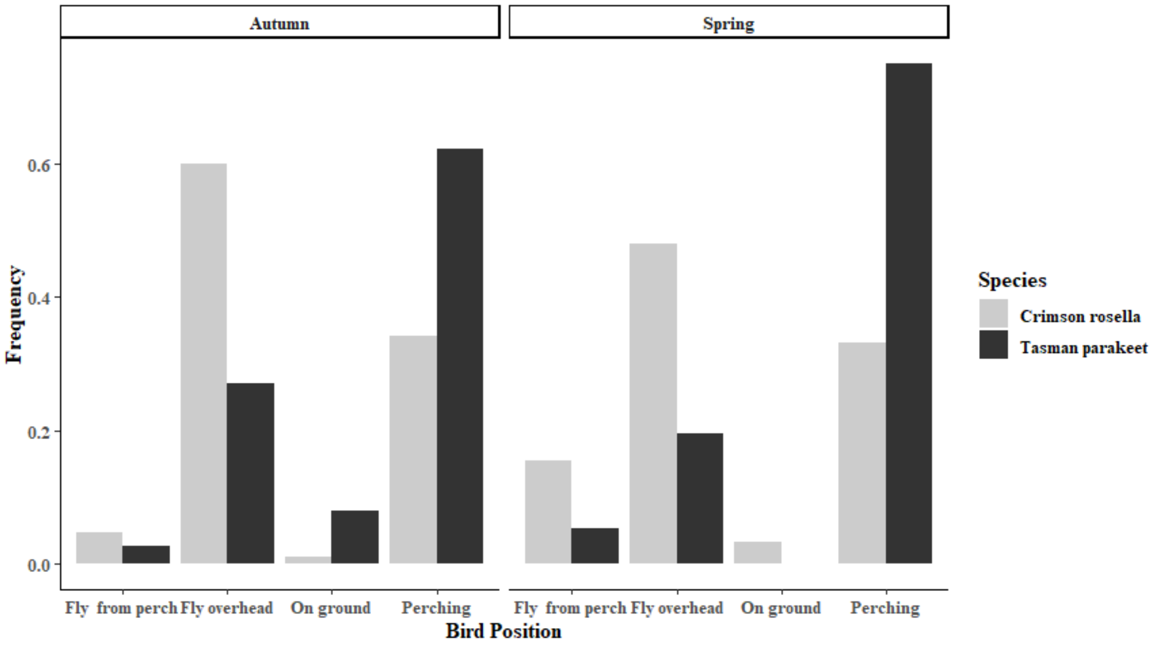


Figure 3.7. Bird state at first sighting.

Parrot feeding species

There were a total of 217 total observations of the Tasman parakeet, of those, 96 were of feeding observations. On-survey observations made up 38.5% of the feeding observations and were during autumn and spring only (n=37). There were a total of 377 observations of the crimson rosella, of which 34 were feeding observations. Of these feeding observations, 52.9% where on-survey collected during autumn and spring only (n=18).

During autumn both the Tasman parakeet and the crimson rosella would spend a majority of their time foraging in forest edge habitats (TP=64%, CR=67%), however, neither parrot had an overlap in the plant species that they were feeding on. During autumn the Tasman parakeets would feed on three species within two habitats. Norfolk pine was a feeding species that the Tasman parakeet would feed on in both habitats that it was observed in during autumn. Consequently, this plant species was also the most prominent in the autumn diet of the Tasman parakeet, making up 82% of the dietary species. Conversely, the crimson rosella fed on only one species, *eucalyptus* sp., within two habitat types (Table 3.6). During spring the both the Tasman parakeet and the crimson rosella shared three habitat types during foraging observations, forest edge, remnant hardwood, and remnant *Araucaria*. Forest edge habitat was the most foraged in habitat type during spring for both the Tasman parakeet and the crimson rosella, who each spent 57% of their time there. Furthermore, both parrots fed on the most plant species within this habitat type (TP=5, CR=3). Ake ake was the most common component of the spring diet for both parrot species (TP=75%, CR=58%), and was foraged upon in more habitat types than any other plant species during spring, for both the Tasman parakeet (habitats=4) and the crimson rosella (habitats=2) (Table 3.6). There were three on-survey observations of the Tasman parakeet in which the part eaten was unknown. The plant species these observations were made on were *Nestegis apetala* (autumn), *Araucaria heterophylla* (autumn), and *Baloghia inophylla* (spring). Crimson rosellas only had one on-survey observation where feeding part was unknown and this was on *Myrsine ralstoniae* in spring.

Non-survey observations were included in the results to present all dietary species observed during this research (Table 3.7). As can be seen from figures 3.9 and 3.10 the trend of species present remains the same between on-survey only (Figure 3.9), and all species present (Figure 3.10). There were species present in the off-survey observations, such as holly, maple (Figure 3.8) and red guava, which were not present in on-survey alone. During spring and summer the crimson rosellas and the Tasman parakeets had a large overlap of feeding species. In spring the Tasman parakeet and the crimson rosella shared three feeding species, with the Tasman parakeet feeding mostly on ake ake (86%), as did the crimson rosella (83%). During summer there was an overlap of two feeding species that the two birds shared. The majority of observations for both species were on red guava, which made up 84% of the Tasman parakeets summer diet and 96% of the crimson rosellas summer diet. The season in which there was the least overlap between the two parrots was autumn.

Figure 3.8. Crimson rosella feeding on holly fruits (left), maple fruits (right).

Photos: L. Ortiz-Catedral.

Table 3.6. All on-survey seasonal feeding species of the Tasman parakeet and the crimson rosella and the associated habitat types. Only using feeding observations where GPS data was present. Part eaten: S= seeds, F= fruit pulp, B= bark, U= unknown.

Season	Bird species	Habitat Type	Plant Species	Frequency	Part Eaten
Autumn	CR	Forest Edge	*Eucalyptus sp.*	0.67	S
		Forestry	*Eucalyptus sp.*	0.33	S
	GP	Remnant Hardwood	*Nestegis apetala*	0.09	U
			Araucaria heterophylla	0.18	U
			Myrsine ralstoniae	0.09	B
		Forest Edge	*Araucaria heterophylla*	0.64	S
Spring	CR	Remnant Hardwood	*Dodonea viscosa*	0.29	F
		Forest Edge	*Dodonea viscosa*	0.29	F
			Pittasporum bracteolatum	0.14	F
			Morus sp.	0.14	F
		Remnant Araucaria	*Myrsine ralstoniae*	0.14	U

GP	Forest Edge	*Dodonea viscosa*	0.33	S, F
		Baloghia inophylla	0.08	F, U
		Olea europaea	0.08	F
		Solanum mauritianum	0.04	F
		Leucaena leucocephala	0.04	S
	Remnant Araucaria	*Dodonea viscosa*	0.25	F, S
	Olive Forest	*Dodonea viscosa*	0.04	F
	Remnant Hardwood	*Dodonea viscosa*	0.13	F

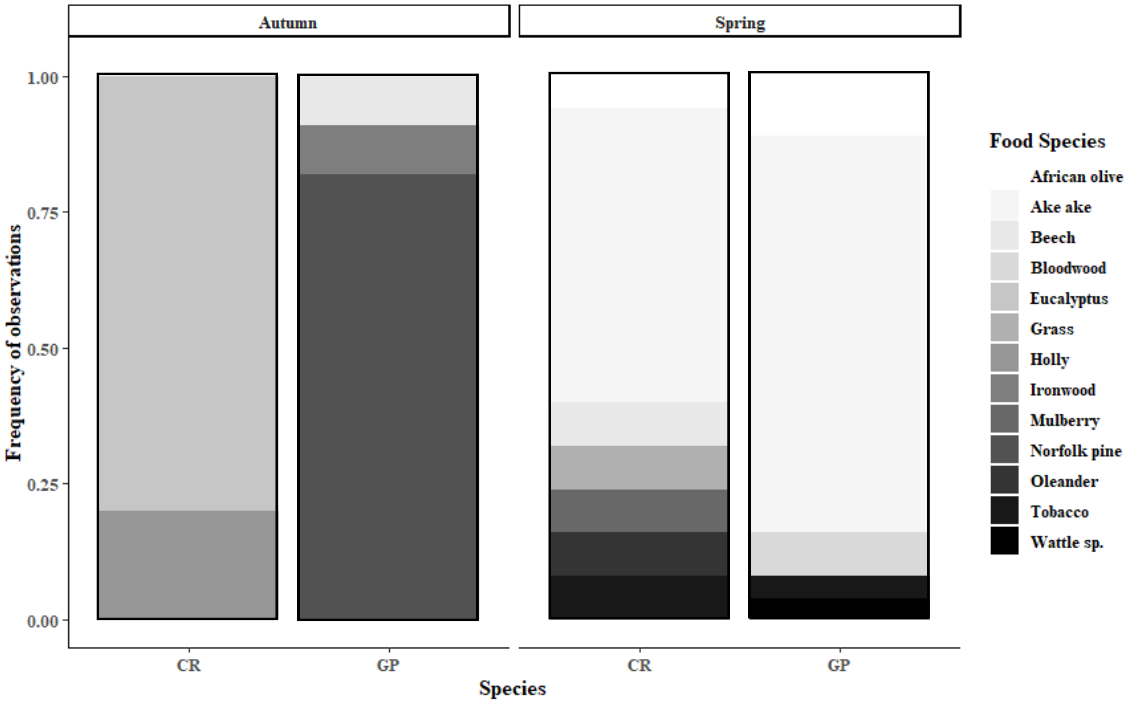


Figure 3.9. All on-survey feeding species during autumn and spring for the crimson rosella (CR) and the Tasman parakeet (GP)

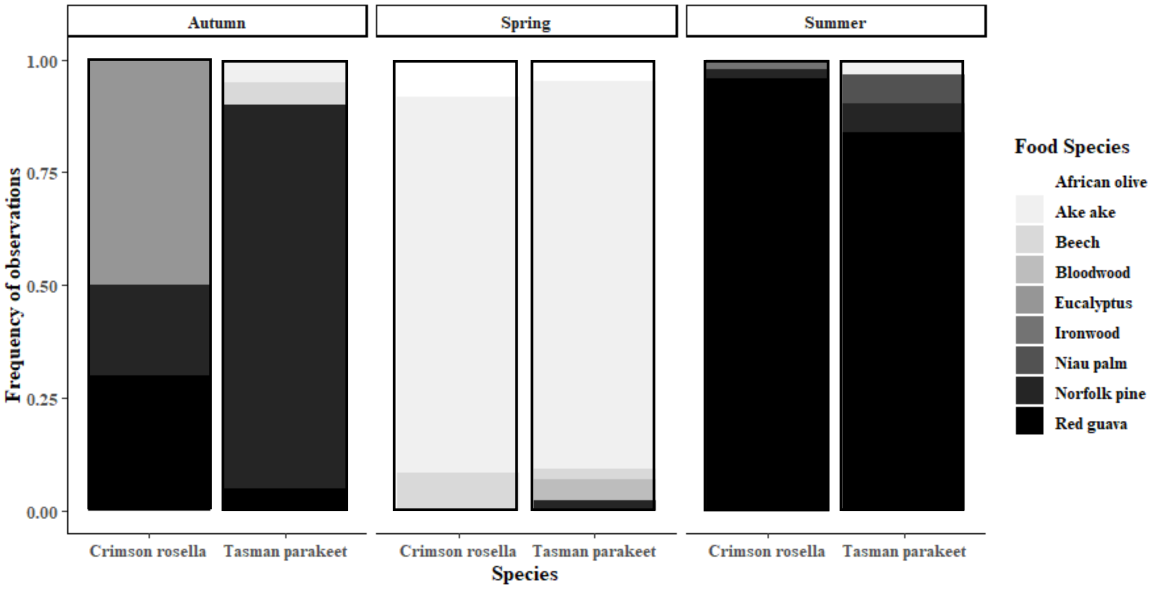


Figure 3.10. Top food species observed (on and off survey) across all three seasons for both the Tasman parakeet and the crimson rosella.

Table 3.7. Off-survey feeding observations of Tasman parakeets and crimson rosellas within the Norfolk Island National Park.

Season: S=summer, A=autumn, Sp=spring. Number of observations in brackets.

Plant Species	Tasman parakeet	Crimson rosella
Red guava	S (26), A (2)	S (46), A (3)
Ake ake	S (1), A (1), Sp (20)	Sp (3)
Lilac	S (1), Sp (2)	-
Maple	S (1)	-
Isaacwood	S (1)	-
Beech	S (1)	-
Peach	S (1), Sp (1)	-
Niau	S (2)	-
Schinus sp.	S (1)	-
Norfolk pine	S (2), A (24), Sp (1)	S (1), A (2)
Lichen sp.	Sp (1)	-
Tobacco	Sp (1)	-
Ironwood	Sp (1)	S (1), A (1)
Wattle	Sp (1)	-
Dianella intermedia	-	S (1)
Oplismenus hirtellus	-	S (1)
Lantana camara	-	Sp (1)
Grass	-	Sp (3)
Eucalyptus sp.	-	A (1)
Paspalum aviculare	-	S (1)

My results indicate a large overlap in the plant part consumed for both autumn and spring, for the Tasman parakeet and crimson rosella (Figure 3.11). In spring the crimson rosella diet was comprised of 82% fruit pulp and the Tasman parakeet diet was comprised of 87% fruit pulp. In autumn the crimson rosella diet contained 75% seeds and the Tasman parakeet diet contained 89% seeds. In autumn both species fed on the same two plant parts (during the on-survey transects): fruit pulp and seeds, while in spring each species fed on two plant parts, however they only shared consumption of one plant part, seeds, with the Tasman parakeet also consuming bark and the crimson rosella also consuming fruit pulp.

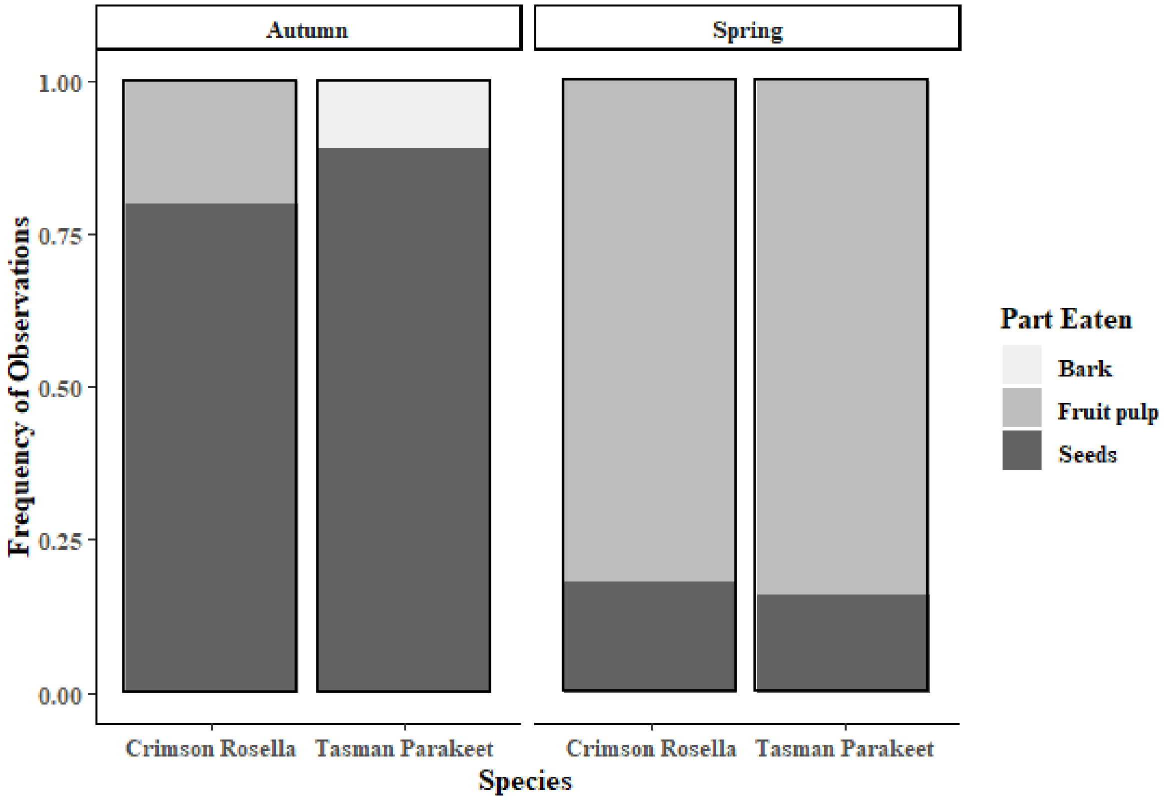


Figure 3.11. Plant part consumed on-survey by the crimson rosella and the Tasman parakeet within the Norfolk Island National Park during both seasons.

Both the Tasman parakeet and the crimson rosella fed on more species during spring than autumn. In both autumn and spring the crimson rosella has a more diverse diet than the Tasman parakeet, and both species exhibited higher diversity in their diets during spring (Table 3.8).

During spring there was a 67% likelihood that crimson rosella diet species were varied, while in autumn there was less than half of the amount of diversity present (1-D=0.67, 0.32 respectively). During spring the Tasman parakeet experienced higher diversity in their diet (1-D=0.44) as compared to autumn (1-D=0.31), however, the diversity of the Tasman parakeet diet was less than that of the crimson rosella diet for both seasons. The diet of the Tasman parakeet was more even in autumn (E=0.49), while the diet of the crimson rosella was more even in spring (E=0.44).

Forage height and flock size

There was no significant difference between the foraging heights during autumn, of the crimson rosella (μ=19.2m; σ=9.83m) and the Tasman parakeet (μ =10.5m, σ=7.72m); t(7)=1.73, p=0.13. There was also no significant difference between the foraging heights of the crimson rosella (μ =4.14m, σ=4.57) and the Tasman parakeet (μ =4.48m, σ=3.23m) during spring; t(21)=-0.24, p=0.81. The crimson rosella displayed a significant seasonal difference in its foraging height; t(5)=3.30, p=0.02. Likewise, the Tasman parakeet displayed a significant seasonal difference in its foraging height; t(10)=2.37, p=0.04. The average and maximum, heights were lower in spring than in autumn for both the Tasman parakeet and the crimson rosella (Figure 3.12, top). The crimson rosella displays both the highest and the lowest variability in foraging heights, the highest was in spring (c_v=110%) and the lowest was in

Table 3.8. Simpson's diversity indices for each season and each species

Season	Autumn		Spring	
Species	Tasman parakeet	Crimson rosella	Tasman parakeet	Crimson rosella
Species Richness (S)	3	2	5	7
Simpson's complement (1-D)	0.31	0.32	0.44	0.67
Evenness	0.49	0.29	0.36	0.44

autumn (c_v=51%). The Tasman parakeet has a similar variability in both autumn and spring (c_v= 74% and 72%) (Table 3.9).

Table 3.9. Forage height (m) of the Tasman parakeet and the crimson rosella during autumn and spring for on-survey observations only.

