Behaviour and Diet of the Tasman parakeet (*Cyanoramphus cookii*) on Norfolk Island, South Pacific.

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Figure 1. Tasman parakeet (*Cyanoramphus cookii*) (top) and Crimson rosella (*Platycercus elegans*) (bottom) on Norfolk Island. Photos: L. Ortiz-Catedral and C. Doolan.

GENERAL ABSTRACT

Conservation of threatened species requires an understanding of their biology in the wild, including aspects of their dietary diversity, general behaviours and interactions with other species. For many threatened species however, obtaining even basic information about their biology in the wild proves challenging. This is because they often occur in small numbers, or in remote locations, limiting our ability to quantitatively describe behaviours. The Tasman parakeet (*Cyanoramphus cookii*) endemic to Norfolk Island, has experienced two cycles of critically low numbers in the last 40 years. Since the 1970s, the species is the subject of regular management, chiefly including introduced predator control and the provisioning and maintenance of predator-proof nests within the Norfolk Island National Park. These actions have resulted in population increases to approximately 400 individuals by 2018. As Tasman parakeets numbers increase, managers face challenges to target interventions that could help Tasman parakeets establish and reproduce as they disperses outside the National Park. In this thesis I examine the behaviour of Tasman parakeets and crimson rosellas (*Platycercus elegans*) during winter and spring to understand the response of both species to disturbance (presence of observers). I also examined the diversity of food species consumed by Tasman parakeets and crimson rosellas within and outside the boundaries of the National Park. During this research, Tasman parakeets were first sighted at shorter distances than crimson rosellas, furthermore, Tasman parakeets were observed at lower heights than crimson rosellas. Overall, these findings reinforce that Tasman parakeets are behaviourally more vulnerable to introduced predators than crimson rosellas, with further research required. I also determined that Tasman parakeets and crimson rosellas overlap in feeding resources and both species rely heavily on seeds of Norfolk pine (*Araucaria heterophylla*) during winter, however further examination of seed availability and potential competition is required.

ACKNOLEDGEMENTS

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 in New Zealand or overseas. Except where acknowledged, 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 copyright restrictions. The research presented here is part of a multi-year research project on the conservation of the Tasman parakeet (*Cyanoramphus cookii*) developed since 2013 by my supervisor Dr. Luis Ortiz-Catedral in conjunction with the Norfolk Island National Park authority, Island Conservation, The World Parrot Trust and BirdLife Australia. Dr. Luis Ortiz-Catedral allowed me to execute the research described according to a research permit by the Australian Department of Environment (Appendix I). Dr. Ortiz-Catedral and I coordinated the logistical support necessary to complete this investigation, and obtained the relevant permissions for accessing study sites. Financial support for the project was obtained from the New Zealand Parrot Trust, World Parrot Trust and Disney Conservation Fund. 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.

Georgia M. Brett

Auckland, New Zealand, August 2020

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CHAPTER I: GENERAL INTRODUCTION

Figure 2. The author at the Point Ross Reserve lookout. Phillip Island in the distance. Photo:

L. Ortiz-Catedral.

INTRODUCTION

The current global biodiversity extinction crisis

The extinction of species or complete disappearance of a reproductive and evolutionary lineage is an ongoing global issue with an estimated 32, 000 species risk across taxonomic groups (Delord, 2007). Recent estimates of extinction risk reveal that between 15-37% species will disappear by 2050 (Thomas et al., 2004). This estimate, however, refers largely to human-caused or human-mediated extinction. In the 540 million years of fossil record evidence, there are five major events where over half of all taxa became extinct (Benton, Wills, & Hitchin, 2000; Raup & Sepkoski, 1982), these events are collectively known as mass extinctions. For certain animal groups well represented in the fossil record, such as mammals, a background rate of extinction can be derived (Ceballos et al., 2015). After examining conservative datasets, Ceballos et al. (2015) estimates a rate of two species extinctions, per 10,000 species per 100 years. At present, the estimated rate of species extinction across vertebrate groups is nearly 100 times higher than the background extinction rate (Ceballos et al., 2015). The alarming rate of species extinctions has led some scientists coining the term 'Anthropocene extinction' or sixth mass extinction (Barnosky et al., 2011; Ceballos et al., 2015; Dirzo et al., 2014) to highlight the role of humans and human activities have on the unprecedently high rate of species extinction.

The onset of the Anthropocene is marked roughly from the early 1600's to the mid 1900's, reflecting a period when humanity began to significantly alter the planet's ecosystems via industrialisation and rapid urban expansion (Lewis & Maslin, 2015). This period is associated with significant changes in the biosphere caused by increased greenhouse gasses from the industrial revolution, resulting in a new era of human dominated activity and environmental modification (Smith & Zeder, 2013). For decades, scientists around the globe

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have warned how the effects of human activity will impact the environment and animals, concluding that if current trends of anthropogenic environmental and climate change continue, the planet's biota will be unable to cope and perhaps reversal of climatic changes will be unattainable without significant loss. The human induced environment environmental effects are not globally homogeneous, where some areas are more threatened with anthropogenic activities than others. In general, these areas generate comparably higher diversities and distinctiveness of taxa. Areas that display above average diversity, richness, endemism or number of threatened of species are known as biodiversity hotspots (Myers, 1988, 1990; Myers, Mittermeier, Mittermeier, Da Fonseca, & Kent, 2000; Reid, 1998). Myers (1988) first described biodiversity hotspots by the former parameters, as well as by a significant loss of habitat, and later defined a hot spot criterion. To be classified as a hotspot, an area must contain at least 1,500 endemic plants, with a proxy for 20 animal species per plant species, and have 30% or less of original vegetation remaining (Myers et al., 2000). Of the 25 biodiversity hotspots identified, Myers (2000) estimates show a high percentage of Earth's plant and animal groups, 44% and 35% respectively, are restricted to only 1.4% of Earth's surface land. Further, anthropogenic changes occur at a faster rate than normal environmental change, increasing risk to vulnerable species with slow rates of adaptation (Joos & Spahni, 2008). Climate change models account for complex systems that forecast for future climate change scenarios, but accounting for uncertainties anthropogenic disturbances, like the introduction of species is also necessary (Allen, Stott, Mitchell, Schnur, & Delworth, 2000). Biodiversity hotspots are used by conservationists to concentrate efforts on threatened species and areas which are most at risk with extinction. Clearly, the task to develop management interventions to prevent the extinction of species in biodiversity hotspots is overwhelming.

Understanding the biology of species for conservation management

Conservation practice, the application of principles of conservation science to downgrade the threat status of species, requires detailed information about the biology of taxa of interest. This is because understanding fecundity, population size, dietary diversity, behaviour etc. can assist wildlife managers and conservation practitioners in identifying factors causing the decline of a population at a given area, or of a species across its range. For instance, marine iguanas (*Amblyrhynchus cristatus*) from the Galapagos Islands, have existed without mammalian predators for some 5-15 my, until humans introduced cats (*Felis catus*) and feral dogs (*Canis faamiliaris*) to the archipelago ca. 1850 (Arteaga et al., 2019; Rödl et al., 2006). During experimental chases of marine iguanas, designed to measure stress response and anti-predator behavioural response, Rödl et al. (2006) found that marine iguanas fail to mount a corticosterone stress response after successive chases, which severely restricts their ability to escape predation from introduced mammals. This study suggests that marine iguanas are behaviourally and physiologically restricted in their response to introduced mammal predation. The feral dog population in Puerto Ayora, the largest township of the Galapagos Islands is estimated at nearly 4000 dogs (Hernandez et al., 2020), which represents a substantial predation pressure to the local marine iguana population. Due to the limited escape response of marine iguanas and growing feral dog population, a potential practical conservation approach would be to upscale current spay-neuter efforts (Hernandez et al., 2020) and promote responsible dog ownership (i.e. maintain dogs on leash) in or around areas of human, dog and marine iguana activity.

Another example highlighting the importance of knowledge about the biology of a species and conservation practice, is the current conservation management of the world's only flightless nocturnal parrot: The Kakapo (*Strigops habroptila*). Kakapo exhibit a lek-breeding

system where males congregate in display arenas and attract females by booming (Powlesland et al., 1992). Females rely on heavy masting (large-scale fruiting) of native trees, in particular rimu (*Dacrydium cupressinum*) to gain weight ahead of the breeding season and reach a minimum body condition to reproduce (Fidler et al., 2008). Interestingly, in accordance to classic Trivers and Willard hypothesis, females in better body condition tend to produce males (Tella, 2001; Clout et all., 2002), which has resulted in a heavily skewed sex ration in offspring towards males. Up until the early 2000s, paradoxically the increase in numbers of Kakapo offspring appear to limit the potential of recovery of the species, as female chicks were very rare. Nevertheless, since the discovery of the link between female body condition and the resulting skewed sex ratios in offspring, the New Zealand Department of Conservation has used this information to monitor the weight gain of females via supplementary feeding, fine tuning thus the production of male and female offspring (Balance, 2010). These two examples serve to illustrate the importance of a detailed understanding of the biology of a species of conservation concern, to develop adequate conservation management interventions. The two examples above refer to island species. Both, marine iguanas and kakapo inhabit or have formerly inhabited various islands in the Galapagos archipelago and New Zealand respectively. In fact, numerous studies documenting the advancement of conservation practice relate to island species. This is because a disproportionately large number of species threatened with extinction occur on islands (Meyers, 2000).