	Autumn		Spring	
	Crimson rosella	Tasman parakeet	Crimson rosella	Tasman parakeet
μ	19.2	10.5	4.14	4.43
Sample size	5	10	14	23
σ	4.40	2.44	1.22	0.66
Min	2	0	0	1.5
Max	26	25	14	13
Mode	NA	10	0	3
C_v	51%	74%	110%	72%

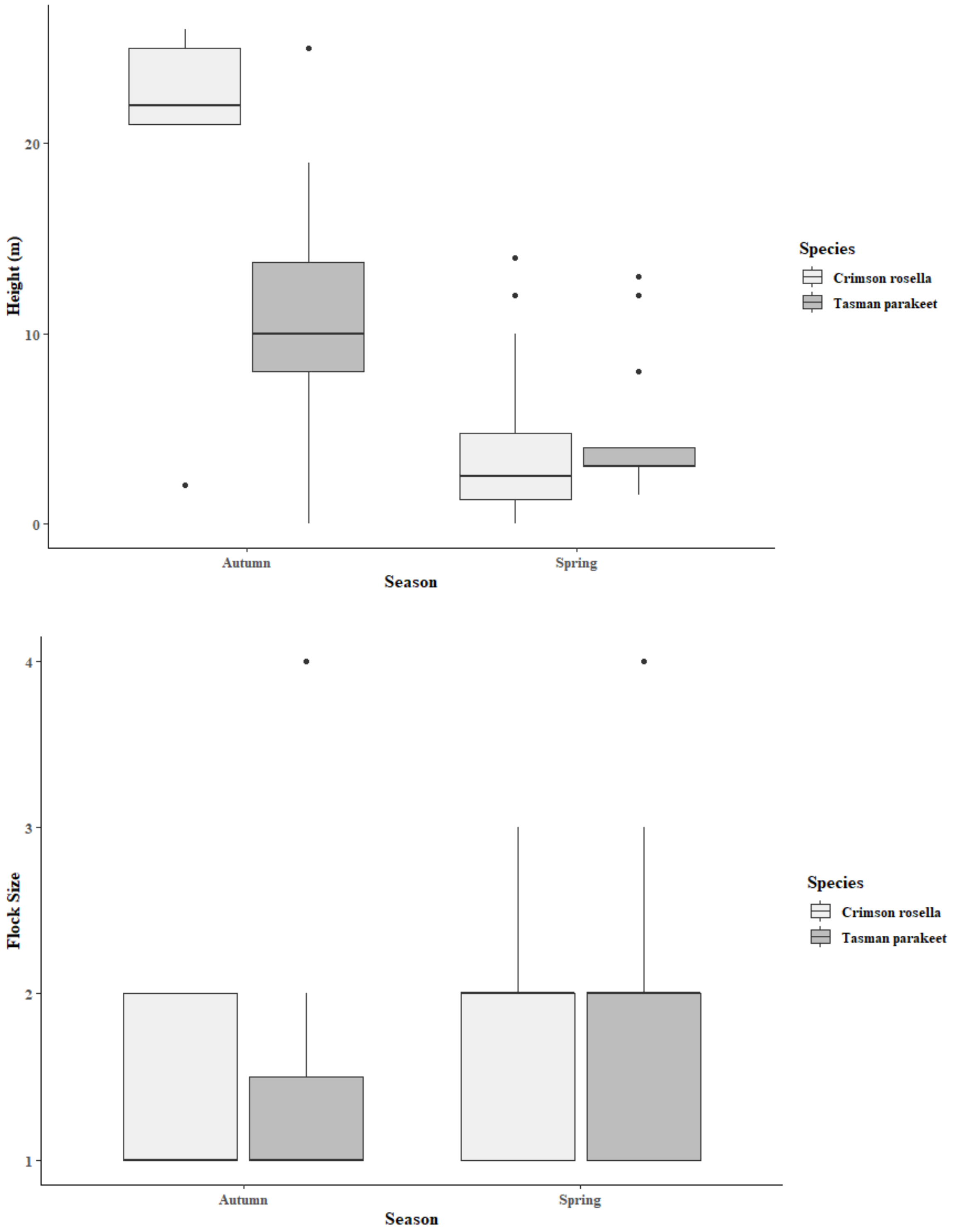


Figure 3.12. Average forage height (top) and flock size (bottom) for the Tasman parakeet and the crimson rosella in autumn and spring.

There was no significant difference during autumn between the flock size of the crimson rosella (μ =1.40, σ=0.55) and the Tasman parakeet (μ =1.45, σ=0.93); t(13)=-0.15, p=0.89, nor was there any significant difference in flock size during spring between the crimson rosella (μ =1.64, σ=0.63) and the Tasman parakeet (μ =1.69, σ=0.79); t(32)=-0.22, p=0.83. There was no significant difference in the seasonal flock size of the crimson rosella; t(8)=-0.82, p=0.44, nor was there a significant difference in the seasonal flock size of the Tasman parakeet; t(16)=-0.74, p=0.47 (Figure 3.12, bottom).

DISCUSSION

The literature available on parrot competition has mostly involved the competition between sympatric species for nesting sites and materials (Heinsohn, Murphy et al. 2003, Kearvell and Van Hal 2016). Literature that does identify patterns of competition for food sources are mostly of mainland species (Kearvell, Young et al. 2002), and therefore the competition for food resources of insular parrot species are underrepresented in the current literature. The Tasman parakeet is a critically endangered parrot that is extremely limited in its breeding range. As such, this species is highly affected by nesting competitors and predators (Director of National Parks 2018). While predator nest competitor control is a key goal of the NINP management plan (Director of National Parks 2018) little is understood on the effect these predators and nest competitors may have on the foraging behaviours of the Tasman parakeet.

The results of my study support those presented by Waldmann (2016) during a pilot study of the seasonal and temporal foraging behaviours of the Tasman parakeet. In that study Waldmann found that the Tasman parakeet exhibits clear seasonal patterns of habitat use within the NINP. While the Waldmann study presented data for four seasons, the current research only presents data for two. However, the sampling method by Waldmann used only incidental observations on visitor tracks, while my research used a method of systematic sampling over a larger area of the NINP.

The overlap of habitat use and foraging behaviours

The habitat preference for the Tasman parakeet does not exhibit a seasonal pattern, as in both seasons surveyed this species displayed a preference for remnant hardwood. In contrast, the habitat preference of the crimson rosella is seasonal, with the birds preferring forest edge in both seasons, remnant hardwood in spring only, while also displaying relative avoidance for guava forests and forestry in spring. The results that indicated relative avoidance for certain habitat types did not mean those habitats were not used, rather, that the use was relatively low in comparison to the use of other habitats by this species during that season.

Autumn presented the lowest overlap between the Tasman parakeets and the crimson rosellas as they neither fed on the same species, nor foraged in the same habitat, as seen both in the habitat preference analysis and that of the feeding species analysis. As the overlap of used habitats and feeding resources was significantly low during this season it has been shown that a high overlap in shared resources results in higher levels of interspecific interactions (Petersen, Savini et al. 2018). The two species displayed a high overlap in habitats used and species fed on during spring. During spring the parrots show a preference for hardwood habitats and they both feed on the fruits of ake ake in remnant hardwood and forest edge habitat types. These results indicate that not only is there likely to be competition for ake ake during spring, but this plant species is also a critical component of the seasonal diet for both Tasman parakeets and crimson rosellas, as the majority of feeding observations were on this plant species for both parrots.

Regenerating vegetation is a habitat type that comprises of a variety of native species, most of which were planted less than ten years ago. Across all 286 observations (all on-survey, both feeding and not feeding) regenerating vegetation was only chosen as a habitat twice, once by the Tasman parakeets in spring and once by the crimson rosellas in spring. This represents only 0.7% of the total observations for this research, indicating that regenerating vegetation is not a preferred habitat for either the Tasman parakeet or the crimson rosella. However, while this habitat type may not currently provide food, shelter, or nesting sites for the parrots, there is potential for preference once the trees have become established. As this habitat type does not provide any current benefit for the Tasman parakeet population conservation managers need to carefully assess the process of removing invasive species, of which the Tasman parakeet feeds on (Table 3.6, Table 3.7), to replace with young native species.

Forest edge is the habitat types that is chosen for the most out of any of the nine assessed habitat types. In autumn the Tasman parakeet was observed in this type 65.7% of the time, and the crimson rosella was observed 76.8% of the time, while in spring the Tasman parakeet was observed in this type 57.7% of the time and the crimson rosella 68.5% of the time. The presence of the parrots within this habitat type may be because forest edges are open habitats that may allow for easier observations of prey species. Out of the nine habitat types, forest edge is both the most common and most species rich habitat type, which could be another factor resulting in such a high abundance of parrot observations. The forest edges in the Norfolk Island National Park are largely due to the modification of the landscape, such as the cutting of paths for roads, visitor tracks and maintenance tracks. Some research indicates that species avoid humanly impacted habitats while other research indicates that species don’t seem to mind (Speziale, Lambertucci et al. 2008, Gurarie, Suutarinen et al. 2011). The high frequency of parrot observations within this habitat type could be an outcome of high foot traffic through forest edges, leading predator species to avoid these areas.

Bird state

The position that an individual bird takes within a habitat, perching or flying, can give an indication of its preference for that type of habitat. Two further categories, on the ground and flying from perch indicate selection for that particular habitat, however these two categories were not used as often as the former two. Many of the observations of Tasman parakeets were of the birds perching, while the majority of crimson rosella observations were made of the birds flying overhead. The flight nature of the crimson rosella is reinforced by results, as they were most often observed flying. If the individual was seen to be flying from its perch it often meant that it had been disturbed by the observer and no feeding observation could be made. Observations of individuals flying overhead did not indicate an avoidance for a certain habitat, rather that the birds were travelling between habitat types, however more research would need to be conducted to assess the flight patterns of each species and how that affects the birds habitat use. In autumn there were more records of both Tasman parakeets and crimson rosellas on the ground, as a likely reflection of the abundance of Norfolk pine seeds present on the ground during that season.

Forage height and flock size

One way species can partition resources and reduce interspecific competition is through the use of different foraging heights (Dziba, Scogings et al. 2003, Makhabu 2005). My research found that height is not a factor reducing interspecific competition in autumn or spring, with both the Tasman parakeet and the crimson rosella foraging at similar heights.

Research by Dutson (2013) estimated the mean group size of both crimson rosella and Tasman parakeet to be 2.0. My research found that the average flock size for Tasman parakeets and crimson rosellas was lower than 2.0 for both autumn (TP=1.45, CR=1.40) and spring (TP=1.69, CR=1.64), however during both autumn and spring there were observations where the flock size was higher, such as up to a flock size of four during autumn and spring for the Tasman parakeet and up to eight during spring for the crimson rosella.

Conclusions

My research identifies that there is a seasonal component to the habitat preference and foraging behaviours of the Tasman parakeet and the crimson rosella. While the two species share aspects of their behaviours, such as foraging height and spring feeding species, there are significant differences in the habitat that they feed on, the diversity and richness of their diets, and the parts of the plant eaten. While the crimson rosella does feed on some of the same plant species as the Tasman parakeet, it is not considered a significant overlap. However, the crimson rosella is an aggressive nest competitor (Director of National Parks 2018) and it is recommended that current management of this species should remain. With the high levels of pest management within the NINP the population size of the Tasman parakeet is increasing yearly (Skirrow 2018). As a consequence of continued rosella management more habitat options may become available to the Tasman parakeet population, which may decrease the need for the movement of this species out of the park and into the private fruit stock of nearby residents.

The results presented within this thesis can be of use in the conservation management of the critically endangered Tasman parakeet as it has identified both species and habitats that are critical for the survival of the species. While I identify that this species is a generalist in terms of diet I also note that some seasonal food species are of more importance than others, which may provide conservation managers with the information needed to protect such feeding species and ensure that these species are present at future relocation sites (see Chapter 4).

Limitations

There were less feeding observations of the crimson rosella as they are a flighty bird that will often fly away before you get close enough to see what they are consuming. Research by Magrath and Lill (1983) state that crimson rosellas drop debris whilst feeding and that this debris is an accurate representation of feeding species. To better understand the complete diet of the crimson rosella on Norfolk Island an analysis of debris located under feeding crimson rosellas could be included to ensure food species could be identified, even if the individual birds have flown away on approach of the researcher.

Only two seasons were systematically surveyed for bird observations, autumn and spring. Due to time constraints and the accessibility of the location we were not able to survey during summer and winter. We were also unable to survey in more than one year, and so we did not have more than one replicate in each season surveyed. Sampling all four seasons will be critical to creating a complete understanding of the seasonal importance of various food species.

Small sample sizes (less than 30 on-survey feeding observations of each bird in each season) may have led to results that aren’t significant. To obtain significant results analyses should be conducted on larger sample size of each species in each season, especially for forage height, part eaten, and habitat preference.

CHAPTER 4 : AVENUES FOR FUTURE RESEARCH

Figure 4.4.1. Lookout at sunrise from the Bridle Track.

Photo: L. Ortiz-Catedral

ABSTRACT

Historically, Tasman parakeets have undergone significant fluctuations in population size according to the degree of management targeting introduced species and shortages of safe nests. Despite intense management, several aspects of the biology of this island endemic remained unstudied. Since 2013, Tasman parakeets have increased steadily in numbers and important aspects of the biology of the species can be documented, to fine tune management and achieve more ambitious conservation milestones. Tasman parakeets co-exist with the introduced Crimson rosella within the Mount Pitt section if the Norfolk Island National Park and nearby private properties and reserves, although it has been suggested that Crimson rosellas strongly compete for resources with Tasman parakeets, there is only limited evidence of competition for feeding resources at present. Both species exhibit significant seasonal changes in patterns of habitat use and preferences. Likewise, both species show significant changes in food types and feeding species. In this Chapter, I present and discuss potential areas for future research including a component originally considered as part of this thesis, but that I could not develop in the field: the monitoring of translocated Tasman parakeets to Phillip Island to characterise their patterns of dispersal and habitat use. There is a range of topics that deserve attention including analyses of pathogen prevalence, the potential for human conflict and the nutritional requirements of Tasman parakeets. Together, these elements can assist the development of a second translocation attempt to Phillip Island to establish a self-sustaining population of Tasman parakeets. The breeding, feeding, and habitat use information that we can gain from the post-release monitoring of translocated parakeets would be invaluable, and would help to conserve and ensure the survival of this species.

INTRODUCTION

Tasman parakeets have increased in numbers thanks to the assisted nesting program implemented by staff from the Norfolk Island National Park, as discussed in Chapter 1 of this thesis. This management program has consisted of supplementing the Tasman parakeet with predator-safe nests, maintaining large-scale predator control and restoring key areas with native plant species (Ortiz-Catedral, Nias et al. 2018). These actions are fundamental for the long-term survival of the species. Prior to this research however, it was unclear whether Tasman parakeets strictly required forest remnants for foraging or if they used all available habitats equally, also it was unclear to what extent Tasman parakeets and Crimson rosellas overlapped in habitat use and feeding resources. Chapter 3 includes an analysis of habitat use and a comparison of food types and feeding species for Tasman parakeets and Crimson rosellas that address these topics. In this Chapter I discuss priority areas of research for an integrated management of the Tasman parakeet in the long-term. Recent successes on translocations of *Cyanoramphus* parakeets in New Zealand (Ortiz-Catedral and Brunton 2008, Brunton and Ortiz–Catedral 2009, Collen, Cash et al. 2014) have laid the basis for a translocation of the Tasman parakeet to Phillip Island, which is considered the next stage in the conservation of the species (Ortiz-Catedral, Nias et al. 2018). Species that exist in small and isolated populations face a higher risk of extinction as there is no option of migration or movement between populations (Hobbs, Jones et al. 2010, Weeks, Stoklosa et al. 2016). Factors that contribute to species loss include inbreeding, lack of migration, and exposure to disease and predators (Terrell, Crosier et al. 2016, DeVivo, Edmunds et al. 2017). One way to address this issue is by assessing viable locations for the translocation of suitable individuals (likely areas of closely related habitat, or areas where they were once known to exist) to create insurance populations (Rout, Baker et al. 2018). An insurance population is a proportion of a population of healthy individuals that has been translocated to an area that will help aid in the prevention of the total extinction of a species if any event was to occur in their native environment, such as a disease outbreak or a severe weather event (Ortiz-Catedral, Nias et al. 2018). A critical step in ensuring the survival of the Tasman parakeet is to establish an insurance population on nearby Phillip Island, as suggested in the 2010 Threatened Species Management Plan (Director of National Parks 2010, Ortiz-Catedral, Nias et al. 2018).

PHILLIP ISLAND: POTENTIAL FOR ECOLOGICAL RESTORATION

Phillip Island is the second largest of the Norfolk Island Group with 190 hectares of uninhabited land, comprised of many tuff and basal lava cliff valleys with few plateaus (Mills 2009, Coyne 2010). The island was included into the protected area of the Norfolk Island National Park in 1996 and under the Environment Protection and Biodiversity Conservation Act 1999 is considered a heritage site (Mills 2009). Phillip Island is an important area for biodiversity as it supports two native reptile species (*Christinus guentheri* and *Cyclodina lichenigera*) and an endemic centipede (*Cormocephalus coynei*). The survival of these species can be attributed to the absence of rats (*Rattus* spp) and cats (*Felis catus*) on the island (Mills 2009, Coyne 2010, Director of National Parks 2018). Phillip Island shares many of the same environmental characteristics as Norfolk Island, such as climate and soil structure, as they were formed from the same volcanic eruptions 3.1 and 2.3 million years ago that formed the Norfolk Ridge (Director of National Parks 2010). Prior to human settlement the Tasman parakeet was found throughout Norfolk Island, and possibly on Phillip Island (Hill 2002, Forshaw and Knight 2017). Phillip Island is located 6 km south of the coast of Norfolk Island, well within the flying and dispersing range of *Cyanoramphus* parakeets (Ortiz-Catedral 2009, Ortiz-Catedral, Ismar et al. 2009). Phillip Island was once covered with native vegetation similar to the subtropical rainforest found on Norfolk Island (Coyne 2010) including common tree species like Norfolk Island pine (*Araucaria heterophylla*), Norfolk Island palm (*Rhopalostylis baueri*) and Ironwood (*Nestegis apetala*) (Hill 2002, Mills 2009, Coyne 2010). When the first settlers arrived on Norfolk Island in the late 1700s they introduced pigs (*Sus scrofa*) to Phillip Island as a food resource. By 1830 both rabbits (*Oryctolagus cuniculus*) and goats (*Capra hircus*) were introduced as game (Coyne 2010). As these pests are all intensive browsers they removed the native vegetation cover of Phillip Island, causing erosion and leading to vast exposed areas of soil that can still be seen today (Figure 4.2). The lack of mechanical anchoring from tree roots would have likely exacerbated the effects of erosion on the top layers of soil on Phillip Island.

Pigs and goats were eradicated by the 1900s (Mills 2009, Coyne 2010), while rabbit eradication did not begin until 1953 when the *Myxoma* was introduced with little impact. By 1978 it was determined that rabbits were contributing to the decline of native flora and fauna and so intensive eradication began. A mix of poisoning and shooting had Phillip Island declared pest free in 1988 (Coyne 2010).

Figure 4.2. Phillip Island. Exposed soil on the hillsides of the island. The light green vegetation (top left) is African olive (*Olea europea*).

Photos: S. Simmonds and L. Ortiz-Catedral.

At present, no browsing pests remain on the island, but the ecological damage they caused is still tangible: the endemic Phillip Island glory pea (*Streblorrhiza speciosa*), has become extinct due to browsing feral pigs and rabbits (Melville 1969, De Lange and Murray 2001) and in some places up to two metres of soil was lost due to the lack of vegetation holding the soil in place (Mills 2009). In normal environmental conditions the root systems of Norfolk pines are underground, however, on Phillip Island some of the roots of these mature trees are exposed and give an example of where the topsoil has eroded (Figure 4.3**Error! Reference source not found.**).

Figure 4.3 Norfolk pine (*Araucaria heterophylla*) on Phillip Island showing loss of soil and exposed roots. Photo: S. Simmonds

Invasive plant species are widespread on Phillip Island. African olive (*Olea europea*) , one of the 60 exotic plant species that can be found on Phillip Island, is considered the most threatening. As mentioned in Chapter Two, the canopy of this species is so dense that it creates monoculture forests, preventing native species from growing underneath (Weber 2017). While it is a pest species, its root system helps to stabilise the loose topsoil to prevent further erosion (Director of National Parks 2018).

Since the eradication of browsers, the island has undergone revegetation that has seen the return of many flora species to the island including 17 native species. Current revegetation efforts continue and include weed management as well as the reintroduction of native flora (Director of National Parks 2010). Seabirds that bred on Phillip Island prior to the eradication of the browsers, such as the red-tailed tropic bird *(Phaethon rubricauda),* showed an increase in breeding individuals on the island post-eradication. Some birds that weren't previously known to breed on the island, such as the Kermadec petrel *(Pterodroma neglecta),* were recorded breeding after rabbit numbers had decreased (Coyne 2010). The present-day vegetation on Phillip Island was broadly assessed in 2013 and 2014 with the aim of determining whether the recovering patches of Norfolk Pine and White oak (*Lagunaria patersonii*) would provide feeding resources for Tasman parakeets (Ortiz-Catedral and Whitwell, pers. com.).

Despite obvious differences in vegetation structure between the Mount Pitt section of NINP and Phillip Island, the later has been suggested as a potential site for reintroduction of the Tasman parakeet at least since the 1970s (Forshaw 2002, Ortiz-Catedral, Nias et al. 2018). In 2014, following extensive discussions between staff from NINP, members of the Flora and Fauna Society of Norfolk Island, Island Conservation, BirdLife Australia and Massey University it was determined that the high fledgling survival of Tasman parakeets in the Mount Pitt section of NINP, would allow for a translocation of Tasman parakeets to Phillip Island. Having only one population restricted to a small area puts the species at risk if any disease outbreak was to occur or if predators, weather, or other events were to cause a population collapse. The Tasman parakeet, as detailed in previous chapters, has come close to extinction twice, with an estimated four breeding pairs in 1988 and six breeding pairs in 2006/7 (Garnett, Szabo et al. 2011, Ortiz-Catedral, Nias et al. 2018). Thus having a second population established on Phillip Island would be beneficial for this species as having an additional population would help to ensure the survival of this species in the unfortunate event something was to happen to the original population on Norfolk Island (Martin, Nally et al. 2012, Australian Government 2017, BirdLife Australia 2017). At the time I began my data collection, the translocation of Tasman parakeets to Phillip Island was planned using chicks of pre-fledging age soft-released into an aviary on site, based on experiences for translocating the closely related Red-fronted parakeet (*Cyanoramphus novaezelandiae*) in New Zealand (Collen, Cash et al. 2014).

Originally, this thesis project considered a field component on Phillip Island in the context of a recent reintroduction attempt of Tasman parakeet nestlings and from 2016-2017 (Jones 2016, Verhagen 2017). I planned a study to monitor the dispersal of fledglings and compare their patterns of habitat use on Phillip Island. This component was a significant element of my thesis (see Appendix A). In April 2017 eight pre-fledged juvenile Tasman parakeets were transferred successfully to Phillip Island, however shortly after their transfer the birds' health deteriorated and the attachment of radio-transmitters and subsequent monitoring of fledglings was cancelled. No further attempts have been made since to transfer Tasman parakeet juveniles or adults to Phillip Island. The causes behind the health deterioration of Tasman parakeet juveniles has not been established (Jones C. in litt.). Therefore research on potential pathogens and diseases is crucial before a second attempt to translocate parakeets to Phillip Island takes place.

PATHOGENS AND DISEASES

Pathogens and disease have the potential to be a key threatening process to island endemics that have not evolved to form resistances to them. One example of disease presented to a community that became disastrous was the spread of avian malaria (*Plasmodium relictum*) to the islands of Hawaii. Avian malaria only became transmissible through the accidental introduction of the southern house mosquito (*Culex quinquefasciatus*) to the island of Maui in 1826. This mosquito acts as a vector (carrier) for avian malaria, allowing the disease to spread quite quickly throughout the lowland areas (>600m) encompassed by the mosquito's habitat. This was the most probable cause of avian extinctions below the altitude of 600m (Warner 1968, Beadell, Ishtiaq et al. 2006, Atkinson and Samuel 2010). This example gives an image of just how damaging diseases can be in the absence of natural resistance and understanding.

Pathogens are viruses, microorganisms, or bacterium that cause disease and can prove fatal if contracted. There are two pathogens that have had a large impact on the flora and Psittacine populations present on Norfolk Island. The Tasman parakeet is affected by Psittacine Beak and Feather Disease (PBFD) and recent testing of chick and adult samples has revealed a prevalence of approximately 10% in the population (Ortiz-Catedral L. pers. comm.). PBFD is caused by the Beak and Feather Disease Virus (BFDV), a common circovirus found in numerous parrot species in the wild as well as captivity (Fogell, Martin et al. 2018). The family to which this pathogen belongs to contains the smallest known pathogens that infect animals and are usually host specific. Symptoms of this disease are caused by necrosis of the epidermal cells and include feather loss or deterioration, and deformities of the beak such as lengthening and breakages (Rahaus and Wolff 2003). This disease can either develop over time or have sudden onset, and has the potential to be fatal (Pass and Perry 1984, Department of the Enivronment and Heritage 2005).

There are three parrots listed by the Department of Environment (an extension of the Australian Government; hence the parrots listed are Australian species) as most at risk of this disease; the orange-bellied parrot (*Neophema chrysogaster*), the swift parrot (*Lathamus discolor*), and the Tasman parakeet (Department of the Enivronment and Heritage 2005, Das, Sarker et al. 2015). In these parrots this disease could be exaggerated because of their small population sizes, which are at risk if their food supply decreases or if there are changes to the habitat (Department of the Enivronment and Heritage 2005).

In a small population, like the Tasman parakeet on Norfolk Island, it is important to ensure that this disease does not become prevalent as any deaths of this species can seriously inhibit population growth. Increasing stress levels can increase the susceptibility of birds contracting the disease. On Norfolk Island, Tasman parakeets are placed under considerable stress during the breeding season as there are more males than females, most likely due to predation of females on the nest (Hill 2002, Ortiz-Catedral, Nias et al. 2018). Young birds have a higher likelihood of infection as the virus is excreted in faeces and feather dust, which is prevalent in a nest (Department of the Enivronment and Heritage 2005).

In 1976, PBFD caused the deaths of many crimson rosellas and in 1977 there was what appeared to be a Tasman parakeets with the disease (Hill 2002, Invasive Species Council and Island Conservation 2017). In 1995, the disease was confirmed in the Tasman parakeets as there was an outbreak within this species and the crimson rosellas, with two Tasman parakeets dying from the disease, both of which were captive birds (Hill 2002).

It is likely that many more birds carry the disease than are seen dying of it, as the symptoms are not always expressed. A study of kākāriki on Te Hauturu o Toi (Little Barrier) Island found that 28% of birds sampled (15 out of 54) contained the DNA of the PBFD, but only two individuals expressed any symptoms (Ortiz-Catedral, McInnes et al. 2009). Research conducted at Taronga Zoo prior to 2001 concluded that the entire population of Tasman parakeets contains the DNA of the disease but it is only expressed when the birds are under stress (Hill 2002). The Director of National Parks has stated that approximately 8% of Tasman parakeets studied are affected by PBFD (of a n=50 study size) (Director of National Parks 2018).

Due to the risk PBFD poses it is important to conduct thorough research into how many individual Tasman parakeets may have it. It is also critical to assess the population of crimson rosellas also, as this disease may pass from one species to the other. It is crucial that biosecurity measures prevent its spread into Norfolk Island and across to Phillip Island. Any birds considered for release to Phillip Island that do not show signs of PBFD may still be carriers, and as such, may still be at risk. The disease may be expressed in birds once they have been translocated and exposed to stress. Ensuring that PBFD does not become rampant in the Phillip Island population will be key to their survival in this new environment.

HUMAN CONFLICT WITH PARAKEETS

One of the results of recovering populations of threatened species, is their expansion into human habituated areas. An example is the New Zealand kaka (*Nestor meridionalis*) and its interactions with the residents surrounding the Zealandia Wildlife Sanctuary (henceforth Zealandia) in Wellington, New Zealand (Cote, Durand et al. 2013). A 2013 study conducted interviews and surveys with residents in the suburbs around the sanctuary and reported that 18% of those surveyed had damage to their roof structures, and 15% reported damage to trees on their property (Cote, Durand et al. 2013). This example demonstrates the need of careful planning when increasing the number of bird populations close to residential areas.

With the increase in population size of the Tasman parakeet over the last five years there has also been an increase in human interaction outside of their range within NINP. Over the course of my research I had the opportunity to talk to members of the public about these birds and many were excited to see the increase of numbers in the park, with some even seeing the birds on their properties (Figure 4.4). However, greater numbers of Tasman parakeets on local gardens on Norfolk Island can cause conflict with orchardists. In the early 1900s Tasman parakeets were shot by locals if they were caught eating and damaging fruit trees, which resulted in a reduced population size (Higgins 1999). The Lord Howe red-crowned parakeet was hunted to extinction due to their reputation as agricultural pests (Forshaw and Knight 2017). The species was last seen in 1869 (Higgins 1999, McAllan, Curtis et al. 2004).

The degree to which negative interactions between the residents of Norfolk Island and the Tasman parakeet could occur needs to be examined as the parakeet population is increasing, making it more likely that an increase in crop damage will occur. One suggestion is to place nets over trees to protect fruit crops, with one or two trees being left uncovered for the birds to eat, so they leave the protected trees alone. Conducting a survey and interviews in a similar way to address the impact of kaka in Wellington (Cote, Durand et al. 2013) will allow managers to understand the extent of the issue and to figure out appropriate ways to ensure a balance between the Tasman parakeet population and the local community.

Figure 4.4. Unripe peach fruit (*Prunus persica*) showing damage caused by a Tasman Parakeet (top left); a Tasman parakeet feeding on an unripe peach fruit (top right); a Tasman parakeet feeding on a peach stone (bottom left); Residents of a property neighbouring the Norfolk Island National Park indicating a peach tree regularly visited by Tasman parakeets. Photos: S. Simmonds and L. Ortiz-Catedral.

NUTRITIONAL ECOLOGY

My research assessed the different food resources available to the Tasman parakeet at different times of the year. Some of the information that we gathered included what part of the plant was fed upon by this species and included flowers, fruits and seeds. To understand how important different food items are, it is essential to understand how abundant they are in different times of the year and what nutritional value they provide to the birds. One aspect to consider is if the Tasman parakeets are choosing food species because of their accessibility or because of their abundance and nutritional value. Such information may contribute to understanding how their daily energy expenditure relates to energy gained from resources and how they may behave in absence of different food species.

There has been research that demonstrates a positive correlation between food abundance and species abundance, that is to say, the numbers of the target species in a given area will increase if food production increases (Stevenson 2001). Whilst conducting my research I observed that there was local variation in the fruiting development for some species of plants across the park. It is also likely that there is variation in how much fruit is provided by trees in different sections of the park.

Knowing how feeding patterns are linked with abundance of a feeding resource can help determine where birds may be in different times of the year, which may help provide an estimate of carrying capacity of the Norfolk Island National Park for the Tasman parakeet. If this population keeps increasing it is important to be aware of how many individuals the environment can sustain before the carrying capacity is reached.

Conducting phenology transects and calculating the diameter at breast height (DBH) of trees containing mature fruits can provide an estimate of abundance across an area (Chapman, Wrangham et al. 1994, Ragusa-Netto 2007). Determining the maturity of fruits across the phenology transects will also provide a measure of how abundance changes within species across the Norfolk Island National Park.

Pest management within the Norfolk Island National Park includes the removal of invasive plant species and the revegetation of certain areas with native species (Director of National Parks 2018). Two of the main invasive weeds that contribute to the diet of the Tasman parakeet are the red guava (*Psidium cattleianum*) and the African olive (*Olea europaea*) (Hill 2002, Waldmann 2016).

Creating a nutrition profile of the key food species for the Tasman parakeet will help with management decisions in regards to plant removal, supplementary feeding during a translocation, and revegetation. Key questions about their feeding behaviours can be answered with this research. If a high energy food was to be removed from the ecosystem would the birds be able to supplement this with a new food source or would they increase their uptake of an existing food? Do foods that they consume more of provide them with more energy or are they low energy foods chosen as they are highly abundant (Hill 2002)?

Previous research on the nutritional requirements of parrots has highlighted the importance of assessing the nutritional needs for a species, especially if it is to be held in captivity (Koutsos, Matson et al. 2001). A potential study would be to quantify the variation in fruit abundance of key Tasman parakeet food resources across the park, while assessing the nutritional content of those key resources. This study would contribute crucial information, not only about feeding resources for the Tasman parakeet, but also about the vegetative structure and composition of the park.

TRACKING AND DISPERSAL

A component of this thesis that did not occur for reasons outside of my control was the post-release monitoring of juvenile Tasman parakeets on Phillip Island. As detailed in this chapter, Phillip Island is an ideal location for the translocation of a small population of Tasman parakeets. A number of studies have examined aspects of Tasman parakeet biology and conservation including preferred diet, nest requirements and the most significant predators and competitors (Garnett, Szabo et al. 2011, Dutson 2013, Waldmann 2016). However, one aspect of their biology that is relatively unknown is the dispersal methodology in post-fledged juveniles.

Post-release monitoring is an important component of avian translocation as it allows managers to track long-term success, and to assess how the newly established population has responded to the translocation in regards to health and dispersal (Parker, Ewen et al. 2013). Due to the nature of the habitat and terrain at many translocation sites it can be difficult to find birds easily post-release, especially if individuals have dispersed away from the release site. Radio-tracking provides a way to find the birds in a time-efficient manner. The monitoring of juvenile dispersal can reveal critical information about factors that contribute to dispersal and survival between fledging and recruitment (Drummond 2017, Irwin 2017).

Studies have shown that most birds exhibit female biased dispersal, with the female dispersing over a greater distance, and males exhibiting philopatric tendencies (Clarke, Sæther et al. 1997). However, a study in the Zealandia on juvenile dispersal of a closely related species to the Tasman parakeet, the New Zealand kakariki, showed that they exhibited a male-biased post-fledgling dispersal method (Irwin 2017). This may prove an important aspect in understanding the biology of this species as there is an assumed sex-ratio imbalance in the Tasman parakeets, with more adult males than adult females, as evidenced by a low amount of breeding pairs (Hill 2002). Understanding if the dispersal system in this species is male or female biased could help in determining probable causes for the sex-ratio imbalance, and therefore could contribute in the increase of breeding pairs.

Juvenile Tasman parakeets tend to feed on the ground for up to five weeks, primarily on invasive species within the park (Hill 2002). This puts the young at risk of predators, such as feral cats (*Felis catus*), rats, and off-leash dogs (*Canis lupus familiaris*) (Hill 2002). Tracking juvenile dispersal may provide quantitative evidence of interactions between juvenile Tasman parakeets and those species that threatens them.

The tracking of adult Tasman parakeets may contribute towards creating a clearer picture of how this species utilises its environment. Information that can be gained from tracking adult birds can include: what influences the birds when choosing territories, mates and nest sites, where they go when they leave the park and what habitat corridors they use when travelling between patches of habitat outside of the park. Tracking adults may also lead researchers to find nesting sites outside of the park, if there are any, and ensure that they are protected. Tracking dispersal after a translocation can give crucial information about habitat use in a new environment, while also providing insight into possible causes of dispersal. This information can provide knowledge of species biology such as if dispersal a product of parental learning, if it is an effect of food and territory availability, or if it is an outcome of inter- and intra-specific competition.

Patterns of Tasman parakeet dispersal may not be limited to areas of high food availability, but may also depend predators and competitors, such as crimson rosella (*Platycercus elegans*) territories, black rat (*Rattus rattus*) densities and the presence of cats (Hill 2002). Management decisions for the Tasman parakeet have been determined through observation of the species in their current habitat, and through comparison with similar species as it is unknown how the these birds use their environment in absence of predators, competitors and introduced food resources (Higgins 1999, Director of National Parks 2018). Radio-tracking the dispersal of newly translocated Tasman parakeets will allow us to see if the juveniles use their habitat in a similar way to juveniles of comparable developmental stage living on Norfolk Island, or if on Phillip Island dispersal methods differ. Suggested methods of post-release monitoring include radio-tracking via tail or harness mount transmitters, locating birds using telemetry gear and geo-referencing to assess home-range. Bird identification should be collected along with monitoring perch and food species, pair bonding, and location. The vegetation composition should be analysed in a similar way to the methods set out in Chapter 2, however, less overall vegetation types would be needed as Phillip Island has a more homogenous pattern of vegetation than Norfolk Island.

If the avenues of research outlined in this chapter are undertaken it can provide critical information into the biology of the Tasman parakeet, including the availability of food resources in its habitat, the affect a growing population has on the residents of Norfolk Island, and what role pathogens play in the mortality of this species. These research opportunities will provide Tasman parakeet managers with the tools needed to ensure a continuing increase in population size, and to prevent any major population decrease.

Dispersal may also depend on appropriate nest sites available. Crimson rosellas were thought to be introduced to Norfolk Island as aviary pets in the 1830s and the first sighting of the European starling was in 1913 (Christian 2005, Director of National Parks 2010). It is likely that since their arrival on Norfolk Island these two species have been in competition with the Tasman parakeet for nests. The starlings fill the nests with materials that the Tasman parakeets find unattractive, and the crimson rosellas directly compete for nesting sites. The breeding season for the crimson rosella peaks between September and November. Consequently the breeding efforts of the Tasman parakeet will decrease during this time as the crimson rosellas react aggressively towards competitors within their territories (Hill 2002, Director of National Parks 2018).

Both the crimson rosella and the European starling are absent from Phillip Island. Radio-tracking of translocated juveniles once they come of breeding age would allow researchers to understand how the Tasman parakeet chooses nest sites in the absence of interspecific competitors. As these birds would be the first of their species on Phillip Island in recent history, it will also provide insight as to how the young choose sites in the absence of pre-claimed territories. It has been reported that the Tasman parakeet will occasionally nest in ground burrows, however, the presence of predators would cause most ground burrows to be unsuccessful. There is the chance that on Phillip Island they would find ground hollows and burrows to nest in and that they would be successful (Threatened Species Scientific Committee 2016).

Assessing the responses of the Tasman parakeet to differing food resource ecology is of equal importance in understanding the biology of this species. While the majority of the Tasman parakeet food resources can be found on Phillip Island, some of the plant species that comprise the diet on Norfolk Island are missing from the Phillip Island ecology. The Norfolk Island plant species that I observed the Tasman parakeet feeding on in the duration of my study, and the food species recorded in previous studies, that are present on Phillip Island can be seen in Table 2.4 (Higgins 1999, Waldmann 2016). Some of the key diet species of the Tasman parakeet that are absent from Phillip Island are native while others are invasive.

In the Norfolk Island Group there are 368 species of invasive plants and only 60 of these are found on Phillip Island. The *Norfolk Island National Park and Botanic Garden Management Plan 2018-2028* lists 11 key weed species that present the greatest threat to the natural biodiversity on Norfolk Island (Director of National Parks 2018). Only six of these are found on Phillip Island, three of which are food resources for the Tasman parakeet. African olive and (*Olea europaea*) and red guava (*Psidium cattlianum*) are considered two of the most prolific invasive species on Norfolk Island and they are both key components of the Tasman parakeet diet. The African olive is in abundance on Phillip Island while the red guava is absent. Other invasive species consumed by parakeets such as, wild tobacco (*Solanum mauritianum*) and lantana (*Lantana camara*), have been recorded in such low numbers on Phillip Island that they may have since been eradicated (Director of National Parks 2008, Mills 2009). Therefore they are not expected to be a key component of the diet of parakeets on Phillip Island.

Native plant species that are absent from Phillip Island that contribute to the diet of the Tasman parakeet include the ake ake (*Dodonea viscosa*), maple (*Elaeodendron curtipendulum*) and beech (*Myrsine ralstoniae*). Given that these species are key food resources for the Tasman parakeet it is important to assess how the birds behave in their absence. Radio-tracking of juvenile Tasman parakeets can answer some questions about diet choice and feeding behaviour: are these actually an important food species for the Tasman parakeet, or are they only consumed because they are available? Will the birds replace the absent food resources with a new food species or will they consume more of an already known food resource? Will there be any noticeable difference between the diet of the Norfolk Island birds and the Phillip Island birds, or will the majority of the diet remain the same?