Islands: globally threatened biodiversity hotspots

While many mainland hotspot areas are threatened, islands make up a large proportion of biodiversity hotspots and face a unique suite of threats. Species which evolve on islands typically share similar life history traits due to the homogeneity of islands conditions, e.g.

reduced fecundity, more time investing in young, young have longer developmental periods (Covas, 2012). Additionally, islands species also exhibit lower species diversity, higher endemism and less available habitat, resulting in island taxa differing in life history and reproductive traits from that of closely related mainland species (Covas, 2012). In most cases, isolation has been reasoned to be the key evolutionary driver that influence the evolution of these traits. Depending on the length of isolation, evolutionary rate has been found to be relatively higher in insular species. For example, a study lead by Millien (2006) was the first to test this hypothesis and found that the morphology of insular mammals over short time periods, up to several 1000 years, displayed faster rates of evolution than mainland groups.

Islands species are therefore positioned to experience high rates of extinction (Frankham, 1998). Besides the intrinsic biological features that make island species vulnerable, an increasing number of island species are at risk of extinction due to potential sea level rise as a result of climate change (Wetzel et al., 2013) and invasive species. Invasive species have been introduced around the globe both deliberately and accidentally. These introductions almost always accompany the spread of human settlement (Blackburn et al., 2004). Islands which are naturally isolated with highly endemic biota can experience dramatic impacts from introduced plants and animals, driven by human colonisation and subsequent agricultural growth (Druett, 1983). Worldwide, island species contribute 19% of the worlds endangered birds (Johnson & Stattersfield, 1990). Introduced predators that have the largest effects on island birds include the Pacific rat (*Rattus exulans*), Norway rat (*Rattus norvegicus*), ship rat (*Rattus rattus*) and feral cat (*Felis catus*), as well as mustelids like stoats (*Mustela erminea*) (Atkinson & Atkinson, 2000). Often island species evolve without the presence of natural mammalian predators making them particularly vulnerable to these introductions (Duron et al., 2017). Mammalian predators rely on different hunting characteristics, specifically more heavily on olfactory senses to track prey. Without anti-predator responses, island species are not adapted to avoid or protect

against invasive mammals. For instance, when New Zealand kiwi (*Apteryx* spp), are exposed to introduced stoats (*Mustela erminea*), kiwi populations are quickly depredated. Kiwi have a distinct, strong scent, and forage and call loudly (Diamond, 1989). Evolving in a mammalian-free environment meant they did not have hunting pressure from scent orientated predators, thus, when stoats, which primarily use scent to track and find prey are introduced, they become highly vulnerable (Prince & Banks, 2016). To mitigate this, conservation efforts in place to protect kiwi at their most vulnerable age, Operation Nest Egg, raises kiwi chicks until they are an appropriate age to be released in the wild, thus increasing the number of kiwi reaching sexual maturity (Colbourne et al, 2005). Island avifauna are more vulnerable to invasive species and therefore need additional preventative measures against predation and competition (Atkinson & Atkinson, 2000).

Psittaciformes conservation

The order Psittaciformes (Parrots and allies) contains a high proportion of endangered and threatened species, and also a high proportion of species whose basic biology remains undocumented (Masello & Quillfeldt, 2002). Approximately 30% of species are classified as threatened with extinction (Snyder et al., 2000; Forshaw, 2017). Parrots diversified during the Cretaceous period (82 million years ago) and today are widely distributed throughout tropic and temperate zones (McNab & Salisbury, 1995; Wright et al., 2008). Their evolutionary distinctiveness and ecological diversity makes Psittciformes a significant element of these temperate, subtropical and tropical environments worldwide. Throughout their distribution, Psittaciformes face a number of regionally variable threats. For instance, in Central and South-America (Wright et al., 2001) as well as Africa and South-East Asia (Pain et al., 2006), several species of parrots are threatened with poaching and illegal trade. Additionally, habitat loss is

an major threat for parrots in these regions (Olah et al., 2006). For island species in particular, depredation by invasive species represents a major threat (Robinet et al., 1998; Engeman et al., 2006; Olah et al., 2018).

In the South Pacific region, *Cyanoramphus* parrots historically experience the largest number of species extinctions as a result of the introduction of invasive species by humans. Invasive species on South Pacific islands, in particular rats, mustelids and feral cats prey on birds at all stages of life: clutches, broods, nesting pairs, fledglings and adults (Taylor, 1979; Karl and Best, 1982; Robinet et al., 1998; Medina et al., 2011). *Cyanoramphus* is exclusively an insular genus, represented predominately on New Zealand and outlying islands (Taylor, 1985; Silva, 1989; Forshaw, 2017). Historically, the genus was distributed from French Polynesia, to New Caledonia, New Zealand and to sub-Antarctic islands of New Zealand and Australia (Macquarie Island) (Taylor, 1979; Taylor, 1985; Forshaw, 2017).

The management of invasive species, including introduced predators in New Zealand has significantly improved the conservation of populations and species of *Cyanoramphus*. For instance, following the eradication of rats and cats on Raoul Island in the Kermadec archipelago, the Kermadec parakeet (*Cyanoramphus novaezelandiae cyanurus*) recolonised Raoul Island from nearby predator-free islets (Ortiz-Catedral et al., 2009). In another example, Red-fronted parakeets (*Cyanoramphus novaezelandiae*) have been successfully reintroduced to Matiu/Somes and Motuihe Islands, following introduced predator eradication and habitat restoration (Ortiz-Catedral et al., 2010; Ortiz-Catedral and Brunton, 2010). Further, the reintroduction of captive-bred Orange-fronted parakeets (*Cyanoramphus malherbi*) to predator-free offshore islands, has enabled the creation of "insurance" populations of the species (Ortiz-Catedral et al., 2010a; Ortiz-Catedral et al., 2010b; Skirrow, 2018). Despite these examples, *Cyanoramphus* parakeets remain threatened with extinction. One species in

particular, the Tasman parakeet (*Cyanoramphus cookii*) (Fig. 1, Fig. 3), endemic to Norfolk Island, has experienced two historical periods of critically low numbers in the 1970s and again in the early 2000s (Hicks and Greenwood, 1989; Ortiz-Catedral et al., 2018). The Tasman parakeet was common at the time of first European colonisation of the island, and also occurred on nearby Phillip Island, where it was registered by Allan Cunningham in 1830 (Mills, 2012). The Lord Howe parakeet (*Cyanoramphus subflavescens*), a subspecies of Tasman parakeet also existed on Lord Howe Island until 1880's, but was hunted to extinction by early settlers (Higgins, 1999; Hill, 2002). Tasman parakeets illustrate the predicament of many island species, and represents a role for conservation and biological understanding in their recovery.

Conservation of Tasman Parakeet

Current conservation of the Tasman parakeet is the responsibility of the Norfolk Island National Park authority, part of the Department of Environment Australia. The National Park authority partners with NGOs, local organizations and universities in Australia and New Zealand to investigate aspects of the biology of the Tasman parakeet that could improve the conservation of the species. The intensity of conservation management for Tasman parakeet has fluctuated according to the severity of declines and newly identified conservation goals (Ortiz-Catedral et al., 2018). Current conservation efforts primarily focus on providing predator proof nest sites, controlling competition with introduced species, and ultimately ongoing monitoring to ensure success and sustainability of the recovery programs (Ortiz-Catedral et al., 2018). These actions have significantly improved the population status of the Tasman parakeet, which has increased from an estimated 50-100 individuals to 220-400 between 2013 and 2018 (Skirrow, 2018). However, these actions take place only within the protected area of the National Park, the last significant remnant of subtropical rainforest on Norfolk Island.

Tasman parakeet's nest in tree hollows and other cavities in competition with Crimson rosellas (*Platycercus elegans*) and European starlings (*Sturnus vulgaris*) (Garnett et al., 2011). To prevent nest predation, tree hollows are modified to prevent rats from gaining access and create a predator free breeding habitat (Ortiz-Catedral et al., 2018). Tasman parakeets indicate positive signs of successful management relatively quickly, laying large clutches and reaching sexual maturity at an early age, with nest success recorded at 70% in the 2016 breeding season. Future conservation efforts include establishing an insurance population on Phillip Island and investigating the possibility of an introduction to Lord Howe Island (Hill, 2002; Ortiz-Catedral et al., 2018).

The Tasman parakeet is categorised as Endangered (environment.gov.au) and has a current estimated population size of approximately 400 individuals (Ortiz-Catedral et al., 2018). A midsized parrot, the Tasman parakeet faces the same threats as other island species: higher extinction risk driven by evolution in predator free environments where common mainland predators and competitors are absent (Biber, 2002), such as the Norway rat, Black rats and the domestic cat (Arcilla, Choi, Ozaki, & Lepczyk, 2015; Biber, 2002; Garnett, Olsen, Butchart, & Hoffmann, 2011). Other invasive species could exacerbate the situation for island endemics, via habitat degradation and destruction, potential new diseases, and increased depredation rates (Arcilla et al., 2015).