REFERENCES

Alatalo, R. V., L. Gustafsson, M. Linden and A. Lundberg (1985). "Interspecific competition and niche shifts in tits and the goldcrest: an experiment." The Journal of Animal Ecology: 977-984.

Alcántara, J. M., J. L. Garrido and P. J. Rey (2019). "Plant species abundance and phylogeny explain the structure of recruitment networks."

Anderson, A. (1996). "Discovery of a prehistoric habitation site on Norfolk Island." Journal of the Polynesian Society 105(4): 479-486.

Anderson, A. (2001). "No meat on that beautiful shore: the prehistoric abandonment of subtropical Polynesian islands." International Journal of Osteoarchaeology 11(1-2): 14-23.

Anderson, A. and P. White (2001). The Prehistoric Archaeology of Norfolk Island, Southwest Pacific, Australian Museum Sydney.

Andren, H. (1994). "Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review." Oikos: 355-366.

Arlettaz, R. (1999). "Habitat selection as a major resource partitioning mechanism between the two sympatric sibling bat species Myotis myotis and Myotis blythii." Journal of Animal Ecology 68(3): 460-471.

Atkinson, C. T. and M. D. Samuel (2010). "Avian malaria Plasmodium relictum in native Hawaiian forest birds: epizootiology and demographic impacts on` apapane Himatione sanguinea." Journal of Avian Biology 41(4): 357-366.

Australian Government (2015). Threatened Species Strategy Action Plan 2015-16 20 birds by 2020. D. o. t. Environment.

Australian Government (2017). Saving one of the world's rarest birds. D. o. t. E. a. Energy.

Baker, J., K. J. Harvey and K. French (2014). "Threats from introduced birds to native birds." Emu 114(1): 1-12.

Beadell, J. S., F. Ishtiaq, R. Covas, M. Melo, B. H. Warren, C. T. Atkinson, S. Bensch, G. R. Graves, Y. V. Jhala and M. A. Peirce (2006). "Global phylogeographic limits of Hawaii's avian malaria." Proceedings of the Royal Society of London B: Biological Sciences 273(1604): 2935-2944.

Beier, P. (1993). "Determining minimum habitat areas and habitat corridors for cougars." Conservation Biology 7(1): 94-108.

Belder, D. J., J. C. Pierson, K. Ikin and D. B. Lindenmayer (2018). "Beyond pattern to process: current themes and future directions for the conservation of woodland birds through restoration plantings." Wildlife Research 45(6): 473-489.

Berg, Å., K.-O. Bergman, J. Wissman, M. Żmihorski and E. Öckinger (2016). "Power-line corridors as source habitat for butterflies in forest landscapes." Biological conservation 201: 320-326.

Best, M. (2007). "Norfolk Island: Thanatourism, history and visitor emotions." Shima: The International Journal of Research into Island Cultures 1(2): 30-48.

BirdLife Australia. (2017). "Operation Green Parrot." from https://www.pozible.com/project/operation-green-parrot.

Blackburn, T. M., P. Cassey, R. P. Duncan, K. L. Evans and K. J. Gaston (2004). "Avian extinction and mammalian introductions on oceanic islands." Science 305(5692): 1955-1958.

Blake, J. G. and B. A. Loiselle (2002). "Manakins (Pipridae) in second-growth and old-growth forests: patterns of habitat use, movement, and survival." The Auk: 132-148.

Bomford, M. and P. O'Brien (1995). "Eradication or control for vertebrate pests?" Wildlife Society Bulletin (1973-2006) 23(2): 249-255.

Boon, W. M., C. H. Daugherty and G. K. Chambers (2001). "The Norfolk Island green parrot and New Caledonian red-crowned parakeet are distinct species." Emu 101(2): 113-121.

Boon, W. M., J. C. Kearvell, C. H. Daugherty and G. K. Chambers (2001). "Molecular systematics and conservation of kakariki (Cyanoramphus spp.)." Science for Conservation 176: 1-46.

Bridgewater, A. (1934). "The food of Platycercus eximius and P. elegans." Emu-Austral Ornithology 33(3): 175-186.

Brooke, M. d. L., T. P. Flower and M. C. Mainwaring (2010). "A scarcity of females may constrain population growth of threatened bird species: case notes from the Critically Endangered Raso Lark Alauda razae." Bird Conservation International 20(4): 382-384.

Brunton, D. H., B. A. Evans and W. Ji (2008). "Assessing natural dispersal of New Zealand bellbirds using song type and song playbacks." New Zealand Journal of Ecology 32: 147-154.

Brunton, D. H. and L. Ortiz–Catedral (2009). "Notes on the diet of the critically endangered orange–fronted parakeet (Cyanoramphus malherbi) on Maud Island." New Zealand Journal of Zoology 36(4): 385-388.

Butchart, S. H., A. J. Stattersfield and N. J. Collar (2006). "How many bird extinctions have we prevented?" Oryx 40(03): 266-278.

Butchart, S. H., M. Walpole, B. Collen, A. Van Strien, J. P. Scharlemann, R. E. Almond, J. E. Baillie, B. Bomhard, C. Brown and J. J. S. Bruno (2010). "Global biodiversity: indicators of recent declines." 328(5982): 1164-1168.

Butler, D., T. Lindsay and J. Hunt (2014). Paradise saved: the remarkable story of New Zealand’s wildlife sanctuaries and how they are stemming the tide of extinction. Auckland, Random House

Byron, N. (2012). "National Park Forestry Zone."

Cafaro, P. (2015). "Three ways to think about the sixth mass extinction." Biological Conservation 192: 387-393.

Caldecott, J., M. Jenkins, T. Johnson and B. Groombridge (1996). "Priorities for conserving global species richness and endemism." 5(6): 699-727.

Carbone, C. and J. L. Gittleman (2002). "A common rule for the scaling of carnivore density." Science 295(5563): 2273-2276.

Cardinale, B. J., J. E. Duffy, A. Gonzalez, D. U. Hooper, C. Perrings, P. Venail, A. Narwani, G. M. Mace, D. Tilman and D. A. J. N. Wardle (2012). "Biodiversity loss and its impact on humanity." 486(7401): 59.

Centeno-Cuadros, A., P. Hulva, D. Romportl, S. Santoro, T. Stříbná, D. Shohami, A. Evin, A. Tsoar, P. Benda and I. Horáček (2017). "Habitat use, but not gene flow, is influenced by human activities in two ecotypes of Egyptian fruit bat (Rousettus aegyptiacus)." Molecular ecology 26(22): 6224-6237.

Chan, C., K. N. Ballantyne, H. Aikman, D. Fastier, C. H. Daugherty and G. K. Chambers (2006). "Genetic analysis of interspecific hybridisation in the world’s only Forbes’ parakeet (Cyanoramphus forbesi) natural population." Conservation Genetics 7(4): 493-506.

Chapman, C. A., R. Wrangham and L. J. Chapman (1994). "Indices of habitat-wide fruit abundance in tropical forest." Biotropica: 160-171.

Chase, D. A., E. E. Flynn and A. E. Todgham (2016). "Survival, growth and stress response of juvenile tidewater goby, Eucyclogobius newberryi, to interspecific competition for food." Conservation physiology 4(1).

Chase, J. M. and M. A. Leibold (2003). Ecological niches: linking classical and contemporary approaches, University of Chicago Press.

Christian, M. (2005). Norfolk Island: the Birds, Green Eyes Publications.

Clarke, A. L., B.-E. Sæther and E. Røskaft (1997). "Sex biases in avian dispersal: a reappraisal." Oikos: 429-438.

Cody, M. L. (2006). Plants on islands: diversity and dynamics on a continental archipelago, Univ of California Press.

Collar, N. (2000). "Globally threatened parrots: criteria, characteristics and cures." International Zoo Yearbook 37(1): 21-35.

Collar, N. and G. M. Kirwan. (2018). "Crimson Rosella (*Platycercus elegans*)." Handbook of the Birds of the World Alive, from https://www.hbw.com/node/54510.

Collen, R., B. Cash, L. Adams, L. Ortiz-Catedral, M. Booth, R. Gray, D. Fastier, K. Nakagawa and T. Ward-Smith (2014). Best practice techniques for the translocation of red-crowned parakeet (kākāriki, Cyanoramphus novaezelandiae novaezelandiae) and yellow-crowned parakeet (kākāriki, Cyanoramphus auriceps).

Comte, L., J. Cucherousset, S. Boulêtreau and J. D. Olden (2016). "Resource partitioning and functional diversity of worldwide freshwater fish communities." Ecosphere 7(6): e01356.

Cote, S., O. Durand, E. LaRoche and R. Warden (2013). "Evaluating the interactions between Wellington residents and the threatened kaka parrot." Prepared for Zealandia Wildlife Sanctuary. Worcester Polytechnic Institute.

Coyne, P. (2010). "Ecological rebound on Phillip Island, South Pacific." Ecological Management & Restoration 11(1): 4-15.

Coyne, P. (2011). Norfolk Island's Fascinating Flora, Peter Coyne.

Cuneo, P. and M. Leishman (2013). Ecological impacts of invasive African olive (Olea europaea ssp. cuspidata) in Cumberland Plain Woodland, Sydney, Australia.

Cuneo, P. and M. R. Leishman (2006). "African Olive (Olea europaea subsp. cuspidata) as an environmental weed in eastern Australia: a review." Cunninghamia 9(4): 545-577.

Cuneo, P., C. A. Offord and M. Leishman (2010). "Seed ecology of the invasive woody plant African olive (*Olea europaea* subsp. *cuspidata*): implications for management and restoration." Australian Journal of Botany 58: 342-348.

Das, S., S. Sarker, A. Peters, S. R. Raidal, A. Phillips, J. Forwood and B. St (2015). Psittacine beak and feather disease virus in wild orange-bellied parrots. Proceedings of Association of Avian Veterinarians Australasian Committee Ltd annual conference, Sydney.

Davidson, P. (1997). "Movements and behaviour of juvenile Green Parrots determined by radio-tracking." Unpub. report (Environment Australia, Canberra).

De la Motte, K. and E. Hall (1988). Report and Recommendations on the Norfolk Island Green Parrot Cyanoramphus Nocaezealandiae Cookii Captive Breeding Program, Taronga Zoo.

De Lange, P. and B. Murray (2001). "A new Achyranthes (Amaranthaceae) from Phillip Island, Norfolk Island group, South Pacific Ocean." New Zealand Journal of Botany 39(1): 1-8.

Department of the Enivronment (2019). Cyanoramphus cookii in Species Profile and Threats Database. D. o. t. Enivronment. Canberra.

Department of the Enivronment and Heritage (2005). Threat abatement plan for beak and feather disease affecting endangered psittacine species. DEH. Canberra.

DeVivo, M. T., D. R. Edmunds, M. J. Kauffman, B. A. Schumaker, J. Binfet, T. J. Kreeger, B. J. Richards, H. M. Schätzl and T. E. Cornish (2017). "Endemic chronic wasting disease causes mule deer population decline in Wyoming." PloS one 12(10): e0186512.

Director of National Parks. "Norfolk Island National Park and Botanic Garden: Phillip Island." from https://parksaustralia.gov.au/norfolk/pub/phillip.pdf.

Director of National Parks (2008). Norfolk Island National Park and Norfolk Island Botanical Garden management plan 2008-2018. A. Government. Canberra.

Director of National Parks (2010). Norfolk Island Region Threatened Species Recovery Plan. Department of the Environment, Water, Heritage and the Arts, Canberra.

Director of National Parks (2011). Norfolk Island National Park and Botanic Garden Climate Change Strategy 2011-2016. E. Department of Sustainability, Water, Population and Communities. Canberra.

Director of National Parks (2018). Norfolk Island National Park and Norfolk Island Botanic Garden

Management Plan 2018-2028. D. o. N. Parks. Canberra.

Doherty, T. S., A. S. Glen, D. G. Nimmo, E. G. Ritchie and C. R. Dickman (2016). "Invasive predators and global biodiversity loss." 113(40): 11261-11265.

Drummond, F. (2017). An integrated approach for predicting the fate of reintroduced populations: a thesis presented in partial fulfilment of the requirements for the degree of Masters of Science in Conservation Biology at Massey University, Palmerston North, New Zealand, Massey University.

Duelli, P., M. K. Obrist and P. F. Flückiger (2002). "Forest edges are biodiversity hotspots - Also for Neuroptera." Acta Zoologica Academiae Scientiarum Hungaricae 48(SUPPL. 2): 75-87.

Dutson, G. (2013). "Population densities and conservation status of Norfolk Island forest birds." Bird Conservation International 23(03): 271-282.

Dvoretsky, A. and V. Dvoretsky (2011). Interspecific competition of symbiotic and fouling species of red king crab in the Barents Sea. Doklady Biological Sciences, Springer.

Dziba, L., P. Scogings, I. Gordon and J. Raats (2003). "The feeding height preferences of two goat breeds fed Grewia occidentalis L.(Tiliaceae) in the Eastern Cape, South Africa." Small Ruminant Research 47(1): 31-38.

Edworthy, A. B., M. K. Trzcinski, K. L. Cockle, K. L. Wiebe and K. Martin (2018). "Tree cavity occupancy by nesting vertebrates across cavity age." The Journal of Wildlife Management 82(3): 639-648.

Ellis, E. C. (2013). "Sustaining biodiversity and people in the world's anthropogenic biomes." Current Opinion in Environmental Sustainability 5(3-4): 368-372.

Fagan, W. F., R. S. Cantrell and C. Cosner (1999). "How habitat edges change species interactions." The American Naturalist 153(2): 165-182.

Fahrig, L. (2003). "Effects of Habitat Fragmentation on Biodiversity." 34(1): 487-515.

Fan, P.-F., H.-L. Fei, M. B. Scott, W. Zhang and C.-Y. Ma (2011). "Habitat and food choice of the critically endangered cao vit gibbon (Nomascus nasutus) in China: implications for conservation." Biological Conservation 144(9): 2247-2254.

Favreau, F.-R., A. W. Goldizen, H. Fritz and O. Pays (2018). "Food supply fluctuations constrain group sizes of kangaroos and in turn shape their vigilance and feeding strategies." Animal Behaviour 135: 165-176.

Fogell, D. J., R. O. Martin, N. Bunbury, B. Lawson, J. Sells, A. M. McKeand, V. Tatayha, C. T. Trung and J. J. Groombridge (2018). "Trade and conservation implications of new beak and feather disease virus detection in native and introduced parrots." Conservation Biology 32: 1325-1335.

Ford, M. (2013). "Shoreline changes interpreted from multi-temporal aerial photographs and high resolution satellite images: Wotje Atoll, Marshall Islands." 135: 130-140.

Forshaw, J. and F. Knight (2017). Vanished and Vanishing Parrots: Profiling Extinct and Endangered Species, CSIRO PUBLISHING.

Forshaw, J. M. (2002). Australian Parrots, Avi-Trader Publishing.

Forshaw, J. M. (2010). Parrots of the World, Princeton University Press.

Forshaw, J. M. and W. T. Cooper (1981). Australian parrots, Howell Book House.

Galbraith, J. A. (2013). "Crimson rosella." New Zealand Birds Online, from www.nzbirdsonline.org.nz.

Galbraith, J. A. (2013). "Eastern rosella." New Zealand Birds Online, from www.nzbirdsonline.org.nz.

Ganzhorn, J. U., P. P. Lowry, G. E. Schatz and S. Sommer (2001). "The biodiversity of Madagascar: one of the world's hottest hotspots on its way out." Oryx 35(4): 346-348.

Garnett, S., J. Szabo and G. Dutson (2011). The action plan for Australian birds 2010, CSIRO publishing.

Garnett, S. T., L. P. Pedler and G. M. Crowley (1999). "The breeding biology of the glossy black-cockatoo Calyptorhynchus lathami on Kangaroo Island, South Australia." Emu 99(4): 262-279.

Gaze, P. and B. Cash (2007). A history of wildlife translocations in the Marlborough Sounds, Department of Conservation,[Nelson/Marlborough Conservancy].

Gil, A., Q. Yu, A. Lobo, P. Lourenço, L. Silva and H. Calado (2011). "Assessing the effectiveness of high resolution satellite imagery for vegetation mapping in small islands protected areas." 1663-1667.

Glennon, M. J. and W. F. Porter (1999). "Using satellite imagery to assess landscape-scale habitat for wild turkeys." 646-653.

Graham, M. and C. Veitch (2002). "Changes in bird numbers on Tiritiri Matangi Island, New Zealand, over the period of rat eradication." Turning the tide: the eradication of invasive species: 120-123.

Grueber, C. E., J. M. Maxwell and I. G. Jamieson (2012). "Are introduced takahe populations on offshore islands at carrying capacity? Implications for genetic management." New Zealand Journal of Ecology: 223-227.

Gurarie, E., J. Suutarinen, I. Kojola and O. Ovaskainen (2011). "Summer movements, predation and habitat use of wolves in human modified boreal forests." Oecologia 165(4): 891-903.

Haddad, N. M., L. A. Brudvig, J. Clobert, K. F. Davies, A. Gonzalez, R. D. Holt, T. E. Lovejoy, J. O. Sexton, M. P. Austin, C. D. Collins, W. M. Cook, E. I. Damschen, R. M. Ewers, B. L. Foster, C. N. Jenkins, A. J. King, W. F. Laurance, D. J. Levey, C. R. Margules, B. A. Melbourne, A. O. Nicholls, J. L. Orrock, D.-X. Song and J. R. Townshend (2015). "Habitat fragmentation and its lasting impact on Earth's ecosystems." 1(2): e1500052.

Hanski, I., A. Moilanen and M. Gyllenberg (1996). "Minimum Viable Metapopulation Size." The American Naturalist 147(4): 527-541.

Hardin, G. (1960). "The competitive exclusion principle." science 131(3409): 1292-1297.

Harper, G. J., M. K. Steininger, C. J. Tucker, D. Juhn and F. Hawkins (2007). "Fifty years of deforestation and forest fragmentation in Madagascar." 34(4): 325-333.

Harper, K. A., S. E. Macdonald, P. J. Burton, J. Chen, K. D. Brosofske, S. C. Saunders, E. S. Euskirchen, D. Roberts, M. S. Jaiteh and P. A. Esseen (2005). "Edge influence on forest structure and composition in fragmented landscapes." 19(3): 768-782.

Harris, L. D. (1984). The fragmented forest: island biogeography theory and the preservation of biotic diversity, University of Chicago press.

Hart, K. M., D. G. Zawada, A. R. Sartain and I. Fujisaki (2016). "Breeding loggerhead marine turtles Caretta caretta in Dry Tortugas National Park, USA, show high fidelity to diverse habitats near nesting beaches." Oryx 50(2): 283-288.

Hatase, H., K. Sato, M. Yamaguchi, K. Takahashi and K. Tsukamoto (2006). "Individual variation in feeding habitat use by adult female green sea turtles (Chelonia mydas): are they obligately neritic herbivores?" Oecologia 149(1): 52-64.

Hawkins, A. and K. Crawford (2018). "Interactions between plants and Soil Microbes may alter the Relative Importance of Intraspecific and Interspecific Plant Competition in a Changing Climate." AoB PLANTS.

Heinsohn, R., S. Murphy and S. Legge (2003). "Overlap and competition for nest holes among eclectus parrots, palm cockatoos and sulphur-crested cockatoos." Australian Journal of Zoology 51(1): 81-94.

Henderson, R. A., J. Meunier and N. S. Holoubek (2018). "Disentangling effects of fire, habitat, and climate on an endangered prairie-specialist butterfly,." Biological Conservation, 218: 41-48.

Hermes, N., O. Evans and B. Evans (1986). "Norfolk Island birds: a review 1985." Notornis 33(3): 141-149.

Herrera, M. and B. Hennessey (2007). "Quantifying the illegal parrot trade in Santa Cruz de la Sierra, Bolivia, with emphasis on threatened species." Bird Conservation International 17(4): 295-300.

Hicks, J. and M. Preece (1991). "Green Parrot. 1991 Recovery Plan." Unpublished Report. Australian Parks and Wildlife Service.

Higgins, P. (1999). "Handbook of Australian, New Zealand and Antarctic Birds: Parrots to Dollarbird. Vol. 4.,(Oxford University Press; Melbourne, Vic.)."

Hill, R. (2002). "National recovery plan for the Norfolk Island Green Parrot Cyanoramphus novaezelandiae cookii Caution: archived content."

Hobbs, J.-P. A., G. Jones and P. Munday (2010). "Rarity and extinction risk in coral reef angelfishes on isolated islands: interrelationships among abundance, geographic range size and specialisation." Coral Reefs 29(1): 1-11.

Hoekstra, J. M., T. M. Boucher, T. H. Ricketts and C. Roberts (2005). "Confronting a biome crisis: global disparities of habitat loss and protection." Ecology letters 8(1): 23-29.

Hooper, D. U., E. C. Adair, B. J. Cardinale, J. E. Byrnes, B. A. Hungate, K. L. Matulich, A. Gonzalez, J. E. Duffy, L. Gamfeldt and M. I. O'Connor (2012). "A global synthesis reveals biodiversity loss as a major driver of ecosystem change." 486(7401): 105.

Hořák, D., A. Tószögyová and D. Storch (2015). "Relative food limitation drives geographical clutch size variation in South African passerines: a large-scale test of Ashmole's seasonality hypothesis." Global Ecology and Biogeography 24(4): 437-447.

Hutton, I., J. Parkes and A. Sinclair (2007). "Reassembling island ecosystems: the case of Lord Howe Island." Animal Conservation 10(1): 22-29.

Iijima, H. and M. Ueno (2016). "Spatial heterogeneity in the carrying capacity of sika deer in Japan." Journal of Mammalogy 97(3): 734-743.

International, B. (2016). "Platycerus elegans." The IUCN Red List of Threatened Species 2016, from http://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22733483A95059107.en.

Invasive Species Council and Island Conservation (2017). Norfolk Island: Protecting an Ocean Jewel. Recommendations for stronger biosecurity for the Norfolk Island group. Fairfield, Victoria, Australia.

Irwin, E. (2017). Breeding biology and post-fledging dispersal of red-crowned parakeets (Cyanoramphus novaezelandiae) translocated to a fenced mainland sanctuary. Master of Science in Ecology and Biodiversity, Victoria University of Wellington.

Jetz, W., G. H. Thomas, J. B. Joy, D. W. Redding, K. Hartmann and A. O. Mooers (2014). "Global distribution and conservation of evolutionary distinctness in birds." Current biology 24(9): 919-930.

Johnson, T. and A. Stattersfield (1990). "A global review of island endemic birds." Ibis 132(2): 167-180.

Jones, C. (2016). Green parrots plan return to Phillip Island. The Norfolk Islander. Burnt Pine, Norfolk Island: 1-3.

Jones, H. P., N. D. Holmes, S. H. M. Butchart, B. R. Tershy, P. J. Kappes, I. Corkery, A. Aguirre-Muñoz, D. P. Armstrong, E. Bonnaud, A. A. Burbidge, K. Campbell, F. Courchamp, P. E. Cowan, R. J. Cuthbert, S. Ebbert, P. Genovesi, G. R. Howald, B. S. Keitt, S. W. Kress, C. M. Miskelly, S. Oppel, S. Poncet, M. J. Rauzon, G. Rocamora, J. C. Russell, A. Samaniego-Herrera, P. J. Seddon, D. R. Spatz, D. R. Towns and D. A. Croll (2016). "Invasive mammal eradication on islands results in substantial conservation gains." 113(15): 4033-4038.

Jones, J. and I. McDougall (1973). "Geological history of Norfolk and Philip islands, southwest Pacific Ocean." Journal of the Geological Society of Australia 20(3): 239-254.

Joseph, L., A. Toon, E. E. Schirtzinger and T. F. Wright (2011). "Molecular systematics of two enigmatic genera Psittacella and Pezoporus illuminate the ecological radiation of Australo-Papuan parrots (Aves: Psittaciformes)." Molecular Phylogenetics and Evolution 59(3): 675-684.

Joseph, L., A. Toon, E. E. Schirtzinger, T. F. Wright and R. Schodde (2012). "A revised nomenclature and classification for family-group taxa of parrots (Psittaciformes)." Zootaxa 3205(2): 26-40.

Joyce, L. J. (2008). Movement Patterns, Home Range and Habitat Selection by Kakapo (Strigops Habroptilus, Gray 1845) Following Translocation to Pearl Island, Southern New Zealand: A Thesis Submitted for the Degree of Doctor of Philosophy at the University of Otago, Dunedin, New Zealand, University of Otago.

Kearney, M. and W. P. Porter (2004). "Mapping the fundamental niche: physiology, climate, and the distribution of a nocturnal lizard." Ecology and Evolution 85(11): 3119-3131.

Kearvell, J. C. and J. Van Hal (2016). "Nest site selection by sympatric orange-fronted (Cyanoramphus malherbi) and yellow-crowned parakeets (C. auriceps) in Nothofagus spp. forest: interspecific competition between two closely related species?" Notornis 63(1): 9-17.

Kearvell, J. C., J. R. Young and A. D. Grant (2002). "Comparative ecology of sympatric orange-fronted parakeets (Cyanoramphus malherbi) and yellow-crowned parakeets (C. auriceps), South Island, New Zealand." New Zealand Journal of Ecology: 139-148.

Kennaway, T. A., E. H. Helmer, M. A. Lefsky, T. J. Brandeis and K. R. Sherrill (2008). "Mapping land cover and estimating forest structure using satellite imagery and coarse resolution lidar in the Virgin Islands." 2(1): 023551.

Kent, M. (2011). Vegetation description and data analysis: a practical approach, John Wiley & Sons.

Kerr, J. T. and M. Ostrovsky (2003). "From space to species: ecological applications for remote sensing,." Trends in Ecology & Evolution, 18(6): 299-305.

Kim, C. (2016). "Land use classification and land use change analysis using satellite images in Lombok Island, Indonesia." Forest Science and Technology 12(4): 183-191.

Koh, L. P. and S. A. Wich (2012). "Dawn of drone ecology: low-cost autonomous aerial vehicles for conservation." 5(2): 121-132.

Kohn, D. and D. Walsh (1994). "Plant species richness--the effect of island size and habitat diversity." Journal of Ecology: 367-377.

Koutsos, E. A., K. D. Matson and K. C. Klasing (2001). "Nutrition of birds in the order Psittaciformes: a review." Journal of Avian Medicine and Surgery 15(4): 257-275.

Kudo, G., T. Y. Ida and T. Tani (2008). "Linkages between phenology, pollination, photosynthesis, and reproduction in deciduous forest understory plants." Ecology and Evolution 89(2): 321-331.

Lande, R. (1993). "Risks of population extinction from demographic and environmental stochasticity and random catastrophes." The American Naturalist 142(6): 911-927.

Lande, R. and G. F. Barrowclough (1987). "Effective population size, genetic variation, and their use in population management." Viable populations for conservation 87: 124.

Lardeux, F., P. Loayza, B. Bouchité and T. Chavez (2007). "Host choice and human blood index of Anopheles pseudopunctipennis in a village of the Andean valleys of Bolivia." Malaria journal 6(1): 8.

Laurance, W. F., T. E. Lovejoy, H. L. Vasconcelos, E. M. Bruna, R. K. Didham, P. C. Stouffer, C. Gascon, R. O. Bierregaard, S. G. Laurance and E. Sampaio (2002). "Ecosystem Decay of Amazonian Forest Fragments: a 22-Year Investigation." 16(3): 605-618.

Levey, D. J. (1988). "Spatial and temporal variation in Costa Rican fruit and fruit-eating bird abundance." Ecological monographs 58(4): 251-269.

Lindenmayer, D. B., R. B. Cunningham, C. F. Donnelly and R. Lesslie (2002). "On the use of landscape surrogates as ecological indicators in fragmented forests." Forest Ecology and Management 159(3): 203-216.

López-Alfaro, C., S. C. P. Coogan, C. T. Robbins, J. K. Fortin and S. E. Nielsen (2015). "Assessing Nutritional Parameters of Brown Bear Diets among Ecosystems Gives Insight into Differences among Populations." PLoS ONE 10(6): 1-28.

Losos, J. B. and R. E. Ricklefs (2009). The theory of island biogeography revisited, Princeton University Press.

Lowe, S., M. Browne, S. Boudjelas and M. De Poorter (2000). "100 of the world's worst invasive alien species: a selection from the global invasive species database."

Lu, D. and Q. Weng (2007). "A survey of image classification methods and techniques for improving classification performance." International Journal of Remote Sensing 28(5): 823-870.

MacArthur , R. H. and E. O. Wilson (1967). The Theory of Island Biogeography. Princeton, Princeton University Press.

Magrath, R. and A. Lill (1983). "The Use of Time and Energy by the Crimson Rosella in a Temperate Wet Forest in Winter." Australian Journal of Zoology 31(6): 903-912.

Maitland, M. (2011). Tawharanui Open Sanctuary—detection and removal of pest incursions. Island Invasives: Eradication and Management Proceedings of the International Conference on Island Invasives. Gland, Switzerland: IUCN and Auckland, New Zealand: CBB2011.

Makhabu, S. W. (2005). "Resource partitioning within a browsing guild in a key habitat, the Chobe Riverfront, Botswana." Journal of Tropical Ecology 21(6): 641-649.

Manly, B., L. McDonald, D. L. Thomas, T. L. McDonald and W. P. Erickson (2004). Resource selection by animals: statistical design and analysis for field studies, Springer Science & Business Media.

Margrath, R. and a. Lill (1985). "Age-related Differences in Behaviour and Ecology of Crimson Rosellas, Platycercus elegans, during the Non-Breeding Season." Wildlife Research 12(2): 299-306.

Martin, T. G., S. Nally, A. A. Burbidge, S. Arnall, S. T. Garnett, M. W. Hayward, L. F. Lumsden, P. Menkhorst, E. McDonald-Madden and H. P. Possingham (2012). "Acting fast helps avoid extinction." Conservation Letters 5(4): 274-280.

Martin-Queller, E., C. H. Albert, P. Dumas and A. Saatkamp (2017). "Islands, mainland and terrestrial fragments: how isolation shapes plant diversity." Ecology and Evolution 7: 6904-6917.

Matuzak, G. D., M. B. Bezy and D. J. Brightsmith (2008). "Foraging ecology of parrots in a modified landscape: seasonal trends and introduced species." The Wilson Journal of Ornightology 120: 353-365.

McAllan, I. A., B. R. Curtis, I. Hutton and R. M. Cooper (2004). "The birds of the Lord Howe Island Group: a review of records." Australian Field Ornithology 21.

McCallum, M. L. (2015). "Vertebrate biodiversity losses point to a sixth mass extinction." Biodiversity and Conservation 24(10): 2497-2519.

McLean, I., C. Hölzer and P. M. Sagar (1994). "Niche overlap and foraging ecology of island Petroica species." Notornis 41: 39-48.

Medina, F. M. and M. Nogales (2009). "A review on the impacts of feral cats (Felis silvestriscatus) in the Canary Islands: implications for the conservation of its endangered fauna." Biodiversity and Conservation 18(4): 829-846.

Melville, R. (1969). "The endemics of Phillip island." Biological Conservation 1(2): 170-172.

Michielsen, N. C. (1966). "Intraspecific and interspecific competition in the shrews Sorex araneus L. and S. minutus L." Archives Neerlandaises de Zoologie 17(1): 73-174.

Mihuc, T. B. (1997). "The functional trophic role of lotic primary consumers: generalist versus specialist strategies." Freshwater biology 37(2): 455-462.

Mills, K. (2009). "The Vegetation of Phillip Island, Norfolk Island Group." Report for Australian Government Envirofund.

Mills, K. (2010). "Defining indigenous plants: some problematic species from Norfolk Island." Cunninghamia 11(4): 407-412.

Miskelly, C. M. and R. G. Powlesland (2013). "Conservation translocations of New Zealand birds, 1863–2012." Notornis 60: 3-28.

Molnár, T., T. Magura, B. Tóthmérész and Z. Elek (2001). "Ground beetles (Carabidae) and edge effect in oak-hornbeam forest and grassland transects." European Journal of Soil Biology 37(4): 297-300.

Montejo-Kovacevich, G., M. G. Hethcoat, F. K. S. Lim, C. J. Marsh, D. Bonfantti, C. A. Peres and D. P. Edwards (2018). "Impacts of selective logging management on butterflies in the Amazon." Biological Conservation 225: 1-9.

Moran, M. D., A. B. Cox, R. L. Wells, C. C. Benichou and M. R. McClung (2015). "Habitat loss and modification due to gas development in the Fayetteville Shale." 55(6): 1276-1284.

Morrant, D. S. and S. Petit (2012). "Strategies of a small nectarivorous marsupial, the western pygmy-possum, in response to seasonal variation in food availability." Journal of Mammalogy 93(6): 1525-1535.

Morris, E. K., T. Caruso, F. Buscot, M. Fischer, C. Hancock, T. S. Maier, T. Meiners, C. Müller, E. Obermaier and D. Prati (2014). "Choosing and using diversity indices: insights for ecological applications from the German Biodiversity Exploratories." Ecology and evolution 4(18): 3514-3524.

Morrison, E. B., C. A. Lindell, K. D. Holl and R. A. Zahawi (2010). "Patch size effects on avian foraging behaviour: implications for tropical forest restoration design." Journal of Applied Ecology 47(1): 130-138.

Mueller-Dombois, D. (2002). "Forest vegetation across the tropical Pacific: a biogeographically complex region with many analogous environments." 163(2): 155-176.

Mueller-Dombois, D. and F. R. Fosberg (1998). Vegetation of the tropical Pacific islands, Springer.

Ni, Q., Z. Liang, M. Xie, H. Xu, Y. Yao, M. Zhang, Y. Li, Y. Li and X. Jiang (2018). "Microhabitat use of the western black-crested gibbon inhabiting an isolated forest fragment in southern Yunnan, China: implications for conservation of an endangered species." Primates 59(1): 45-54.

Nogales, M., E. Vidal, F. M. Medina, E. Bonnaud, B. R. Tershy, K. J. Campbell and E. S. Zavaleta (2013). "Feral cats and biodiversity conservation: the urgent prioritization of island management." Bioscience 63(10): 804-810.

Ornithological Society of New Zealand (2010). Checklist of the birds of New Zealand, Norfolk and Macquarie islands, and the Ross Dependency, Antarctica, Te Papa Press.

Ortiz-Catedral, L. (2009). "Homing of a red-crowned parakeet (*Cyanoramphus novaezelandiae*) from Motuihe Island to Little Barrier Island, New Zealand." Notornis 56: 165-166.

Ortiz-Catedral, L. and D. H. Brunton (2008). Clutch parameters and reproductive success of a translocated population of red-crowned parakeet (Cyanoramphus novaezelandiae). 56: 389-393.

Ortiz-Catedral, L. and D. H. Brunton (2010). "Success of translocations of red-fronted parakeets Cyanoramphus novaezelandiae novaezelandiae from Little Barrier Island (Hauturu) to Motuihe Island, Auckland, New Zealand." Conservation Evidence 7: 21-26.

Ortiz-Catedral, L., S. M. H. Ismar, K. Baird, D. H. Brunton and M. E. Hauber (2009). "Recolonization of Raoul Island by Kermadec red-crowned parakeets *Cyanoramphus novaezelandiae cyanurus* after eradication of invasive predators, Kermadec Islands archipelago, New Zealand." Conservation Evidence 6: 26-30.

Ortiz-Catedral, L., K. McInnes, M. E. Hauber and D. H. Brunton (2009). "First report of beak and feather disease virus (BFDV) in wild Red-fronted Parakeets (Cyanoramphus novaezelandiae) in New Zealand." Emu 109(3): 244-247.

Ortiz-Catedral, L., R. Nias, J. Fitzsimons, S. Vine and M. Christian (2018). "Back from the brink–again: the decline and recovery of the Norfolk Island green parrot." Recovering Australian Threatened Species: A Book of Hope: 105.

Osborne, W. and K. Green (1992). "Seasonal changes in composition, abundance and foraging behaviour of birds in the Snowy Mountains." Emu-Austral Ornithology 92(2): 93-105.

Otto, R., V. Garzón-Machado, M. del Arco, S. Fernández-Lugo, L. de Nascimento, P. Oromí, M. Báez, M. Ibáñez, M. R. Alonso and J. M. Fernández-Palacios (2017). "Unpaid extinction debts for endemic plants and invertebrates as a legacy of habitat loss on oceanic islands." Diversity and Distributions 23(9): 1031-1041.

Pacala, S. and J. Roughgarden (1982). "Resource partitioning and interspecific competition in two two-species insular Anolis lizard communities." Science 217(4558): 444-446.

Palomares, F. and T. M. Caro (1999). "Interspecific killing among mammalian carnivores." The American Naturalist 153(5): 492-508.

Parker, K. A., J. G. Ewen, P. J. Seddon and D. P. Armstrong (2013). "Post-release monitoring of bird translocations: why is it important and how do we do it." Notornis 60(1): 85-92.

Parkes, J. and E. Murphy (2003). "Management of introduced mammals in New Zealand." New Zealand Journal of Zoology 30(4): 335-359.

Parr, M. and T. Juniper (2010). Parrots: a guide to parrots of the world, Bloomsbury Publishing.

Pass, D. and R. Perry (1984). "The pathology of psittacine beak and feather disease." Australian Veterinary Journal 61(3): 69-74.

Paulay, G. (1994). "Biodiversity on oceanic islands: its origin and extinction1." American Zoologist 34(1): 134-144.

Pavey, C. R., C. E. Nano, J. R. Cole, P. J. McDonald, P. Nunn, A. Silcocks and R. H. Clarke (2014). "The breeding and foraging ecology and abundance of the Princess Parrot (Polytelis alexandrae) during a population irruption." 114(2): 106-115.

Pell, A. and C. Tidemann (1997). "The impact of two exotic hollow-nesting birds on two native parrots in savannah and woodland in eastern Australia." Biological Conservation 79(2-3): 145-153.

Peña, M. A. and J. Ulloa (2017). Mapping the post-fire vegetation recovery by NDVI time series. 2017 First IEEE International Symposium of Geoscience and Remote Sensing (GRSS-CHILE), IEEE.

Petersen, W. J., T. Savini, R. Steinmetz and D. Ngoprasert (2018). "Periodic resource scarcity and potential for interspecific competition influences distribution of small carnivores in a seasonally dry tropical forest fragment." Mammalian Biology.

Pires, S. F. (2012). "The illegal parrot trade: a literature review." Global Crime 13(3): 176-190.

Plumb, G. E., P. J. White, M. B. Coughenour and R. L. Wallen (2009). "Carrying capacity, migration, and dispersal in Yellowstone bison." Biological Conservation 142(11): 2377-2387.

Pough, F. H., C. M. Janis and J. B. Heiser (2013). Vertebrate life, Pearson Higher Ed.

Poulsen, J. R., C. J. Clark and T. B. Smith (2001). "Seasonal variation in the feeding ecology of the grey-cheeked mangabey (Lophocebus albigena) in Cameroon." American Journal of Primatology: Official Journal of the American Society of Primatologists 54(2): 91-105.

Powlesland, R., A. Roberts, B. Lloyd and D. Merton (1995). "Number, fate, and distribution of kakapo (Strigops habroptilus) found on Stewart Island, New Zealand, 1979–92." New Zealand Journal of Zoology 22(3): 239-248.