Although conservation management outlined above has been successful and has resulted in measurable population increase, the conservation of the species is entering a new phase. Increasingly, Tasman parakeets venture outside the National Park into private gardens and farms (Simmonds, 2020) as well as urban areas and regional reserves (M. Christian, pers. comm.). Areas outside the National Park do not have the same level of predator control or nest provisioning and have significantly different habitat features and vegetation composition. This

situation resembles a source-sink system (Perkins et al., 2003) where parakeets move from a high-quality environment (the National Park) to suboptimal areas. Moreover, while there is a general understanding of the biology of the species within the National Park (Waldmann, 2016; Skirrow, 2018; Simmonds, 2020) little is known about the biology of the species outside the National Park boundaries. Specifically, it is not known whether Tasman parakeets forage on the same plant species, and whether they exhibit behavioural flexibility that would enable them to successfully establish in forested areas outside the National Park. Understanding their patterns of habitat use and behaviour outside the National Park area, can provide information to develop targeted management to extend the area inhabited by Tasman parakeets. For instance, if Tasman parakeets outside the National Park nest on cliffs or rocky outcrops, targeted baiting and predator control could be implemented in addition to forested areas. Since management actions on Norfolk Island convey a considerable cost, fine-tuning of these to maximise conservation cost-benefits requires as much information as possible on the biology of the species outside the boundaries of the National Park.

A similar-sized parrot, the crimson rosella has successfully established within and outside the boundaries of the National Park. Furthermore, this is a very abundant species commonly seen on private gardens, paddocks, urban areas and reserves (Christian, 2005). To date, no study has simultaneously investigated the behaviour of crimson rosellas and Tasman parakeets within and outside the National Park.

The present study

This thesis aims to contribute to conservation planning for Tasman parakeets on Norfolk Island at a time when the species is expanding and potentially establishing in habitats outside boundaries of the National Park. Management of the Tasman parakeet within the National Park consists of nest modifications to prevent access to introduced predators (Ortiz-Catedral et al.,

2018), baiting introduced rats, culling feral cats, and culling of crimson rosellas, which compete for nesting sites (Skirrow, 2018). These actions are complemented with replanting of native vegetation and removal of introduced plants (Director of National Parks, 2008). There are considerable areas of regenerating habitat outside the National Park where Tasman parakeets could establish, mostly reserves managed by the Norfolk Island Regional Council, and vegetated edges between private properties and farms (see Chapter 4). There are also thickly vegetated road edges that could act as stepping stones of corridors for Tasman parakeets (see Chapter 4). All these areas are inhabited by crimson rosellas and have limited to no predator control. Although there is a general agreement on the negative effects of crimson rosellas on the Tasman parakeet population (Hicks and Greenwood, 1989; Forshaw 2017; Snyder et al., 2000), it is unclear what behavioural traits enable crimson rosellas to thrive on Norfolk Island in stark contrast to the similar-sized Tasman parakeet.

Study species: Tasman Parakeet and Crimson Rosella

Tasman parakeet

(*Cyanoramphus cookii* sensu Boon et al., 2001; Platycercinae; Psittaciformes)

Locally known as "green parrot" or "griin paerat" in Norfuk language, or by other common names; Norfolk Island Green parrot or Norfolk parakeet, Tasman Parakeet, this is a medium-sized bird (30-35 cm length; 120-150 g) (Ortiz-Catedral, unpublished). The plumage is uniformly green, except in the forehead, crown and behind the eye, where they exhibit

crimson colouration (Fig. 3). They also have blue edging of the primary-covert feathers of the wings (Forshaw, 2017).   Their coloration closely resembles that of other *Cyanoramphus* species such as New Zealand Red-crowned (*C. novaezelandiae*), New Caledonian parakeet (*Cyanoramphus saisseti*) and the extinct Macquarie parakeet (*Cyanoramphus erythrotis*) (Higgins, 1999). This results in a complex taxonomy and inconsistencies in the recognition of the Tasman parakeet as a separate species to the nominal red-crowned parakeet (see Chapter 4).

Adult male and female Tasman parakeets are similar in appearance, however, are distinguishable by size and beak shape. Males have a larger head, larger red crown and a wider culmen than females (Hill, 2002) (Fig. 4). Juveniles have flesh-coloured beak and bare parts (Hill, 2002) (Fig. 5). The Tasman parakeet is categorised as Endangered under the EPBC Australia (environment.gov.au) and is limited to last major tract of subtropical rainforest within the National Park (350-400ha) (Hill, 2002). Tasman parakeets feed on leaves, flower buds, fruits and seeds (Waldmann, 2016) (see also Chapter 3 and Appendix IV).

Crimson rosella

 (*Platycercus elegans*; Platycercinae; Psittaciformes)

Known locally on Norfolk Island as "red parrots", crimson rosellas are medium-sized birds (32-38 cm length, 120-170 g) with bright red plumage covering most of the body and blue patches on the cheeks, dark blue tail diffusing to white, light blue upper wing, with a black pattern on back and inner wing (Higgins, 1999) (Fig. 3). Adult males and females are similar in colouration, but males are approximately 15% larger than females (Krebs, 1998) and have larger heads, and broader culmen (Higgins, 1999; Forshaw, 2006) (Fig. 4). Juvenile crimson

rosellas are very different in colouration exhibiting a wash of bright green over most of the body and head, and thus can be mistaken for Tasman parakeets (Higgins, 1999; Forshaw 2006) (Fig. 5).

Crimson rosellas have a wide distribution, native to eastern and south-eastern territories of Australia, with introduced populations in Norfolk Island as well as North Island, New Zealand (Higgins, 1999; Forshaw, 2006). Crimson rosellas were introduced to Norfolk Island as cage birds by the first penal colonists in the 1800s (Higgins, 1999; Christian, 2005). Escaped or deliberately released birds then established a wild population and were recorded in large numbers by the early 1990s (Higgins, 1999). Since then, crimson rosellas are abundant throughout almost all available habitat on Norfolk Island, including the National Park (Skirrow, 2018), regional reserves and private land and gardens (Christian, 2005). Crimson rosella population inside the National Park is estimated to be 1, 200 – 1, 300 (Duston, 2013; Skirrow, 2018). In their native range they feed on fruits, seeds, flowers, leaves and invertebrates (Higgins, 1999). Crimson rosellas are secondary cavity nesters, and nest in a variety of hollows in their native range (Krebs, 1998).

Figure 3. Adult Tasman parakeet (top) and adult crimson rosella (bottom). Both species exhibit a distinct colouration, although juvenile crimson rosellas have green feathers and can be mistaken for Tasman parakeets (see text). Note dark skin of feet. Photos: L. Ortiz-Catedral and B. Tregear.

Figure 4. Top: Male and female Tasman parakeet, the female is perched higher on the branch.

Bottom: Male and female crimson rosellas, female on the left.

Figure 5. Juvenile Tasman parakeet (top) and crimson rosella (bottom). Note the lighter colour of feet's skin, and the green colouration in juvenile crimson rosellas. Photos: L. Ortiz-Catedral and G. Rose.

Study area and study sites

I conducted the research on Norfolk Island (29^0 02' S, 167 ^{0}57' E), south west in the Pacific Ocean (Garnett et al., 2011) (Fig. 6). Norfolk Island and its outlying islands and islets represent an isolated landmass of complex origin with an approximate area of 3455 ha (Director of National Parks, 2008). Norfolk Island is located 1,676 km north east of Sydney (GHD, 2016). The Norfolk Ridge, which underlies Norfolk Island and its islets and islands, separated from Gondwana in the late Cretaceous (Coyne, 2009). Norfolk Island is administered by the Australian Government, and its official title is "Territory of Norfolk Island", and it has a human population of approximately 1,900 people (Geoscience Australia, 2020). The topography of Norfolk Island is varied, with steep hillsides, coastal areas, rocky outcrops and boulder beaches (GHD, 2016). The climate of Norfolk Island is maritime subtropical, with average summer temperatures in the 19° - 25° C range, and average winter temperature in the 13° – 19° C (Maynard et al., 2018).

The largest section of native habitat on Norfolk Island is the National Park, which contains the last significant remnant of subtropical rainforest (Fig. 7). The National Park has multiple accessible visitor tracks that cover a diversity of habitats and altitudinal range. There are approximately 180 native plants, 40 of which are endemic. Some examples of significant plant species in the National Park include the Norfolk Pine (*Araucaria heterophylla*), Niau (*Rhopalostylis baueri*), Cabbage tree (*Cordyline australis*) and Norfolk tree fern (*Sphaenopteris excelsa*) (Simmonds, 2020). Outside the National Park the largest forested areas consist of a network of 16 mainland reserves administered and managed by the Norfolk Island Regional Council, in addition to Nepean Island, a small islet off the southern coast of Norfolk Island, also administered by the Norfolk Island Regional Council. Mainland reserves vary in size from 0.2 ha (Middleridge Reserve) to 32.45 (Cascade Reserve) (Appendix V). The

vegetation in reserves is variable but often consists of a mix of pasture (GCH, 2016) (cattle grazing is allowed in five mainland reserves), as well as introduced weedy species like Hawaiian holly (*Schinus therebintifolia*), African olive (*Olea europea cuspidata*), and wild tobacco (*Solanum mauritianum*) (Appendix V). Eight of these reserves include significant portions of remnant native vegetation and were selected for this study based on their habitat structure and vegetation characteristics (Fig. 8) (Table 1). Access to the reserves to conduct filed observations was granted by the Norfolk Island Regional Council (Appendix II).
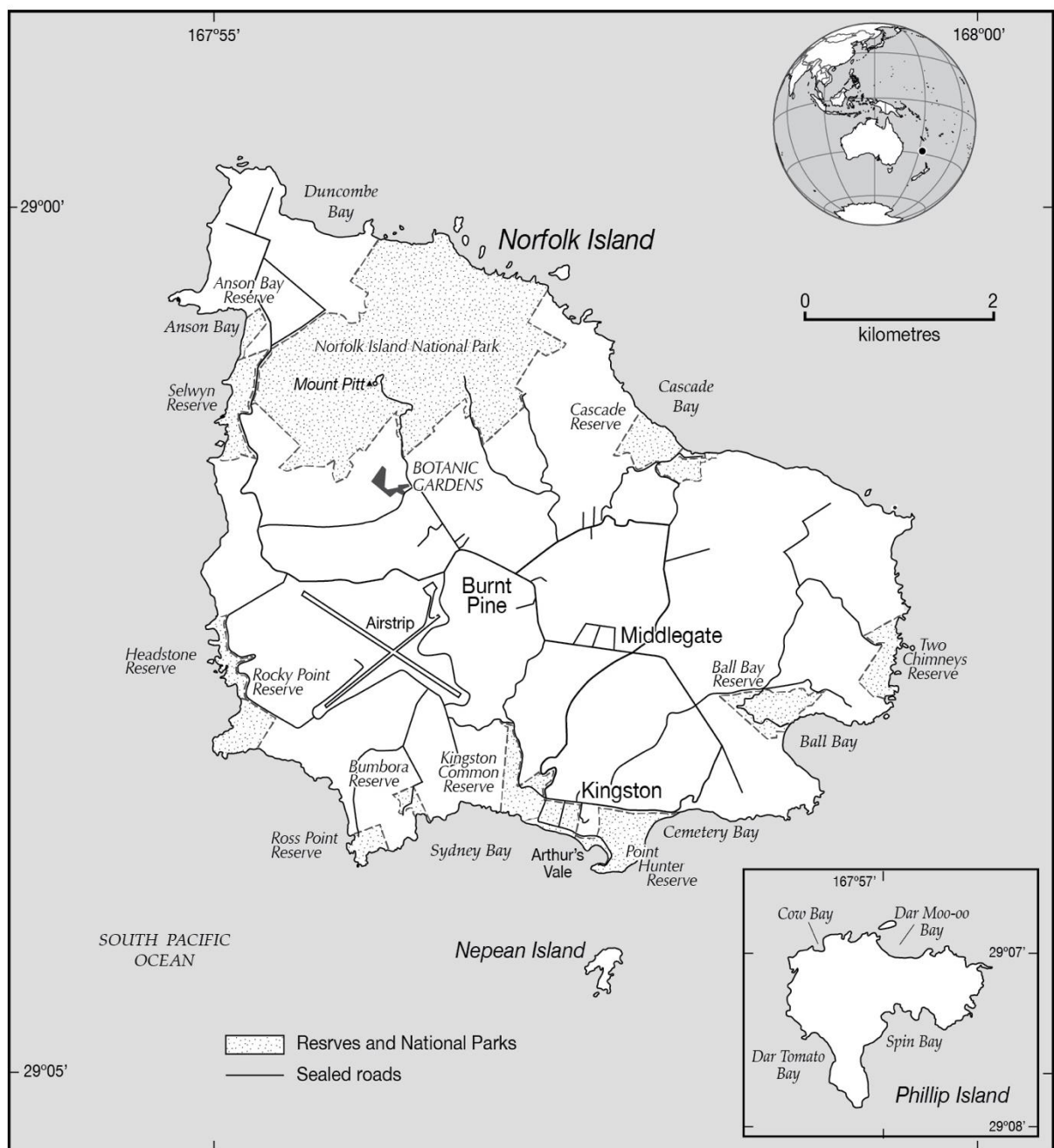
Figure 6. Norfolk Island map showing road network, reserves and National Park. Image:
Norfolk Island Regional Council.

Figure 7. Top: Entrance to the Norfolk Island National Park, via Red Road. The sign at the entrance displays the visitor track network. Bottom: view from the summit of Mount Pitt, the highest point on the island. Photos: L. Ortiz-Catedral.

Figure 8. Landscape view of reserves selected for this study. Reserve area in parentheses. Photos: L. Ortiz-Catedral.

Figure 8 continue. Landscape view of reserves selected for this study. Reserve area in parentheses. Photos: L. Ortiz-Catedral.

Thesis aims

The general aim of this thesis is to understand the biology of the Tasman parakeet across the diverse habitats of Norfolk Island to better assess the potential for recovery of the species, taking into account current habitat types and use by Tasman parakeets and crimson rosellas. To this end, I measured the behavioural responses of Tasman parakeets and crimson rosellas to disturbance (presence of an observer) within and outside the boundaries of the National Park. I also determined the dietary preferences of both species within the National Park and on the reserves managed by the Norfolk Island council. Specifically, I was interested in determining the extent of overlap and potential for resource competition between both parrot species.

COVID-19 declaration

The project presented here was originally planned to cover all four seasons, not only winter and spring. However, due to circumstances beyond my control, I was only able to visit Norfolk Island in two occasions in 2019. My supervisor and I discussed the possibility of at least one field visit in early 2020, however due to the COVID-19 pandemic and the travel restrictions in place, these plans did not eventuate. Besides the restrictions in place that prevented me from visiting Norfolk Island, the COVID-19 pandemic and the resulting lockdown in New Zealand from March to June 2020, and again during August 2020 have affected my ability to analyse datasets, and organise the results of this thesis as originally planned.

Thesis outline

The present thesis consists of four chapters, prepared in the standard thesis format. I also include an article I had the opportunity to write during the development of this thesis (Appendix IV). This article includes preliminary observations on the behaviour of Tasman parakeets conducted by my supervisor and volunteers on Norfolk Island in 2015. These data were useful in helping me prepare the current thesis. I prepared drafts of this paper and together with my supervisor completed the relevant analyses.

Chapter one

In this chapter I present a general introduction outlining the extent of the species extinction crisis and highlight threats to parrots worldwide. I also describe threats to island parrot species, in particular Tasman parakeets. I also provide a description of my study species, study sites and the general aims of this thesis.

Chapter two

Chapter two focuses on an investigation into the behaviour of Tasman parakeets and crimson rosella. Specifically, I investigate the responses of both species to disturbance: presence of an observer. These responses represent proxies to understand vulnerability to potential predators and can help us better understand the behavioural flexibility of Tasman parakeets to establish in new environments.

Chapter three

In this chapter I compare the dietary diversity and niche overlap of Tasman parakeet and the crimson rosella to better understand the potential of competition for food resources between both species. Historically, crimson rosellas are considered strong competitors to Tasman parakeets. While there is information on interference caused by crimson rosellas to nesting pairs, there is little information available on the range of food types and food species that crimson rosellas consume, and what degree of overlap exists with Tasman parakeets.

Chapter four

This chapter includes recommendations for future studies that can help advance the conservation of the Tasman parakeet. The long-term conservation of the Tasman parakeets could be substantially improved by strategically restoring habitats outside the boundaries of the National Park. I outline three potnetial avenues for future research to explore this aspect.

CHAPTER TWO: COMPARATIVE BEHAVIOUR OF TASMAN PARAKEETS (*CYANORAMPHUS COOKII*) AND CRIMSON ROSELLAS (*PLATYCERCUS ELEGANS*).

Figure 9. Crimson rosella. (*Platycercus elegans*) (Left) and Tasman parakeet (*Cyanoramphus cookii*) (Right) feeding. Photos: B. Tregear and L. Ortiz-Catedral.

ABSTRACT

In this chapter I present a comparative analysis of behavioural responses of the endangered endemic Tasman parakeet (*Cyanoramphus cookii*) and introduced crimson rosella (*Platycercus elegans*) behaviour. I investigate how behaviour and disturbance responses differ between both species. As indicators of response to disturbance and behavioural flexibility, I compared the average height at first sighting, height at start of observation and distance from observers between seasons and species. I compared spatial and seasonal differences among the Norfolk Island National Park and eight regional reserves, during winter and spring 2019. Crimson rosella rested alert ($p = 0.0001$) and perform agonistic behaviours ($p = 0.04$) more frequently that Tasman parakeets. Additionally, Tasman parakeets feed more frequently ($p = 0.0001$). During winter, Tasman parakeets were found at lower heights at the start of observations ($p = 0.03$). In the National Park , crimson rosellas are found at significantly different distances between seasons ($p = 0.001$, winter: x̄ = 24.2 m, spring: x̄ = 36.1 m, σ = 3.41). Comparing the National Park and reserves, crimson rosellas were found resting alert significantly more frequently in reserves than in the National Park ($p = 0.04$), and are able to be observed for longer periods ($p < 0.0001$) and further distances in reserves (0.0007). Between species, Tasman parakeets occur at lower heights and further distances than crimson rosellas in the National Park (Table 4). Moreover, Tasman parakeets are observed for longer periods than crimson rosellas ($p = 0.04$). The Tasman parakeets' lower response to disturbance, as assessed by the presence of observers and predominant foraging at lower altitudes, highlights the dependence on introduced predator control to protect the species. Targeted control of introduced predators on Norfolk Island reserves is thus a requirement for the establishment of Tasman parakeets beyond the boundaries of the National Park.

INTRODUCTION

Understanding the behaviour of threatened species is important to identify and advance conservation goals. One of the earliest examples of behavioural observations assisting the recovery of a threatened species, relates to the Puerto Rican Parrot (*Amazona vittata*), an island endemic reduced to only 13 individuals in the 1970s (Snyder et al., 1987). Puerto Rican parrots exhibit age-related differences in patterns of nest attendance behaviour: young, often first-time breeding birds incubate and attend broods less consistently than older individuals, which leads to higher rates of egg and chick loss (Snyder et al., 1987; Wilson et al., 1995). By artificially incubating eggs at risk, alongside predator control and nest-box provisioning, the species has recovered to approximately 400 captive individuals and 84 wild birds (White, Engeman, & Anadon, 2016) by 2013.