Prugh, L. R., K. E. Hodges, A. R. Sinclair and J. S. Brashares (2008). "Effect of habitat area and isolation on fragmented animal populations." Proceedings of the National Academy of Sciences 105(52): 20770-20775.

Ragusa-Netto, J. (2007). "Feeding ecology of the Green-cheeked parakeet (Pyrrhura molinae) in dry forests in western Brazil." Brazilian Journal of Biology 67(2): 243-249.

Rahaus, M. and M. H. Wolff (2003). "Psittacine Beak and Feather Disease: a First Survey of the Distribution of Beak and Feather Disease Virus Inside the Population of Captive Psittacine Birds in Germany." 50(8): 368-371.

Recher, H., R. Holmes, M. Schulz, J. Shields and R. Kavanagh (1985). "Foraging patterns of breeding birds in eucalypt forest and woodland of southeastern Australia." Australian Journal of Ecology 10(4): 399-419.

Recio, M. R., P. J. Seddon and A. B. Moore (2015). "Niche and movement models identify corridors of introduced feral cats infringing ecologically sensitive areas in New Zealand." Biological Conservation 192: 48-56.

Reed , D. H. (2004). "Extinction risk in fragmented habitats." 7(2): 181-191.

Renton, K. (2001). "Lilac-crowned Parrot diet and food resource availability: resource tracking by a parrot seed predator." The Condor 103(1): 62-69.

Reside, A. E., J. Beher, A. J. Cosgrove, M. C. Evans, L. Seabrook, J. L. Silcock, A. S. Wenger and M. Maron (2017). "Ecological consequences of land clearing and policy reform in Queensland." 23(3): 219-230.

Roeleke, M., L. Johannsen and C. C. Voigt (2018). "How bats escape the competitive exclusion principle-Seasonal shift from intraspecific to interspecific competition drives space use in a bat ensemble." Frontiers in Ecology and Evolution 6: 101.

Rojas, M. (1992). "The species problem and conservation: what are we protecting?" 6(2): 170-178.

Romero-Muñoz, A., R. Torres, J. Noss Andrew, J. Giordano Anthony, V. Quiroga, J. Thompson Jeffrey, M. Baumann, M. Altrichter, R. McBride, Jr., M. Velilla, R. Arispe and T. Kuemmerle (2019). "Habitat loss and overhunting synergistically drive the extirpation of jaguars from the Gran Chaco." Diversity and Distributions 25(2): 176.

Rout, T. M., C. M. Baker, S. Huxtable and B. A. Wintle (2018). "Monitoring, imperfect detection, and risk optimization of a Tasmanian devil insurance population." Conservation Biology 32(2): 267-275.

Ruiz, J., M. C. Fandiño and R. L. Chazdon (2005). "Vegetation Structure, Composition, and Species Richness Across a 56-year Chronosequence of Dry Tropical Forest on Providencia Island, Colombia 1." 37(4): 520-530.

Russell, J. C., D. R. Towns, S. H. Anderson and M. N. Clout (2005). "Intercepting the first rat ashore." Nature 437: 1107.

Saunders, A. and D. Norton (2001). "Ecological restoration at mainland islands in New Zealand." Biological Conservation 99(1): 109-119.

Saunders, D., G. T. Smith and I. Rowley (1982). "The availability and dimensions of tree hollows that provide nest sites for cockatoos (Psittaciformes) in Western Australia." Wildlife Research 9(3): 541-556.

Scherber, C., N. Eisenhauer, W. W. Weisser, B. Schmid, W. Voigt, M. Fischer, E.-D. Schulze, C. Roscher, A. Weigelt and E. Allan (2010). "Bottom-up effects of plant diversity on multitrophic interactions in a biodiversity experiment." Nature 468(7323): 553.

Schweizer, M., M. Guentert and S. T. Hertwig (2013). "Out of the Bassian province: historical biogeography of the Australasian platycercine parrots (Aves, Psittaciformes)." Zoologica Scripta 42(1): 13-27.

Shafie, H., I. Amiri, A. R. Shahriari, A. Fakhireh, S. Noori and S. Hosseini (2011). "RS-based assessment of vegetation cover changes in Sistan Plain." 1(1): 159-167.

Silcock, J. L. and R. J. Fensham (2018). "Using evidence of decline and extinction risk to identify priority regions, habitats and threats for plant conservation in Australia %J Australian Journal of Botany." 66(7): 541-555.

Simberloff, D. (2002). "Today Tiritiri Matangi, tomorrow the world! Are we aiming too low in invasives control." Turning the tide: the eradication of invasive species: 4-12.

Skirrow, M. (2018). Estimating the Population Size of Two Critically Endangered South Pacific Parakeets: The Tasman Parakeet and Malherbe’s Parakeet. Master of Science in Conservation Biology, Massey University.

Skole, D. and C. Tucker (1993). "Tropical deforestation and habitat fragmentation in the Amazon: satellite data from 1978 to 1988." 260(5116): 1905-1910.

Slatyer, R. A., M. Hirst and J. P. Sexton (2013). "Niche breadth predicts geographical range size: a general ecological pattern." Ecology letters 16(8): 1104-1114.

Smithers, C. and H. d. S. Disney (1969). "The distribution of terrestrial and freshwater birds on Norfolk Island." Aust. J. Zool 15: 127-140.

Snyder, N. F. (2000). Parrots: status survey and conservation action plan 2000-2004, IUCN.

Spatz, D. R., K. M. Zilliacus, N. D. Holmes, S. H. M. Butchart, P. Genovesi, G. Ceballos, B. R. Tershy and D. A. Croll (2017). "Globally threatened vertebrates on islands with invasive species." 3(10): e1603080.

Specht, M. J., S. R. R. Pinto, U. P. Albuquerque, M. Tabarelli and F. P. I. Melo (2015). "Burning biodiversity: Fuelwood harvesting causes forest degradation in human-dominated tropical landscapes." Global Ecology and Conservation 3: 200-209.

Speziale, K. L., S. A. Lambertucci and O. Olsson (2008). "Disturbance from roads negatively affects Andean condor habitat use." Biological Conservation 141(7): 1765-1772.

Steven, R., C. Pickering and J. Guy Castley (2011). "A review of the impacts of nature based recreation on birds." Journal of Environmental Management 92(10): 2287-2294.

Stevenson, P. R. (2001). "The relationship between fruit production and primate abundance in Neotropical communities." Biological Journal of the Linnean Society 72(1): 161-178.

Strøm, J. F., E. B. Thorstad, R. D. Hedger and A. H. Rikardsen (2018). "Revealing the full ocean migration of individual Atlantic salmon." Animal Biotelemetry 6(1): 2.

Szabo, J. K., S. H. Butchart, H. P. Possingham and S. T. Garnett (2012). "Adapting global biodiversity indicators to the national scale: A Red List Index for Australian birds." Biological Conservation 148(1): 61-68.

Taubert, F., R. Fischer, J. Groeneveld, S. Lehmann, M. S. Müller, E. Rödig, T. Wiegand and A. Huth (2018). "Global patterns of tropical forest fragmentation." Nature 554: 519.

Taylor, R. (1979). "How the Macquarie Island parakeet became extinct." New Zealand Journal of Ecology: 42-45.

Tella, J. L. and M. G. Forero (2000). "Farmland habitat selection of wintering lesser kestrels in a Spanish pseudosteppe: implications for conservation strategies." Biodiversity & Conservation 9(3): 433-441.

Terrell, K. A., A. E. Crosier, D. E. Wildt, S. J. O'Brien, N. M. Anthony, L. Marker and W. E. Johnson (2016). "Continued decline in genetic diversity among wild cheetahs (Acinonyx jubatus) without further loss of semen quality." Biological Conservation 200: 192-199.

Tershy, B. R., K.-W. Shen, K. M. Newton, N. D. Holmes and D. A. Croll (2015). "The Importance of Islands for the Protection of Biological and Linguistic Diversity." BioScience 65(6): 592-597.

Threatened Species Scientific Committee (2016). Conservation Advice Cyanoramphus cookii Norfolk Island green parrot. D. o. E. a. Energy. Australia, Australian Government.

Tilman, D. and P. Kareiva (2018). Spatial ecology: the role of space in population dynamics and interspecific interactions (MPB-30), Princeton University Press.

Turner, W., S. Spector, N. Gardiner, M. Fladeland, E. Sterling and M. Steininger (2003). "Remote sensing for biodiversity science and conservation, ." Trends in Ecology & Evolution, 18(6): 306-314.

Tyne, J. A., D. W. Johnston, R. Rankin, N. R. Loneragan and L. Bejder (2015). "The importance of spinner dolphin (Stenella longirostris) resting habitat: implications for management." Journal of Applied Ecology 52(3): 621-630.

Verhagen, S. (2017). "The time is now to save one of the world’s most endangered birds." Australian Geographic 3: 132.

Vijay, V., C. D. Reid, M. Finer, C. N. Jenkins and S. L. Pimm (2018). "Deforestation risks posed by oil palm expansion in the Peruvian Amazon." Environmental Research Letters 13(11): 114010.

Waldmann, A. (2016). Foraging ecology of the world's only population of the critically endangered Tasman parakeet (Cyanoramphus cookii), on Norfolk Island: a thesis presented in partial fulfilment of the requirements for the degree of Master of Science in Conservation Biology at Massey University, Auckland, New Zealand, Massey University.

Wallenius, T., L. Niskanen, T. Virtanen, J. Hottola, G. Brumelis, A. Angervuori, J. Julkunen and M. Pihlström (2010). "Loss of habitats, naturalness and species diversity in Eurasian forest landscapes." Ecological Indicators 10(6): 1093-1101.

Wangchuk, S., T. Bolch and J. Zawadzki (2019). "Towards automated mapping and monitoring of potentially dangerous glacial lakes in Bhutan Himalaya using Sentinel-1 Synthetic Aperture Radar data." International Journal of Remote Sensing: 1-26.

Warner, R. E. (1968). "The role of introduced diseases in the extinction of the endemic Hawaiian avifauna." The Condor 70(2): 101-120.

Watson, J., M. Trueman, M. Tufet, S. Henderson and R. Atkinson (2010). "Mapping terrestrial anthropogenic degradation on the inhabited islands of the Galapagos Archipelago." 44(1): 79-82.

Watson, J. E., K. R. Jones, R. A. Fuller, M. D. Marco, D. B. Segan, S. H. Butchart, J. R. Allan, E. McDonald-Madden and O. Venter (2016). "Persistent disparities between recent rates of habitat conversion and protection and implications for future global conservation targets." Conservation Letters 9(6): 413-421.

Weber, E. (2017). Invasive plant species of the world: a reference guide to environmental weeds, CABI.

Weeks, A. R., J. Stoklosa and A. A. Hoffmann (2016). "Conservation of genetic uniqueness of populations may increase extinction likelihood of endangered species: the case of Australian mammals." Frontiers in zoology 13(1): 31.

Weston, M. and M. Memon (2009). "The illegal parrot trade in Latin America and its consequences to parrot nutrition, health and conservation." Bird populations 9: 76-83.

Xi Xu, Yujing Xie, Ke Qi, Zukui Luo and X. Wang (2018). "Detecting the response of bird communities and biodiversity to habitat loss and fragmentation due to urbanization,." Science of The Total Environment, 624: 1561-1576.

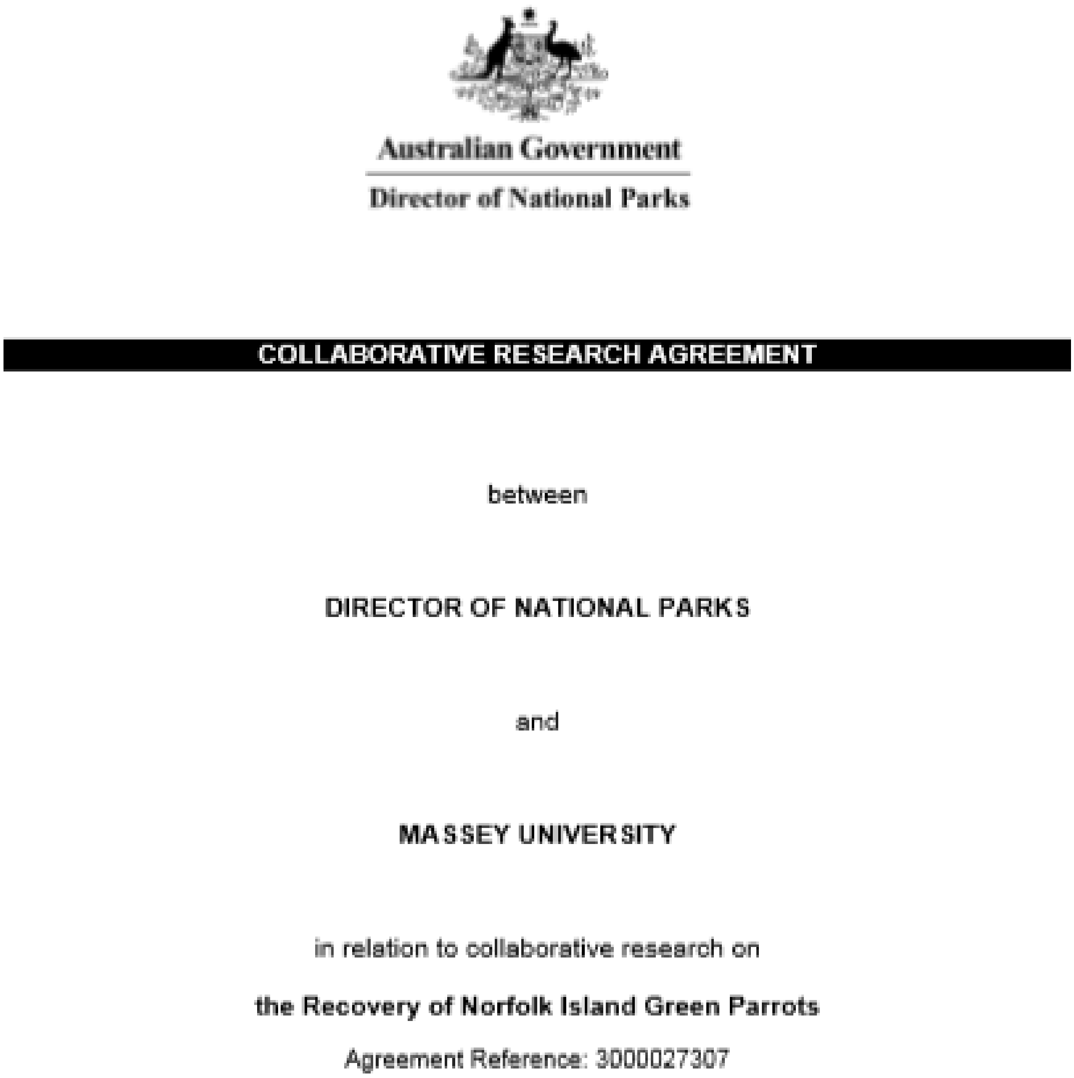
Yue, S., J. F. Brodie, E. F. Zipkin and H. Bernard (2015). "Oil palm plantations fail to support mammal diversity." 25(8): 2285-2292.

Zegeye, H., D. Teketay and E. Kelbessa (2006). "Diversity, regeneration status and socio-economic importance of the vegetation in the islands of Lake Ziway, south-central Ethiopia." 201(6): 483-498.

Zhou, Q., M. Robson and P. Pilesjo (1998). "On the ground estimation of vegetation cover in Australian rangelands." International Journal of Remote Sensing 19(9): 1815-1820.

APPENDIX

APPENDIX A: COLLABORATIVE RESEARCH AGREEMENT



Australian Government

Director of National Parks

COLLABORATIVE RESEARCH AGREEMENT

between

DIRECTOR OF NATIONAL PARKS

and

MASSEY UNIVERSITY

in relation to collaborative research on

the Recovery of Norfolk Island Green Parrots

Agreement Reference: 3000027307

TABLE OF CONTENTS

DATE

This Agreement is made the day of 2017.

PARTIES

DIRECTOR OF NATIONAL PARKS, ABN 13 051 694 963 (**DNP**)

and

MASSEY UNIVERSITY, a body corporate of Palmerston North with offices in Palmerston North, Wellington and Old Albany Highway, Auckland, New Zealand, 0632 (**Research Organisation**)

BACKGROUND

A. DNP is vested with the title to, and is responsible for the management of, Norfolk Island National Park and Botanic Gardens, a Commonwealth reserve established under the *Environment Protection and Biodiversity Act 1999* (**the Reserve**).

B. The Research Organisation has proposed to collaborate with DNP to conduct research in the Reserve.

C. DNP is satisfied that the proposed research addresses the current research and monitoring priorities of the Reserve.

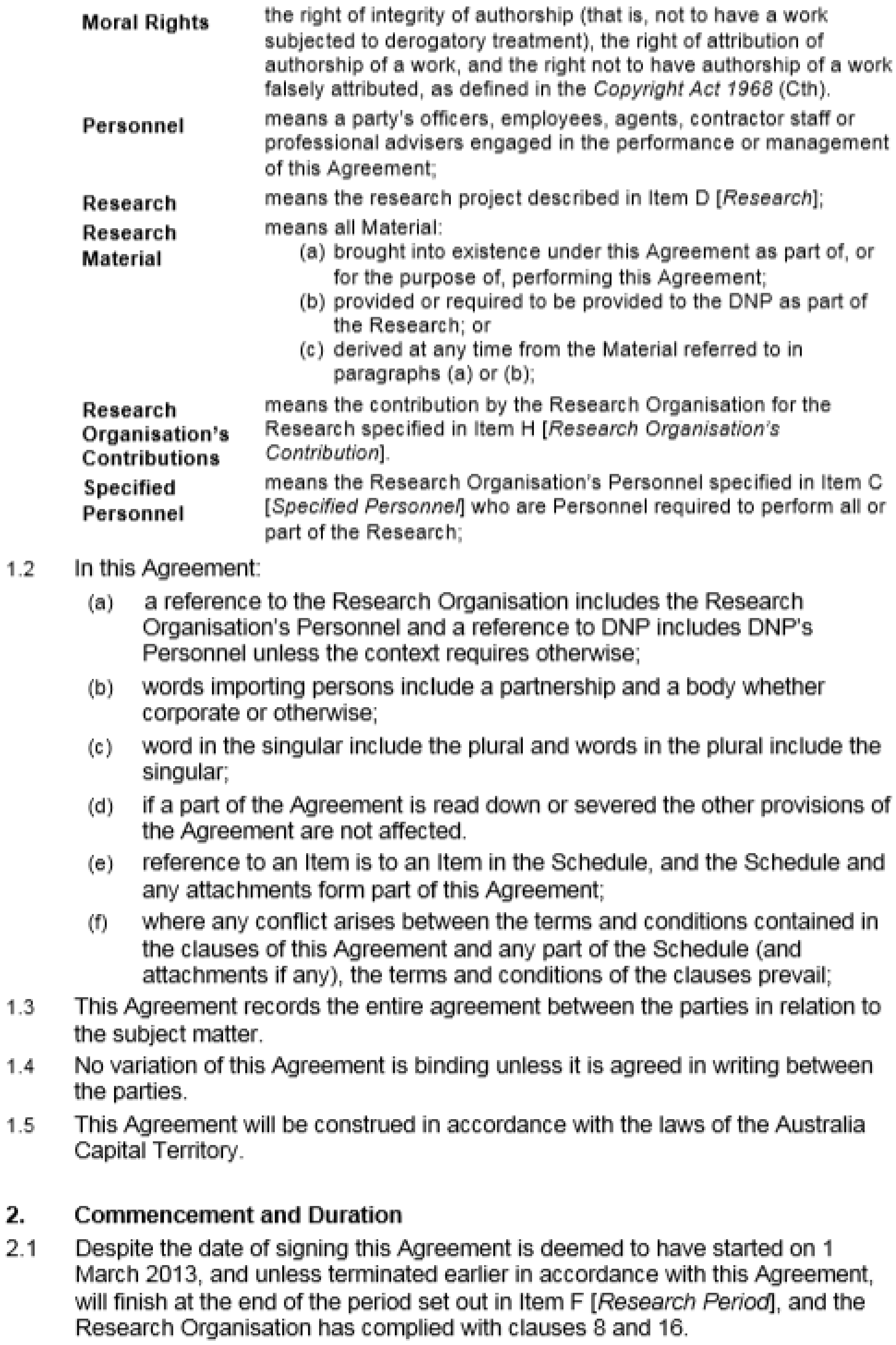
D. DNP and the Research Organisation have agreed to carry out collaborative research in accordance with the terms and conditions of this Agreement.