Another example is the New Zealand endemic Kakapo (*Strigops habroptila*). The reproductive success of female kakapo is constrained by access to and availability of food, which has led to the development of a successful feeding program (Clout and Merton, 1998). An unexpected outcome of the feeding program has been the disproportionate production of male offspring, due to the breeding system of kakapo which can be explained by the Trivers-Willard hypothesis (1973), which broadly predicts that in polygynous species, females in better condition gain greater fitness by producing males. Kakapo are lek-breeders, but at the onset of the kakapo conservation program, details about their behaviour were not known, making it difficult to explicitly integrate these into conservation planning. At present, the conservation of kakapo is fine-tuned with ongoing research into its behaviour and habitat requirements, and the species has recovered over 120 individuals (Ballance, 2018).

More recently, research has shown behavioural plasticity among some island species. For instance, South Island robins (*Petroica australis*) inhabiting predator-free areas exhibit

lower intensity of anti-predator displays towards rat models than individuals on areas with high predator density (Muralidhar, 2017). Given that a disproportionate number of threatened species inhabit islands (Simberloff, 2000; Bellard et al., 2016), and introduced predators represent one of the biggest threatening factors to these species (Spatz et al., 2017), conservation planning of threatened island species could greatly benefit from a better understanding of the behavioural plasticity of target species.

The Tasman parakeet (*Cyanoramphus cookii*) is an endemic species to Norfolk Island, which has experienced cycles of population decline and recovery since the first human settlement of the island in the late 1700s (Hicks and Greenwood, 1989; Forshaw, 2017; Higgins, 1999). Tasman parakeets inhabit a variety of habitats within the National Park, which includes Norfolk pine (*Araucaria heterophylla*) forest, hardwood forest, niau (*Rhopalostylis baueri*) forest, forest edges, forestry areas as well as patches of introduced vegetation (Simmonds, 2019). Within the boundaries of the National Park, these habitats are subject to sustained rat and feral cat control (Director of National Parks, 2018). Tasman parakeet records outside the perimeter of the National Park have increased in the 2013-2019 period, with some individuals venturing to the urban area of Burnt Pine and Middlegate, as well as reserves manged by the Norfolk Island Regional Council (Fig. 6; M. Wilson, C. Jones, M. Christian, L. Ortiz-Catedral, pers. comm.; Simmonds, 2019). Areas outside the National Park lack sustained management of introduced predator control, comparable to the Norfolk Island National Park. At present it is unclear whether Tasman parakeets can successfully establish in these areas.

A similar-sized parrot, the introduced Crimson rosella (*Platycercus elegans*) was introduced to Norfolk Island in the 1800s (Higgins, 1999; Christian, 2005) and has successfully established within the National Park (Skirrow, 2018) as well as reserves, farms and urban areas of the island (Christian, 2005). Crimson rosellas are culled within the National Park to

minimise competition for nesting holes with the Tasman parakeet (Skirrow, 2018). Crimson rosellas are also culled by the general public on private land, to prevent damage to fruiting trees (N. Tavener, J. Christian, M. King, pers. comm.). In general, crimson rosellas appear more wary of people, showing flight response and alarm calls quickly after detection (L. Ortiz-Catedral, pers. comm.). It has been generally assumed that this alert response might confer crimson rosellas a competitive ability over Tasman parakeets, however this has not been formally evaluated in the field.

While the disruption of nesting Tasman parakeets by Crimson rosellas has been documented (Ortiz-Catedral et al., 2018; Skirrow, 2018), little attention has been paid to potential non-breeding negative effects such as competition for food resources. Simmonds (2020) reported that crimson rosellas within the National Park preferentially use edge habitats during autumn and spring, while Tasman parakeets preferentially used hardwood forest. The same study suggests a degree of spatial separation between both species. However as the Tasman parakeet population increases in numbers and the species starts to use areas of habitat outside the National Park (Skirrow, 2018; Simmonds, 2020) it is important to understand whether crimson rosellas could displace Tasman parakeets from establishing on areas such as reserves, managed by the Norfolk Island Regional Council. In this chapter, I describe a study on the behaviour of Tasman parakeets and crimson rosellas within and outside the National Park. My main interest is to compare the response to disturbance – presence of an observer – on both species in areas subject to predator control (the National Park) and areas with no predator control (regional reserves). The aim of this analysis was to evaluate whether Tasman parakeets outside the predator-control area exhibit greater anti-disturbance responses than within predator-control areas, which would indicate behavioural flexibility to a broader range of habitats and predator-levels. I evaluated this alongside sympatric crimson rosellas.

METHODS

Behavioural categories

Based on preliminary observations on Tasman parakeets in 2015 (see Appendix V), I identified 11 general categories of behaviours applicable to Tasman parakeets and crimson rosellas (Table 1). These categories are broadly equivalent to behavioural categories identified by Magrath and Lill (1983) for crimson rosellas inhabiting the mainland. The repertoire of behaviours of both species is much broader (Higgins, 1999) however, I only observed these species in winter and spring which excluded other behaviours and interactions, for instance the interactions between adults and their offspring following fledging of chicks in late spring and summer (Ortiz-Catedral, pers. comm.). Males, females and juveniles are easily identified in both species (see Chapter 1). Therefore, each bird was classified under these categories. Neither Tasman parakeets or crimson rosellas were banded during this study, therefore my volunteers and I could not distinguish between individual birds. However, we minimized the chances of re-sampling the same individual by restricting observations to a maximum of 15 minutes per bird, before moving on to another individual along transects and roads of the National Park and the reserves administered by the Norfolk Island Regional Council.

Table 1. Repertoire of behavioural states for Norfolk Island parrots.

State	Description
Feeding	Ingesting food items, using beak to manoeuvre food items, placing food into beak with claws.
Preening	Ruffling body feathers, head shake, tail shake, passing through and nibbling feathers with beak, scratching, stretching (wings and feet), billing, wing-flapping.
Resting	Bird is still on perch; eyes often closed; relaxed body position.
Resting alert	Bird is still but actively looking at surroundings; alert, neck stretched out.
Flying	Wing flapping, leaving perch or taking off from ground.
Calling	Contact or alarm calls. In Tasman parakeets: distinguishable parakeet chatter kek-kek-kek-kek

In crimson rosellas: soft chatter, chalk call or chinka-chink calls. |

Table 1. continued. Repertoire of behavioural states for Norfolk Island parrots.

State	Description
Walking	Walking, sidling, hopping, jumping, climbing, climbing with bill as an accessory leg.
Agonistic	Bird posture intimidating, neck stretched out, often calling, chasing, no contact.
Fighting	Flying toward rival bird; biting; clawing.
Courting	In Tasman parakeets: head bob by male Tasman parakeet; Male feeding female, mutual preening feeding.
	In Crimson rosellas: tail fanning and wagging sideways.
Mating	Male climbs on back of female, followed by active copulation.

Data collection

I conducted observations in the field during June and September 2019 with the assistance of two volunteers. Prior to data collection, volunteers unfamiliar with the area and study species were trained on identifying and recording behavioural categories and distinguishing between sexes and age classes to ensure consistency in data collection. Volunteers and I collected information on the visitor track and road network of the National Park (Fig. 10). Initially, this project considered the inclusion of tracks outside the visitors' grid. These tracks are used by staff to conduct maintenance, rat baiting and cat control within the National Park. However, I was unable to complete the four field trips originally planned. Therefore, only data collected along the visitor's grid was collected. For reserves administered by the Norfolk Island Regional Council, access to the main tracks and roads was granted (Appendix III). According to Simmonds (2016), reserves are comprised of main habitat types found within the National Park. One advantage of observing birds from the roads and tracks is that there is a clear field of sight, whereas the thick vegetation outside the tracks could make it difficult to observe birds in certain areas. One disadvantage of only using roads and tracks is that the sampling of behaviours is biased towards edge vegetation and birds on open areas. Future studies could focus on the behaviours of Tasman parakeets and crimson rosellas away from roads and tracks. In this study that approach was not possible as I could only complete half of the expected field trips for data collection. Observations were conducted between 7:00 am to 12:00 pm and from 2:00 pm to 5:30 pm. Tasman parakeets are generally less active between 12:00 and 2:00 pm (Waldmann, 2016; Skirrow, 2018), so this period was omitted.
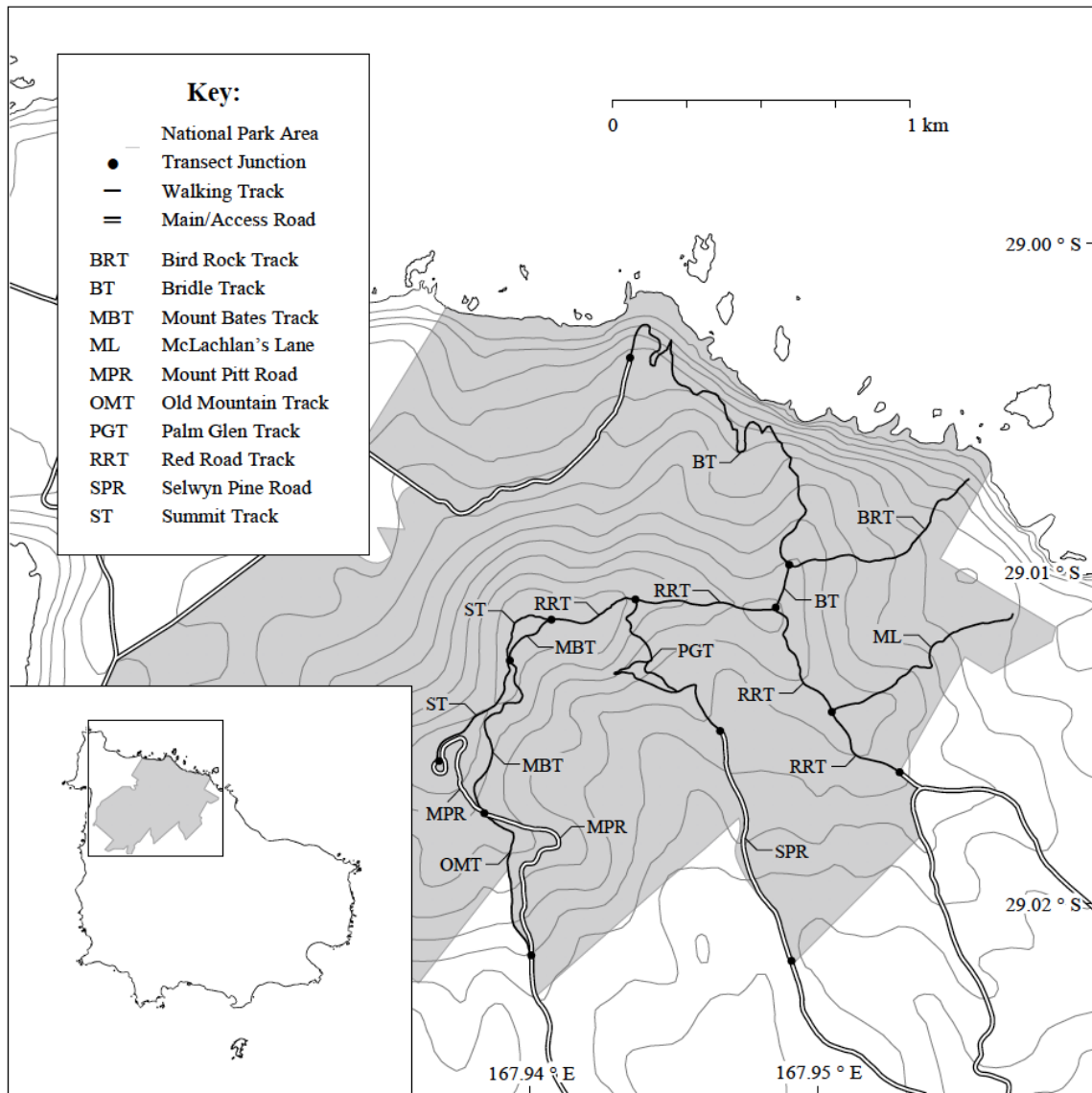
Figure 10. Map of the Norfolk Island National Park showing the visitor tracks and access roads used in this study. Map modified from Skirrow (2018).

Once a bird was detected, a GPS point was marked on a handheld GPSMap64s (Garmin Ltd., Olathe, Kansas), and a stopwatch started (Acculsplit stopwatch A601x, Livermore, California). The distance between observer and focal bird was estimated to the nearest half meter. After 30 seconds, a record of behaviours started, alternating 30 seconds of observations with 30 seconds of rest or no-observations. This sampling technique is similar to the focal animal sampling techniques described by Altmann (1974). Each observation of a species will be classed as a

new sampling event/period, of which I recorded the length of time each sample period lasts (Altmann, 1974). This methodology has been used on Tasman parakeets previously (see Appendix V). Records were made by hand on formatted record sheets. Every bird was observed for a maximum of 15 minutes. If birds were located in pairs or groups, a separate record was kept per every bird. Volunteers and I also identified the height at first sighting and the height once the observations begun. The perch species was also registered as were notes on food items ingested.

Data analysis

My analysis includes observations on the behaviour of Tasman parakeets and Crimson rosellas collected by myself and volunteers in June and September 2019. I used the differences in average distance from the observer and difference in average height from first sighting to start of observations, as an indicator of response to disturbance, namely the presence of observers. Many studies use Flight initiation distance (FDI), or the flight response of a bird to perceived danger, as general indicator of response to disturbance by birds (Weston et al., 2016). In the Norfolk Island context, this approach was not considered adequate because it would require deliberately approaching Tasman parakeets to elicit a response. The species is currently the focus of intense conservation work and a core element of this management is to minimise disturbance to birds (Ortiz-Catedral, pers. comm.). Instead, I focused my analysis on distance at detection, and the difference in heights from detection to start of observations as measures of the parakeets response to the presence of observers. The underlying assumption of this study was that parakeets outside the National Park would react more strongly (i.e. longer distance at detection, greater difference between heights) than parakeets within the National Park , as they would be exposed to greater disturbance outside the National Park . I expected crimson rosellas

to exhibit no difference in disturbance response within and outside the National Park. For analyses including regional reserves, I assume by combing the eight sampled reserves, they have the same effects on behaviours observed. I tested the normality of data using the Bartlett test. I compared intra and inter-species responses and frequencies in behaviours with Welch's two sample t-tests (unequal variances t-test), chi-squared test, and one-way ANOVA (Welch, 1938). Results are presented as means ± SD. All results are presented as means ± standard error and sample size in parentheses. Statistical tests were carried out using R Studio Version 3.6.1.

RESULTS

Behavioural states

I sampled a total of 252 parrots over two seasons on Norfolk Island in 2019. This yielded 1405 bird observations, 347 for Tasman parakeet and 1058 crimson rosella. In this analysis, I omit age as there were only two instances of juveniles observed in the study period, making the resulting analysis based on adults only. During this study, no Tasman parakeets were observed outside of the National Park , although they were heard while surveying in Selwyn reserve over the study period. However, crimson rosellas were observed in larger numbers in regional reserves (Table 2). Behavioural states within the National Park are compared between Tasman parakeets and crimson rosellas observed in the National Park. Tasman parakeets spent more time feeding ($p < 0.0001$, TP 21%) and walking ($p = 0.04$, TP 22%). Crimson rosellas were observed flying more frequently than Tasman parakeets ($p = 0.03$, TP 13%, CR 19%; Table 2).

When comparing behavioural frequencies between Tasman parakeets (only in the National Park) and crimson rosellas observed in regional reserves, crimson rosellas spent more time behaving agonistically ($p = 0.04$, CR 2%) and resting alert ($p < 0.0001$, CR 28%). Similarly, to comparisons of crimson rosellas in the National Park, Tasman parakeets allocated more time to feeding than crimson rosellas in regional reserves ($p < 0.0001$, CR 10%). Between crimson rosellas observed in the eight sampled regional reserves and National Park, crimson rosellas spent more time feeding ($p = 0.04$, 10%) and resting alert ($p = 0.04$, 28%) in reserves, while spending more time calling ($p = 0.04$, 11%) and resting ($p = 0.003$, 13%). Over all sites on Norfolk Island, crimson rosellas spent more time resting ($p < 0.0001$, TP 17%, CR 28%). Tasman parakeets spent more time feeding ($p = 0.0001$, TP 21%, CR 10%) and walking ($p = 0.05$, TP 22%, CR 18%). Agonistic behaviours were significantly higher in crimson rosellas ($p = 0.04$), showing that they are the generally more aggressive species.

Table 2. Relative frequencies of behavioural state for Tasman parakeets and crimson rosellas within the National Park.

	Tasman parakeet (64)	Crimson rosella (57)	Crimson rosella (188)
	National Park	National Park	Regional Reserves
Agonistic	0.01 ± 0.01	0.01 ± 0.01	0.02 ± 0.01
Calling	0.08 ± 0.04	0.11 ± 0.02	0.07 ± 0.01
Courting	0.02 ± 0.02	0.01 ± 0.02	0.01 ± 0.01
Feeding	0.21 ± 0.06	0.06 ± 0.03	0.10 ± 0.03
Fighting	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01
Flying	0.13 ± 0.06	0.19 ± 0.03	0.17 ± 0.02
Mating	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Preening	0.07 ± 0.05	0.06 ± 0.03	0.08 ± 0.02
Rest Alert	0.17 ± 0.05	0.23 ± 0.04	0.28 ± 0.03
Resting	0.07 ± 0.06	0.13 ± 0.04	0.07 ± 0.03
Walking	0.22 ± 0.06	0.16 ± 0.02	17.9 ± 0.02

Relative frequencies of behaviours associated with vigilance, or lack of (resting alert, rest and calling), as well as differences between sexes, were also compared for their inter and intra effects to observer disturbance. Tasman parakeet frequencies for resting alert behaviour ($R^2 = 0.01$, $p = 0.81$), and rest ($R^2 = 0.02$, $p = 0.25$) were not related to distance from observers. There was no significant difference between rest behaviour between seasons. Male and female Tasman parakeets displayed resting alert behaviour at similar frequencies ($p = 0.83$, male 0.17 ± 0.02, female 0.18 ± 0.03). There was no significant difference between frequency of calling between sexes ($p = 0.18$, male 0.10 ± 0.01, female 0.06 ± 0.03). Group means of sex; male, female and unknown were not related to distance from observer (ANOVA: F value $(2,54) = 0.58$, $p = 0.56$), although males were observed at subjectively shorter distances than females (female 30.4 ± 5.54 m, male 25.2 ± 3.01 m, unknown 23.5 ± 5.47 m). Crimson rosellas showed a significant difference of groups between resting alert and distance ($R^2 = 0.18$, $p < 0.001$), where resting alert increased with distance from the observer.