OPERATIVE PART

1. Interpretation

1.1 In this Agreement, unless the contrary intention appears:

Confidential Information	means: (a) the information described in Item K [*Confidential Information*]; and (b) the information that is agreed between the Parties after the commencement of this Agreement as constituting Confidential Information for the purposes of this Agreement.
DNP's Contribution	means the resources (including Funds and in-kind contribution) specified in Item G [*DNP's Contribution*] that will be contributed by DNP towards the Research under this Agreement;
DNP Material	means any Material: (a) provided by the DNP to the Service Provider for the purposes of this Agreement; or (b) derived at any time from the Material referred to in paragraph (a);
Intellectual Property	includes all copyright (including rights in relation to phonograms and broadcasts), all rights in relation to inventions (including patent rights), plant varieties, registered and unregistered trademarks (including service marks), designs, and circuit layouts, and all other rights resulting from intellectual activity in the industrial, scientific, literary or artistic fields but does not include Moral Rights, the rights of performers or rights in relation to Confidential Information;
Material	includes information and the subject matter of any category of Intellectual Property rights;



Moral Rights	the right of integrity of authorship (that is, not to have a work subjected to derogatory treatment), the right of attribution of authorship of a work, and the right not to have authorship of a work falsely attributed, as defined in the *Copyright Act 1968* (Cth).
Personnel	means a party's officers, employees, agents, contractor staff or professional advisers engaged in the performance or management of this Agreement;
Research	means the research project described in Item D [*Research*];
Research Material	means all Material: (a) brought into existence under this Agreement as part of, or for the purpose of, performing this Agreement; (b) provided or required to be provided to the DNP as part of the Research; or (c) derived at any time from the Material referred to in paragraphs (a) or (b);
Research Organisation's Contributions	means the contribution by the Research Organisation for the Research specified in Item H [*Research Organisation's Contribution*].
Specified Personnel	means the Research Organisation's Personnel specified in Item C [*Specified Personnel*] who are Personnel required to perform all or part of the Research;

1.2 In this Agreement:

(a) a reference to the Research Organisation includes the Research Organisation's Personnel and a reference to DNP includes DNP's Personnel unless the context requires otherwise;

(b) words importing persons include a partnership and a body whether corporate or otherwise;

(c) word in the singular include the plural and words in the plural include the singular;

(d) if a part of the Agreement is read down or severed the other provisions of the Agreement are not affected.

(e) reference to an Item is to an Item in the Schedule, and the Schedule and any attachments form part of this Agreement;

(f) where any conflict arises between the terms and conditions contained in the clauses of this Agreement and any part of the Schedule (and attachments if any), the terms and conditions of the clauses prevail;

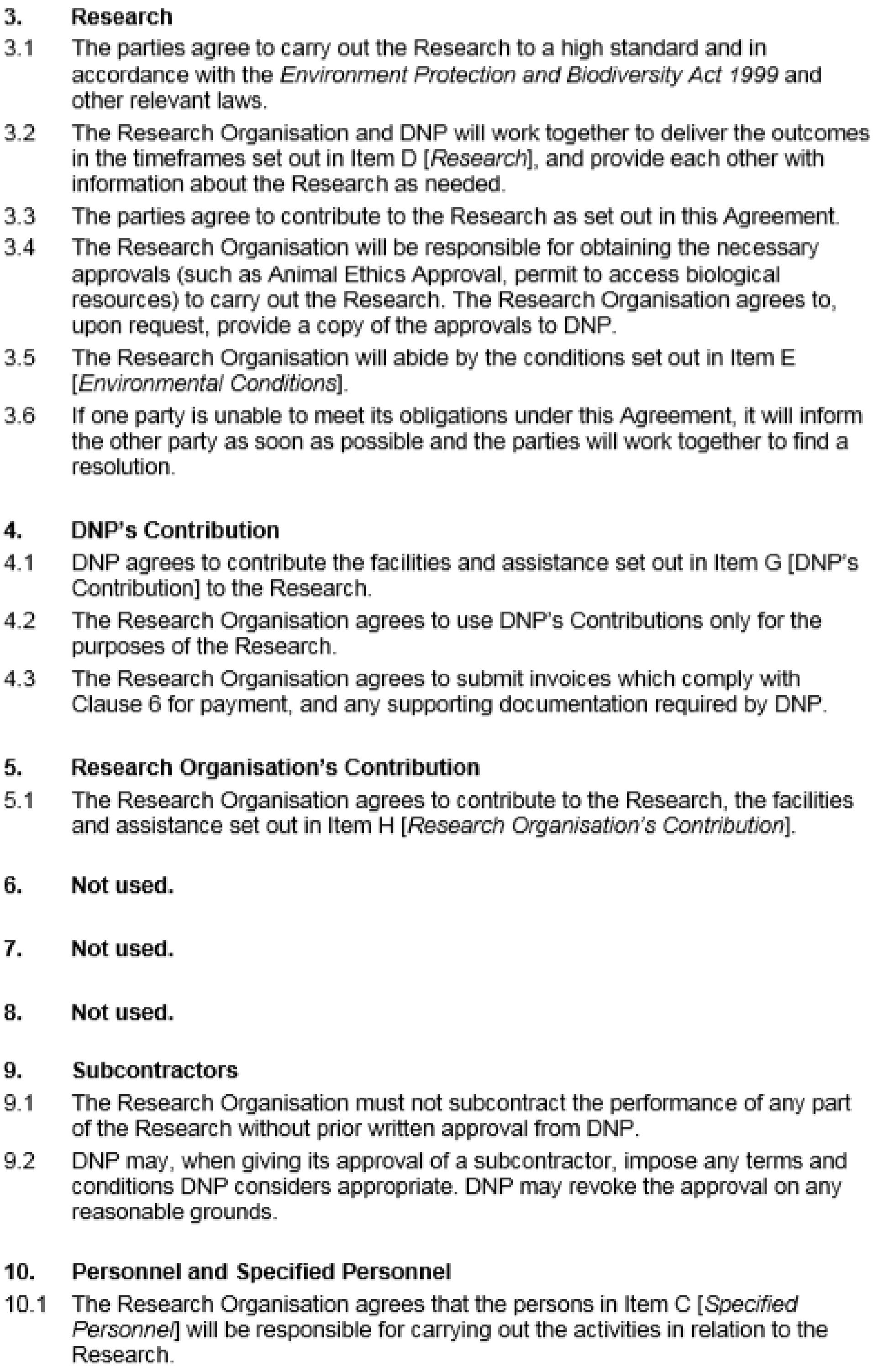
1.3 This Agreement records the entire agreement between the parties in relation to the subject matter.

1.4 No variation of this Agreement is binding unless it is agreed in writing between the parties.

1.5 This Agreement will be construed in accordance with the laws of the Australia Capital Territory.

2. Commencement and Duration

2.1 Despite the date of signing this Agreement is deemed to have started on 1 March 2013, and unless terminated earlier in accordance with this Agreement, will finish at the end of the period set out in Item F [*Research Period*], and the Research Organisation has complied with clauses 8 and 16.



3. Research

3.1 The parties agree to carry out the Research to a high standard and in accordance with the *Environment Protection and Biodiversity Act 1999* and other relevant laws.

3.2 The Research Organisation and DNP will work together to deliver the outcomes in the timeframes set out in Item D [*Research*], and provide each other with information about the Research as needed.

3.3 The parties agree to contribute to the Research as set out in this Agreement.

3.4 The Research Organisation will be responsible for obtaining the necessary approvals (such as Animal Ethics Approval, permit to access biological resources) to carry out the Research. The Research Organisation agrees to, upon request, provide a copy of the approvals to DNP.

3.5 The Research Organisation will abide by the conditions set out in Item E [*Environmental Conditions*].

3.6 If one party is unable to meet its obligations under this Agreement, it will inform the other party as soon as possible and the parties will work together to find a resolution.

4. DNP's Contribution

4.1 DNP agrees to contribute the facilities and assistance set out in Item G [DNP's Contribution] to the Research.

4.2 The Research Organisation agrees to use DNP's Contributions only for the purposes of the Research.

4.3 The Research Organisation agrees to submit invoices which comply with Clause 6 for payment, and any supporting documentation required by DNP.

5. Research Organisation's Contribution

5.1 The Research Organisation agrees to contribute to the Research, the facilities and assistance set out in Item H [*Research Organisation's Contribution*].

6. Not used.

7. Not used.

8. Not used.

9. Subcontractors

9.1 The Research Organisation must not subcontract the performance of any part of the Research without prior written approval from DNP.

9.2 DNP may, when giving its approval of a subcontractor, impose any terms and conditions DNP considers appropriate. DNP may revoke the approval on any reasonable grounds.

10. Personnel and Specified Personnel

10.1 The Research Organisation agrees that the persons in Item C [*Specified Personnel*] will be responsible for carrying out the activities in relation to the Research.

10.2 DNP may give notice on reasonable grounds, requiring the Research Organisation to remove Personnel (including Specified Personnel) from the Research.

10.3 Where clause 10.2 apply, the DNP may request the Research Organisation to provide suitable replacement Personnel (including Specified Personnel) at the earliest opportunity.

10.4 If the request(s) made under clause 10.3 can not be met, DNP may terminate this Agreement in accordance with the clause 25.1.

11. DNP Material

11.1 DNP agrees to provide Material to the Research Organisation as specified in Item I [*Material to be Provided by DNP*].

11.2 DNP grants to the Research Organisation a royalty-free, non-exclusive licence to use, reproduce and adapt the DNP Material for the purposes of this Agreement.

11.3 The Research Organisation agrees to ensure that all DNP Material is used strictly in accordance with any conditions or restrictions set out in Item J [*Use of DNP Material*], and any direction by DNP.

12. Intellectual Property in Research Material

12.1 This clause 12 does not affect the ownership of Intellectual Property in any Material which came into existence prior to the commencement of this Agreement.

12.2 Intellectual Property in Research Material shall, upon creation, vest in accordance with Item P [*Intellectual Property*]; and if not specified in Item P, will vest in DNP.

12.3 Where specified in Item P [*Intellectual Property*], DNP grants to the Research Organisation a permanent, irrevocable, royalty-free, world-wide, non-exclusive licence (including a right of sub-licence) to use, reproduce, adapt and exploit the relevant Material for its own non-commercial educational and research purposes.

12.4 Where specified in Item P [*Intellectual Property*], the Research Organisation grants to DNP a permanent, irrevocable, royalty-free, world-wide, non-exclusive licence (including a right of sub-licence) to use, reproduce, adapt and exploit the relevant Material (including any Research Organisation's Material that is incorporated into that Material, or from which the Material is derived) for non-commercial purposes relating to reserve management.

12.5 If requested by DNP, the Research Organisation agrees to bring into existence, sign, execute or otherwise deal with any document which may be necessary or desirable to give effect to clause 12.4.

12.6 The Research Organisation warrants that it is entitled, or will be entitled at the relevant time, to deal with the Intellectual Property in the Research Material in the manner provided for in this clause 12.

12.7 This clause will survive the expiration or termination of this Agreement.

13. Moral Rights

13.1 Other than as provided in clause 13.2, the Research Organisation will, unless otherwise agreed by DNP in writing, ensure that each person who is or will be the author of any Research Material provides a written consent to DNP permitting DNP (including its Personnel) to conduct any act which would otherwise infringe the Moral Rights held by that person.

13.2 Research Materials such as scientific journals, reports, thesis, conference papers, lectures, multimedia presentations, which are in a draft format prepared for publication or becomes published, will be attributed in accordance with Item L [*Attribution*].

13.3 This clause will survive the expiration or termination of this Agreement.

14. Confidential Information

14.1 Parties agree not to disclose each other's Confidential Information (unless required or authorised by law or Parliament) without prior written consent.

14.2 A Party may impose any conditions or restrictions it considers appropriate when giving its approval under clause 14.1 and the other Party must comply with any such conditions.

15. Personal Information

15.1 The parties agree, when dealing with personal information arising from this Agreement, to maintain the privacy of Personal Information in accordance with the Australian Privacy Principles set out in the *Privacy Act 1988* (Cth).

16. Reporting

16.1 The Research Organisation and DNP agree to meet to discuss and review the progress of the Research as specified in Item N [*Reporting*].

16.2 The Research Organisation agrees to prepare and provide DNP with the information and documents specified in Item N [*Reporting*].

17. Acknowledgment and Publications

17.1 In:

(a) promotional Materials arising from Research; and

(b) in Research Materials which are intended for or results in publication

the parties agree to use the acknowledgement set out in Item M [*Acknowledgment*].

17.2 Where DNP is an author in Research Materials which are intended for or results in publication, the parties agree to observe the publishing policy in Attachment C [*DNP's Publishing Policy*].

18. Media

18.1 The Research Organisation agrees to notify DNP as soon as possible after receiving any request for media comment about the Research and consult DNP prior to issuing any comment to the media regarding the Research.

19. Conflict of Interest

19.1 The Research Organisation warrants that, to the best of its knowledge,

(a) no conflict with the interests of DNP exists; or

(b) the Research Organisation has disclosed known conflicts of interests to DNP

as at the signing of this Agreement.

19.2 If, during the term of this Agreement a conflict of interest arises, or appears likely to arise, the Research Organisation agrees to:

  (a) notify DNP immediately in writing; and
  (b) make full disclosure of all relevant information relating to the conflict; and
  (c) take such steps as DNP may reasonably require to resolve or otherwise deal with the conflict.

20. Work Health and Safety

20.1 In carrying out its obligations under this Agreement, both parties must comply, and use reasonable endeavours to ensure that its Personnel complies with relevant work health and safety legislation.

20.2 The Research Organisation agrees, when using DNP's premises or facilities, to comply with all reasonable DNP directions and procedures relating to work health, safety and security (including the Commonwealth's smoke-free work-place policy) whether specifically drawn to the attention of the Research Organisation or as might reasonably be inferred from the circumstances.

21. Access to Premises and Records

21.1 The Research Organisation agrees to assist DNP in respect of any inquiry into or concerning the Research or this Agreement, including providing reasonable access to premises, records and Materials relevant to the Research.

22. Indemnity

22.1 The Research Organisation indemnifies DNP from and against any:

  (a) costs or liability incurred by the DNP;
  (b) loss of or damage to property of the DNP; or
  (c) loss or expense incurred by the DNP in dealing with any claim against it, including legal costs and expenses on a solicitor/own client basis and the cost of time spent, resources used or disbursements paid by the DNP,

arising from either:

  (d) a breach by the Research Organisation of this Agreement; or
  (e) an act or omission involving fault on the part of the Research Organisation or its Personnel in connection with this Agreement.

22.2 The Research Organisation's liability to indemnify DNP under clause 22.1 will be reduced proportionately to the extent that any act or omission involving fault on the part of DNP contributed to the relevant cost, liability, damage, loss or expense.

22.3 The right of the DNP to be indemnified under this clause 22 is in addition to, and not exclusive of, any other right, power or remedy provided by law, but the DNP is not entitled to be compensated in excess of the amount of the relevant cost, liability, damage, loss or expense

22.4 In this clause,

  (a) "DNP" includes officers, employees and agents of the DNP; and
  (b) "fault" means any negligent or unlawful act or omission or wilful misconduct.

22.5 This clause will survive the expiration or termination of this Agreement.

23. Insurance

23.1 The parties agree, for so long as any obligations remain in connection with this Agreement:

(a) to effect and maintain the insurance specified in Item O [*Insurance*], including those which survive the expiration or termination of this Agreement; and

(b) upon request, to provide proof of insurance.

24. Dispute Resolution

24.1 The parties agree to use their best endeavours to resolve any dispute arising from this Agreement via direct negotiation, before initiating any legal proceedings as follows:

(a) If one party has concerns regarding the performance of the Research, that party will raise concerns with the other party in writing; and

(b) Both parties will work together to address the concerns raised under this clause;

24.2 If no resolution results from direct negotiation, the parties agree to engage in mediation or another form of alternative dispute resolution before initiating any legal proceedings.

24.3 This clause does not preclude either party from commencing legal proceedings for urgent interlocutory relief.

25. Termination

25.1 One party may terminate this Agreement at any time by written notice of at least 3 months to the other party.

25.2 Where one party:

(a) fails to comply with its obligations under the Agreement and the other party considers the failure can not be remedied; or

(b) repeatedly fails to comply with its obligations under the Agreement; or

(c) by written notice, withdraws from carrying out the Research; or

(d) being a corporation, comes under one of the forms of external administration referred to in chapter 5 of the *Corporations Act 2001*, or an order has been made for the purpose of placing the corporation under external administration; or

(e) being an individual, becomes bankrupt or enters into a scheme of arrangement with creditors;

the other party may, by written notice -

(f) terminate this Agreement.

26. Negation of Employment, Partnership and Agency

26.1 Parties are not by virtue of this Agreement an officer, employee, partner or agent of the other party, nor does one party have any power or authority to bind or represent the other party.

27. Waiver

27.1 If a party does not exercise (or delays in exercising) any of its rights, that failure or delay does not operate as a waiver of those rights.

27.2 A single or partial exercise by a party of any of its rights does not prevent the further exercise of any right by that party.

27.3 In this clause, 'rights' means rights or remedies provided by this Agreement or at law.

28. Assignment

28.1 Both parties agree not to assign its rights and obligations under this Agreement without prior approval in writing from the other party.

29. Notices

29.1 A notice under this Agreement must be in writing, and:

(a) if given by the Research Organisation to DNP – signed by the Research Organisation and addressed to the DNP's Representative in Item B [*DNP's Representative*] or as otherwise notified by DNP; or

(b) if given by DNP to the Research Organisation – signed by the DNP's Representative and addressed to Research Organisation's Representative indicated in Item A [*Research Organisation's Representative*] or as otherwise notified by the Research Organisation.

THE SCHEDULE

A. Research Organisation's Representative

Dr. Luis Ortiz-Catedral

Massey University East Precinct
Dairy Flat Highway (SH17)
Albany
0632
New Zealand

Telephone: +64 (09) 414 0800 ext. 43197
Facsimile: 06 350 5618
Email: L.Ortiz-Catedral@masssey.ac.nz

B. DNP's Representative

Craig Doolan

Norfolk Island National Park and Botanic Garden
PO BOX 310, Norfolk Island, South Pacific, 2899

Telephone: +6723 22695
Email: Craig.Doolan@environment.gov.au

C. Specified Personnel

C.1 Lead Researcher - Professor Dianne Brunton

i. The Lead Researcher is responsible for all Research Organisation's Personnel and for the Research Organisation's activities in relation to the Research.