In spring, Tasman parakeets spent most of their time walking 25% and feeding 23%, and resting alert 20% (Fig. 11), while crimson rosellas more frequently rested alert, walked and flew (33%, 19%, 17% respectively). Feeding and rest alert during spring presents the largest apparent difference between the species, where crimson rosellas dedicated more energy to resting alert than feeding, though the opposite is true for Tasman parakeets. In winter, both species exhibit more even partitioning of behaviours (Fig. 12). Tasman parakeet behaviour was allocated between feeding, flying and resting (16% each behaviour), while also preening 14%, walking 13% and calling 12%. Crimson rosellas spend most of their time resting in winter, 27%, while also walking and flying (14% each behaviour).
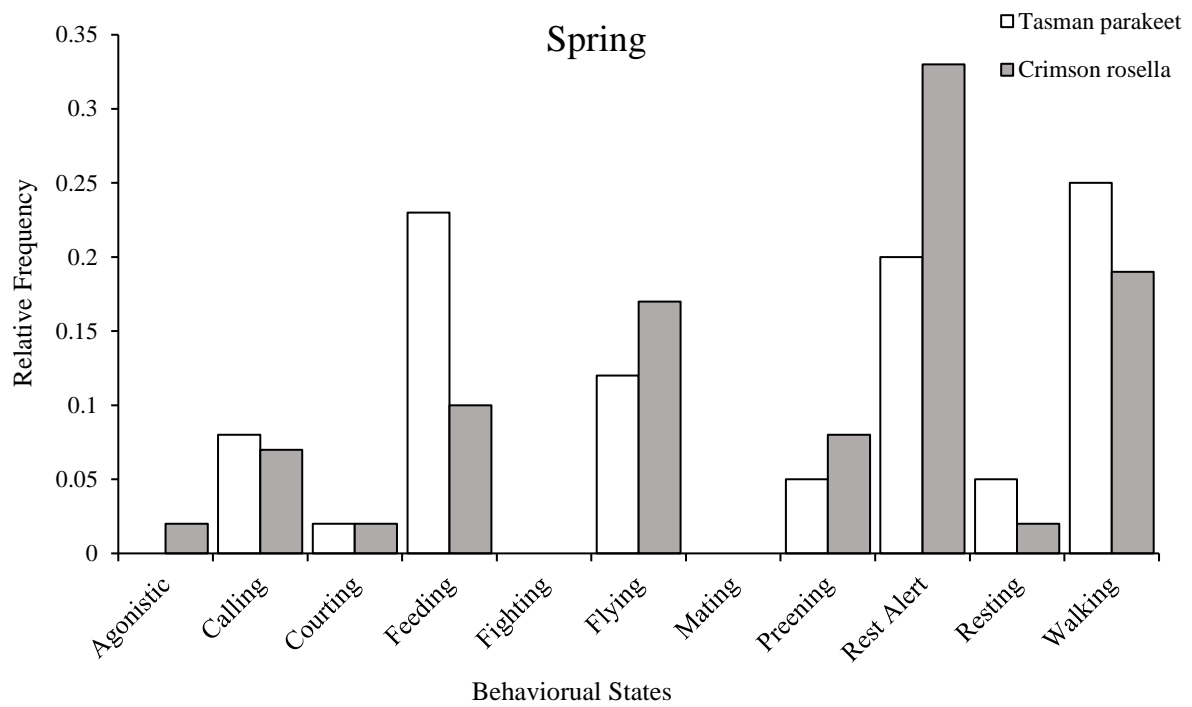
Figure 11. Relative frequencies of behavioural states of Tasman Parakeets (48) and crimson rosellas (149) in Spring 2019.
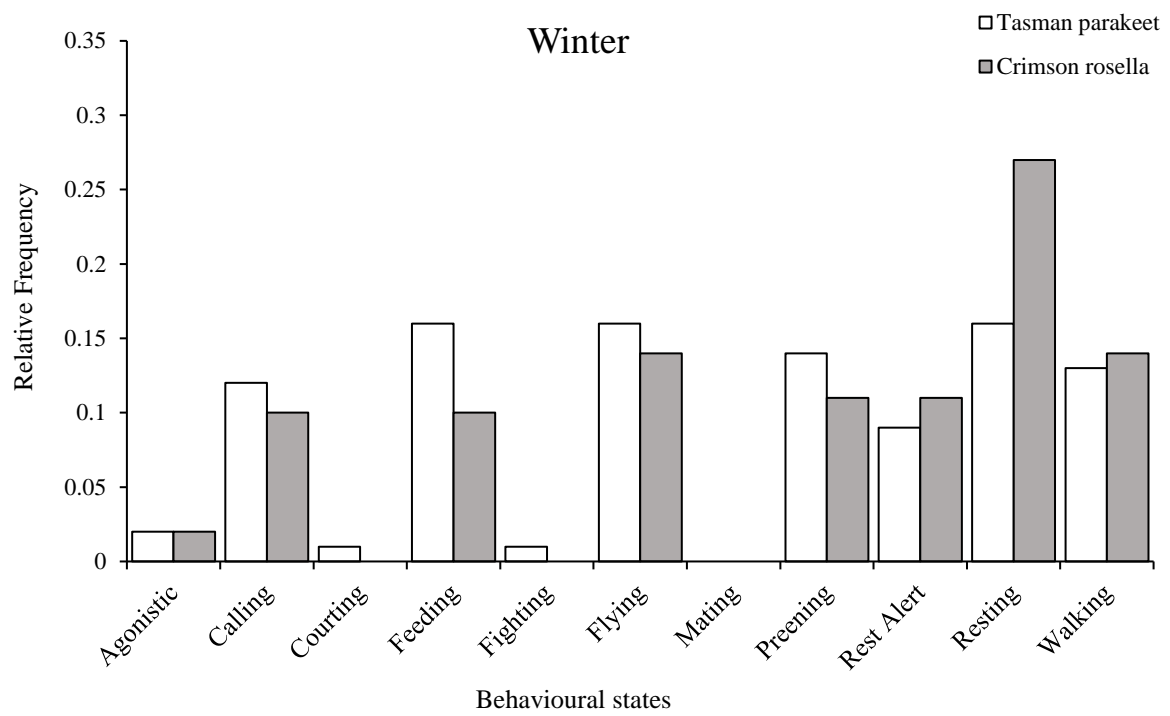
Figure 12. Behavioural states of Tasman Parakeets and crimson rosellas in Winter 2019.

Variation of observer disturbance

Spatial observations of Tasman parakeets differed seasonally and in winter height at sighting was significantly higher ($p = 0.0527$, winter 8.69 ± 2.32 m), similarly, height at start of observation was higher in winter ($p = 0.03$, winter 9.09 ± 3.18). Tasman parakeets were detected at similar distances in both seasons, suggesting season has no effect on the distance at which parakeets respond to observer disturbance (Table 3). The length of time a Tasman parakeet was observed was also not related to distance from observers (Linear regression $R^2 = 0.01$, $p = 0.56$). One third of observations with Tasman parakeets were within 5m and furthest observation of a Tasman parakeet was 35 m.

Within the National Park, crimson rosellas were observed at further distances during spring ($p = 0.02$, spring 30.8 ± 4.07 m). Crimson rosellas showed no significant difference between height at first sighting between seasons ($p = 0.14$), though height at observation almost reached statistical significance ($p = 0.05494$). Crimson rosellas did not indicate significant differences between males and females (Table 4).

Table 3. Tasman parakeet and crimson rosella height and distance observations between winter and spring, 2019, across the National Park and regional reserves.

	Height at first sight (m)	Height at observation (m)	Distance at observation (m)
Tasman parakeet			
Winter (16)	8.69 ± 2.32	9.09 ± 3.18	11.6 ± 2.22
Spring (48)	3.61 ± 0.79	3.54 ± 0.09	9.16 ± 0.94
Crimson rosella			
Winter (25)	11.3 ± 2.25	11.0 ± 3.81	21.0 ± 1.62
Spring (32)	16.7 ± 2.92	17.9 ± 2.77	30.8 ± 4.07

Table 4. Tasman parakeet and crimson rosella heights and distances observations between sexes in the National Park.

	Height at first sight (m)	Height at observation (m)	Distance at observation (m)
Tasman parakeet			
Male (42)	5.67 ± 1.23	5.74 ± 1.22	10.5 ± 1.11
Female (21)	3.07 ± 0.82	3.07 ± 0.82	8.52 ±1.52
Crimson rosella			
Male (29)	15.6 ± 5.19	16.5 ± 5.03	30.4 ± 8.07
Female (17)	15.1 ± 2.73	15 ± 2.68	25.2 ± 2.81

In relation to crimson rosellas across the eight reserves and the National Park, distance from observer indicates a significant difference of means, showing that crimson rosellas can be observed at a closer distance in the National Park ($p < 0.001$, 26.4 ± 2.49 m; Table 5). Height at first sighting ($p = 0.96$) and height at start of observation ($p = 0.84$) were not significantly different. Duration of crimson rosella sampling events in the Regional reserves and National Park are significantly different, where crimson rosellas are observed for less time in the National Park when compared to reserves ($p < 0.001$, National Park 2.04 ± 0.22 mins, Reserves 3.11 ± 0.22 mins).

Table 5. Crimson rosella heights and distance observations in the National Park and regional reserves.