C.2 Lead Researcher will be supported by the following Specified Personnel

Position	Name	Brief description of responsibilities
Lecturer	Currently Dr. Luis Ortiz-Catedral and Lead Researcher will seek DNP approval of any changes.	1. As outlined in Attachment A [*Research Plan*]

D. Research

1. A Research Title

A PCR based survey for beak and feather disease virus on Norfolk Island (see Attachment A [*Research Plan*])

Research Objectives

1) whether or not the species is currently harbouring BFDV;
2) prevalence in the population i.e. 10% 50% etc.;
3) contrast prevalence of infection in Green parrots and Crimson rosellas;

4) determine if the virus is an endemic or introduced strain;
5) model the demographic trajectory of the Green parrot and Crimson rosella in a worst case scenario

Research Outcomes

This research will determine whether or not Green parrots and Crimson rosellas on Norfolk Island currently harbour Beak and Feather Disease Virus. If the virus is detected, we will be able to determine its placement within viruses worldwide by comparing genome sequences to available sequences on GeneBank. This information will be relevant for the management of the species since it will indicate the prevalence of the virus and its most likely source

Research Activities

DNP is responsible for the collection of samples
Research Organisation is responsible for analysis of samples and dissemination of results

2. Research Title

Breeding biology

Research Objectives

1) to establish breeding success rates;
2) collect morphological data to assist in other research areas and assess chick growth rates;
3) investigate historical versus current management practices;
4) investigate breeding behaviour

Research Outcomes

This research will assist in establishing baseline information about the ecology and biology of the species

Research Activities

1) DNP is responsible for all data collection
2) Research Organisation is responsible for assisting in data analysis
3) DNP and Research Organisation will co-author a peer reviewed journal article

4. Research Title

Investigating movements and behaviour via radio-tracking

Research objectives

To investigate:
1. Home range / territories
2. Dispersal rates
3. Survival rates / causes of mortality
4. Intra-specific interactions
5. Staff capacity building

Research outcomes

To understand how far away juveniles disperse in the landscape, to prioritise areas for cat/rat control/ nest provisioning and also to better understand their family dynamics and patterns of survival, pair formation and territories. This project will also enable DNP staff capacity building so that DNP staff have the skills to monitor parrots using radio telemetry once they have been translocated to Phillip Island.

Research Activities

1) DNP is responsible for all elements of this project
2) Research Organisation is responsible for advice on project implementation

5. Research Title

Spatio-temporal variation in foraging areas of the Tasman Parakeet in the Norfolk Island National Park

E. Environmental Conditions

i. The Research Organisation must take all reasonable steps to minimise the impact of the Research on the environment.
ii. The Research must be conducted out of view of the general public where possible.
iii. Before entering or moving around the Reserve, the Research Organisation must take all reasonable steps to clean vehicles and other transport if they have been off sealed or graded roads.
iv. When visiting Phillip Island, the Research Organisation must abide by the Phillip Island Biosecurity Plan.
v. All traps, nets and any other devices used for capturing and securing animals, and any devices that are to be attached to animals, must be thoroughly cleaned, and free of any pathogens that may cause disease, before they are brought into the Reserve or moved between areas within the Reserve.
vi. The Research Organisation must comply with the conditions specified in Attachment B.

F. Research Period

The Research Period will commence 1st March 2017 and will end on, unless terminated earlier in accordance with this Agreement.

G. DNP's Contribution

DNP agrees to provide the following assistance and facilities, subject to the Reserve's operational needs:

i. Lifts in DNP vehicles;
ii. Use of DNP computers in the Reserve;
iii. Transfers to Phillip Island, so long as they coincide with existing staff transfers;
iv. Use of the Ranger Hut accommodation on Phillip Island;
v. Staff time and expertise;

H. Research Organisation's Contributions

The Research Organisation agrees to provide the following:

i. training and up-skilling DNP staff capacity to monitor Green Parrots using distance sampling methods

ii. a licence to DNP to use data, photos, analysis and other material resulting from the Research for non-commercial Reserve management purposes;

iii. radio trackers and equipment for monitoring

I. Material to be provided by DNP

DNP agrees to provide the following material to the Research Organisation, on the condition that the Research Organisation will use DNP's Material in accordance with the conditions and restrictions set out in Item J [*Use of DNP Material*].

i. DNP's data (such as photos and geo coordinates) relating to Green Parrots;

ii. The following biological material:

Description of biological material	Quantity
(A) Blood and feather samples from Green Parrot specimens	All specimens collected between July 2014 – July 2015
(B) Whole Crimson Rosella specimens	All specimens collected between July 2014 – July 2015

J. Use of DNP Material

Use of DNP's Material by the Research Organisation is on the condition that the Research Organisation agrees to:-

i. only use DNP's Material for the purposes of Item D [*Research*];

ii. obtain written approval from DNP before disclosing or sharing DNP Materials to a third party; and

iii. upon termination of this Agreement (unless DNP agrees otherwise), return all DNP Materials provided and destroy any copies held in the Research Organisation's possession.

K. Confidential Information

i. Location of Green Parrot nest sites

L. Attribution

L.1 – For Research Materials created jointly by DNP and the Research Organisation:

i. Abigail Smith and Dr. Luis Ortiz-Catedral or

ii. as agreed between the parties (including waiving attribution where appropriate).

L.2 – For Research Materials created by DNP or its Personnel:

i. or

ii. as advised by DNP (including waiving attribution where appropriate).

L.3 – For Research Materials created by the Research Organisation or its Personnel:

i. Dr. Luis Ortiz-Catedral; or

ii. as advised by the Research Organisation (including waiving attribution where appropriate).

M. Acknowledgment

DNP is to be acknowledged as follows:

i. This research acknowledges the support provided by the Director of National Parks, and park staff of Norfolk Island National Park and Parks Australia. The views expressed in this document do not necessarily represent the views of the Australian Government."

N. Reporting

N.1 – Meetings

The Research Organisation and DNP agree to meet:

- i. At least once every 3 months during the Research Period to discuss and review the progress of the Research; and
- ii. once at the end of the Research Period

N.2 – Reports

Reports to DNP are to be sent to

Norfolk Island National Park
PO BOX 310, Norfolk Island, South Pacific, 2899

The Research Organisation will provide:

- i. reports as per Research Outcomes in Item D of the Schedule,
- ii. copy of all reports, published documents (such as survey, journals, chapters), and recommendations for management and research arising from the Research within 1 month of publication or finalisation

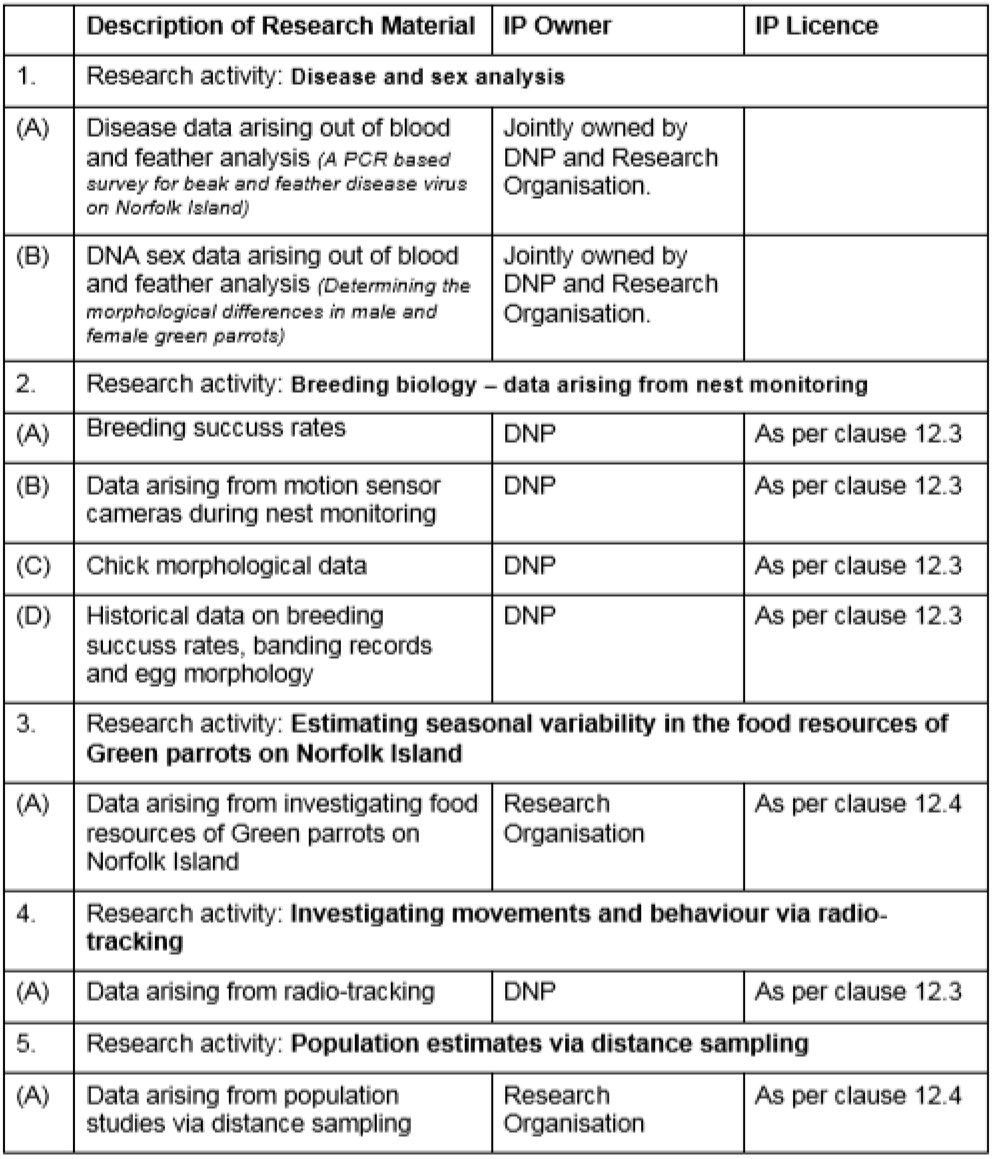
O. Insurance

Each party shall maintain:

- i. workers' compensation insurance for an amount required by the relevant State or Territory legislation; and

P. Intellectual Property

Parties agree that the intellectual property rights in the Research Material will be as follows:



	Description of Research Material	IP Owner	IP Licence
1.	Research activity: **Disease and sex analysis**		
(A)	Disease data arising out of blood and feather analysis *(A PCR based survey for beak and feather disease virus on Norfolk Island)*	Jointly owned by DNP and Research Organisation.	
(B)	DNA sex data arising out of blood and feather analysis *(Determining the morphological differences in male and female green parrots)*	Jointly owned by DNP and Research Organisation.	
2.	Research activity: **Breeding biology – data arising from nest monitoring**		
(A)	Breeding succuss rates	DNP	As per clause 12.3
(B)	Data arising from motion sensor cameras during nest monitoring	DNP	As per clause 12.3
(C)	Chick morphological data	DNP	As per clause 12.3
(D)	Historical data on breeding succuss rates, banding records and egg morphology	DNP	As per clause 12.3
3.	Research activity: **Estimating seasonal variability in the food resources of Green parrots on Norfolk Island**		
(A)	Data arising from investigating food resources of Green parrots on Norfolk Island	Research Organisation	As per clause 12.4
4.	Research activity: **Investigating movements and behaviour via radio-tracking**		
(A)	Data arising from radio-tracking	DNP	As per clause 12.3
5.	Research activity: **Population estimates via distance sampling**		
(A)	Data arising from population studies via distance sampling	Research Organisation	As per clause 12.4

EXEUCTION

Signed as an Agreement

Signed on behalf of **Director of National Parks** by its duly authorised officer in the presence of:)))))

……………………………………….. ……………………………………

[signature of witness] Park Manager

……………………………………….. ……………………………………

[name of witness] [date of signature]

Signed on behalf of **Massey University**, by its duly authorised officer in the presence of:))))) ……………………………………

………………………………………..

[signature of witness] Hon. Steve Maharey

Vice-Chancellor

……………………………………….. ……………………………………

[name of witness] [date of signature]

ATTACHMENT A

Attachment A to the Collaborative Research Agreement.

Spatio-temporal variation in foraging areas of the Tasman Parakeet in the Norfolk Island National Park

ATTACHMENT B

A. General Conditions

A.1 In this Attachment B, unless the contrary intention appears:

EPBC Act means the *Environment Protection and Biodiversity Conservation Act 1999* and all regulations, management plans and instruments made under it, and includes any legislation that amends or replaces it;

EPBC Regulations means the *Environment Protection and Biodiversity Conservation Regulations 2000* and includes all regulations that amend or replace them.

A.2 The Research Organisation must comply with the EPBC Act, the EPBC Regulations, the management plan, the conditions set out in this Agreement, and any other signs, notices, information, guidelines, codes of conduct, protocols or directions issued by, or under the authority of, DNP relating to the reserve.

A.3 The Research Organisation must comply with all Commonwealth, State or Territory laws relating to the Research.

A.4 The Research Organisation must hold all permits, licences and other authorities required by law for the conduct of the Research.

A.5 The Research Organisation must maintain, and must ensure its Personnel maintain, relevant training, qualifications and experience to competently conduct the Research.

A.6 The Research Organisation must carry a copy of this Agreement while conducting the Research, and must produce it for inspection when requested by a ranger or warden.

A.7 The Research Organisation must not, and must take all reasonable steps to ensure that its Personnel do not, walk off track or use any road, track or area that is permanently, temporarily or seasonally closed or restricted by fences, gates or signs, unless specifically authorised by this Agreement or a permit.

A.8 The Research Organisation must not, and must take all reasonable steps to ensure its Personnel do not:

- (a) behave contrary to the EPBC Regulations or any warning or regulatory signs;
- (b) pick fruits, flowers or branches, or otherwise damage any native plants;
- (c) interfere with, feed, handle or disturb any native animal, or damage or disturb a nest or dwelling place of a native animal;
- (d) touch or interfere with any rock art, sacred site or cultural artefact;
- (e) impede public access to any part of the reserve.

A.9 The Research Organisation must notify DNP, in writing, within seven days if:

- (a) the Research Organisation sells any part of the organisation to which the Agreement relates, or for any other reason ceases to conduct the Research;
- (b) the Research Organisation is a company and there is a change in the owners of the majority of issued shares in the company.

A.10 If the Research Organisation is a company or other incorporated body, it must not, without the approval of DNP, have as a director or office holder a person who has been convicted[1] of an offence[2] against the EPBC Act within the previous ten years.

A.11 The Research Organisation must not, without the approval of DNP, use directly in the conduct of the activity to which this Agreement relates the services of any person who has within the previous ten years been convicted of an offence against the EPBC Act prior to the commencement of the Agreement.

A.12 If any of the Research Organisation's Personnel contravene a provision of the Agreement, DNP may:

- (a) notify the Research Organisation of the contravention; and,
- (b) direct the Research Organisation to cease using the services of that person within the reserve for a specified time, and the Research Organisation must forthwith comply with that request.

Note: In this situation DNP will give written notice to that person of the decision, stating that he or she may apply to the DNP to reconsider the decision and that, subject to the Administrative Appeals Tribunal Act 1975*, he or she may subsequently apply to the Administrative Appeals Tribunal for review of the reconsideration.*

A.13 The Research Organisation must ensure that its Personnel are fully informed of and understand these conditions before they commence taking part in the Research.

A.14 The Research Organisation must ensure that appropriate risk management systems, strategies and procedures are in place to minimise foreseeable risks to its Personnel, DNP Personnel, members of the public, and the environment and heritage values of the reserve, and must produce evidence of such systems, strategies and procedures upon request by DNP.

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[1] A person is taken to have been convicted of an offence if, within five years, the person has been charged with, and found guilty of, the offence but discharged without conviction or has not been found guilty of the offence, but a court has taken the offence into account in passing sentence on the person for another offence. Part VIIC of the *Crimes Act 1914* includes provisions that, in certain circumstances, relieve persons from the requirement to disclose spent convictions and require persons aware of such convictions to disregard them.

[2] Such an offence includes, for an offence under such a law, section 6 of the *Crimes Act 1914* or sections 11.1, 11.4 or 11.5 of the Criminal Code (which deal with being an accessory after the fact, attempting to commit offences, inciting to or urging the commission of offences by other people and conspiring to commit offences) or an equivalent provision of a law of a State or Territory.

A.15 The Research Organisation is responsible for the safety, well-being and behaviour of its Personnel, and must take all reasonably practicable steps to ensure that no person is exposed to risks to their health or safety whilst in the reserve.

A.16 If any of the Research Organisation's Personnel is killed, injured, becomes ill, goes missing or is involved in or witnesses a dangerous incident while in the reserve, DNP must be notified as soon as possible and the Research Organisation and its Personnel must comply with all requests and directions from DNP Personnel.

Note: "dangerous incident" means an incident that exposes a person to a serious risk to their health or safety.

A.17 The Research Organisation must ensure its Personnel carry sufficient potable water for the conduct of activities in the reserve.

Note: DNP recommends that, in hot weather, people carry and drink one litre of water for every hour they are active.

A.18 The Research Organisation must make good all damage to the reserve, to the extent that the damage was caused or contributed to by the conduct of the Research or a breach of the Agreement by the Research Organisation.

B. Scientific Research Conditions

B.1 The Research Organisation must take all reasonable steps to minimise the impact of the Research on the environment.

B.2 As much as possible, the Research must be conducted out of the view of the general public.

B.3 The Research Organisation must notify DNP as soon as possible after receiving any request for media comment about the Research. The Research Organisation must consult DNP prior to issuing any comment to the media regarding the Research.

B.4 The Research Organisation must take all reasonable steps to clean vehicles and other transport used in the conduct of the Research, before entering or moving around the reserve, if they have been off sealed or graded roads, to minimise the spread of weed seeds and pathogens in the reserve.

B.5 The Research Organisation must ensure that any vessel used in the conduct of the Research is registered, has appropriate safety equipment on board at all times, and is operated and maintained in accordance with all relevant and applicable laws, and must, if requested by DNP, provide copies of all relevant certificates and other documents evidencing compliance with this condition.

B.6 The Research Organisation must ensure that all traps, nets and other devices used for capturing and securing animals, and any devices that are to be attached to animals, are thoroughly cleaned and free of pathogens that may cause disease, before they are brought into the reserve or moved within the reserve.

B.7 If the Research involves taking whole or part of any organisms, the Research Organisation must record the name of each type of organism, location, date and quantity taken at each location.

B.8 The Research Organisation must ensure that all waste materials and chemical substances relating to the Research are placed in appropriate containers designed to fully confine material, removed from the reserve, and disposed in an environmentally responsible manner.

B.9 The Research Organisation must not discharge into the environment any fuels, fuel-tainted bilge water, chemical wastes from treatment or cleaning of vessels, or any other substance that is likely to adversely affect the environment.

B.10 The Research Organisation must not use a vessel with anti-fouling that contains tributyltin compounds.

B.11 The Research Organisation must ensure compliance with instructions issued from time to time by DNP regulating boat speed and measures to be taken to avoid or minimise environmental damage from water-related activities.

C. Norfolk Island Conditions

C.1 On each visit to the reserve, and at least five business days prior to conducting any Research activities, the Research Organisation must provide DNP with details of all vehicles and persons participating in the Research activities during the visit, and all further details DNP may reasonably request.

C.2 The Research Organisation must be contactable via radio or telephone (or both) at all times when conducting Research activities in the reserve, including on Phillip Island.

C.3 Research Organisation Personnel must not drive, ride or tow vehicles other than on designated roads and parking areas.

Note: Maximum size of vehicle permitted in the reserve:

Mount Pitt Road	*Park except Mt Pitt Road)*
Length: 6.5 metres	*Length: 7.0 metres*
Width: 2.2 metres	*Width: 2.3 metres*
Wheelbase: 3.7 metres	*Wheelbase: 2.8 metres*

C.4 The Research Organisation must endeavour to minimise damage to tracks, and in particular not to cause the tracks to become deeply rutted.

C.5 The Research Organisation must comply with directions from DNP staff and officers of the Norfolk Parks and Forestry Service regarding access conditions in the Forestry Area.

C.6 The Research Organisation must not interfere with any seabirds or nests on Phillip Island unless specifically authorised by this Agreement.

C.7 The Research Organisation must be accompanies by a guide approved by the Park Manager when undertaking Research on Phillip Island.

ATTACHMENT C

Attachment C to the Collaborative Research Agreement.

Parks Australia Research Publishing Policy