	Height at first sight (m)	Height at observation (m)	Distance at observation (m)
National Park (57)	14.3 ± 1.93	14.4 ± 1.24	26.4 ± 2.49
Regional reserve (188)	14.2 ± 1.23	14.9 ± 1.88	14.2 ± 1.23

Within the National Park, Tasman parakeets and crimson rosellas were found at significantly different distances from the observer ($p < 0.0001$, crimson rosella 26.4 ± 3.23 m), height at first sighting ($p < 0.0001$, crimson rosella 14.3 ± 2.54 m), and height at start of observation ($p < 0.0001$, crimson rosella 14.8 ± 2.47 m; Table 6). In addition, Tasman parakeets were observed for significantly longer durations; 2.72 ± 0.34 mins more than crimson rosella (2.03 ± 0.34 mins, $p = 0.04$), allowing observers to remain closer to Tasman parakeets for longer.

Table 6. Tasman parakeet and crimson rosella heights and distance observations in the National Park.

	Height at first sight (m)	Height at observation (m)	Distance at observation (m)
Tasman parakeet (64)	4.88 ± 0.86	4.93 ± 0.90	9.76 ± 0.90
Crimson rosella (57)	14.3 ± 2.54	14.8 ± 2.47	26.4 ± 3.23

DISCUSSION

As an interdisciplinary field, conservation behaviour can bridge gaps in conservation and act as a powerful tool to assist conservation efforts (Clout and Merton, 1998; Snyder et al., 1987). Other *Cyanoramphus* species have largely focused on nesting behaviour; orange-fronted parakeet (*C. malherbi*) (Catedral-Ortiz, 2009; Kearvell, 2002); yellow-crowned parakeets (*C. auriceps*) (Kearvell, 2002), and red-fronted parakeets (*C. novaezelandiae novaezelandiae*) (Greene. 2003), while Tasman parakeet behaviour on a whole remains relatively understudied. In contrast, crimson rosella biology and behaviour have been studied for some time (Magrath and Lil, 1983; Krebs, 1998; Krebs, 2004).

Simmonds (2020) reported that crimson rosellas within the National Park preferentially use edge habitats during autumn and spring, while Tasman parakeets preferentially used hardwood forest, suggesting a degree of spatial separation between both species. As the Tasman parakeet population increases in numbers and the species starts to use areas of habitat outside the National Park (Skirrow, 2018; Simmonds, 2020), it is important to understand whether crimson rosellas could displace Tasman parakeets from establishing on areas such as reserves, managed by the Norfolk Island Regional Council (Fig. 6). In this study, I present behavioural observations for two seasons of the endangered Tasman parakeet and introduced crimson rosella on Norfolk Island. As Tasman parakeets were only found within the National Park, comparisons of Tasman parakeets and crimson rosellas in regional reserves were not able to be made.

Winter is typically the more energetically stressful season for birds where investment in feeding increases and investment in resting decreases (Magrath, 1983). Tasman parakeets consistently spent more time feeding in both winter and spring, than crimson rosellas insie and

outside the National Park (Table 3). Magrath (1983) found that crimson rosellas from Melbourne, Australia, feed less and rested more in winter when compared to autumn, as this was related to fewer daylight hours. Similarly, this study showed that crimson rosellas invested less of their time to feeding for both winter and spring and rested 27% winter and 2% in spring. Resting behaviours were especially higher in reserves. Food nutrient quality may have an effect on this trend, suggesting crimson rosellas have higher foraging efficiency, indicating differences in time-energy budgets between the two species.

During this study, crimson rosellas were seen behaving agonistically more frequently than Tasman parakeets, and were especially more agonistic in reserves. Waldman (2016) reported an instance where a Tasman parakeet was attacked by a crimson rosella and fell from the tree in which it was foraging. In this study, no instances of interspecies agonistic interactions were recorded. However, it is likely that as Tasman parakeets expand to reserves, they could experience high levels of competition for nesting sites, due to the large, uncontrolled population of crimson rosellas in reserves (Hill, 2002).

When individuals leave predator-controlled sanctuaries or parks, they can experience varying levels of establishment success. Species selected for translocation are often from mammal free populations. Red-crowned parakeets (*C. novaezelandiae novaezelandiae*) translocated to the mainland sanctuary, ZELANDIA, are supported with predator control within the sanctuary, however, outside the park is largely unprotected (Irwin, 2017). Parakeets which fly beyond the boundaries of the sanctuary experience higher levels of predations. One-third of juveniles that leave the sanctuary are killed by predators. Dispersal outside these protected areas occurs for a number of reasons; inbreeding avoidance, competition, and optimizing breeding locations (Liu & Zhang, 2008). Therefore, isolated species, unaware of mammal predator hunting behaviours have little anti-predator defence to avoid or deter

predators (Whitwell, 2009). Anti-predator behaviour can be highly plastic, where some populations can lose the ability to recognise predators. South Island robins from predator free regions lost their ability to respond effectively to predator (Muralidhar, 2017). Within the National Park, Tasman parakeets indicate poor responses to disturbance (presence of observer). They are found at significantly lower heights and closer distances (Table 3, Table 6). Specifically, Tasman parakeet females are found at significantly lower altitudes, increasing their vulnerability in a male dominated sex skewed population, as depredation by feral cats and rat are known to primarily decimate nesting adults and young (Hill, 2002). Considering behavioural plasticity changes with composition and abundance of predators, Tasman parakeets could exhibit greater anti-disturbance responses outside the predator-controlled areas, however the population is currently too limited to study.

Alternatively, crimson rosellas are more successful at being vigilant when predation risks are higher. In reserves, crimson rosellas tend to be further from observers and spend more time resting alert and are subsequently more wary. The National Park may also act as an unintended sanctuary from higher levels of predation and intraspecies competition, with routine removal of crimson rosellas. Magrath (1985) suggests immature crimson rosellas are pushed out to the fringes of forests, where adult population density remains even in mature forests throughout seasons, where food would be more constant. This could account for low numbers of juveniles observed during the study. Resting alert occurs less frequently in the National Park and although crimson rosella can be observed closer, these distances are significantly larger than Tasman parakeets. This is likely due to differing habitat structure between the sample sites. The National Park forest structure may allow for increased levels of concealment from observes, therefore allowing closer observations to be made.

Limitations and further studies

During this study, Tasman parakeets were not observed outside the National Park. This greatly reduces the inferences I can make for response to disturbance in areas with no predator control. During sampling, birds in the same groups were observed simultaneously. This means there is potential for behaviours to be highly correlated were pseudo-replication of observation occurs. In other studies, potentially correlated observations were removed to ensure the remaining observations are independent (McArdle, 1996).

Sampling only took place in two seasons due to time and logistical constraints. A complete study of Tasman parakeet behaviour over all seasons, with repeated sampling in each season, should be included in future research. Studies in the future may need to collect larger samples (>65 for Tasman parakeet and >245 for crimson rosellas), as limitations of sample size in this study could be a contributor to many tests providing insignificant results (Taborsky, 2010). In the future, this would make an important comparison when the Tasman parakeet population is larger and more dispersed.

Conclusions

I have provided behavioural evidence that crimson rosellas show the potential to displace Tasman parakeets from establishing in areas such as reserves. Overall, these findings reinforce the view that Tasman parakeets are behaviourally more vulnerable to introduced predators than crimson rosellas. The distribution of Tasman parakeets into the wider habitats will rely on predator control and crimson rosella population management. Defining behaviours of these two species will enable researchers and managers to gain a clearer picture as to how these species differ in an evolutionarily context and the different management strategies needed.

CHAPTER THREE: COMPARATIVE DIET OF TASMAN PARAKEET (*CYANORAMPHUS COOKII*) AND CRIMSON ROSELLA (*PLATYCERCUS ELEGANS*).

Figure 13. Tasman parakeet (top) and Crimson rosella (bottom) feeding. Photo: L. Ortiz-Catedral and B. Tregear.

ABSTRACT

Understanding the diversity of diet and degree of dietary niche overlap are key aspects of conserving endangered species where introduced species have to the potential to outcompete vulnerable species for resources. On Norfolk Island, introduced crimson rosellas (*Platycercus elegans)* have been documented competing for nest sites with the endemic Tasman parakeets (*Cyanoramphus cookii*), but the degree of overlap on food resources has not been investigated in detail. In this chapter I present the first comparative analysis on dietary niche differences between both species within and outside the boundaries of the Norfolk Island National Park to determine potential competition between Norfolk Island parrots. I compared spatial and seasonal differences among the National Park and eight regional reserves, during winter and spring 2019. Crimson rosellas and Tasman parakeets showed a difference in niche breadth, where crimson rosellas consume a greater diversity of species. Crimson rosellas presented a higher dietary diversity inside the National Park than Tasman parakeets (TP $H = 0.94$, CR $H = 1.26$) and in reserves. Tasman parakeet and crimson rosellas differed significant between seasonal food type consumed ($\chi^2_{df = 9}$ 75.2, $p = >0.0001$). Tasman parakeets exhibited higher flock size ($p = 0.009$), especially larger in spring. Tasman parakeet consistently forage at lower heights and closer distances than crimson rosellas in the National Park. Crimson rosellas forage at significantly higher altitudes in the National Park compared to reserves. Crimson rosella also forages further away winter compared to spring ($p = 0.0007^*$; Winter: $\bar{x} = 17.8$ m, $\sigma_{\bar{x}} = 33.1$ m; Spring: $\bar{x} = 4.09$ m, $\sigma_{\bar{x}} = 2.33$ m). Crimson rosellas have a broader niche than Tasman parakeets, though both species rely heavily on Norfolk pine seeds in winter, suggesting they do not significantly overlap with niche and spatial foraging altitudes. However, further information on summer and autumn is necessary to determine the year-round overlap in feeding resources between both species.

INTRODUCTION

Introduction of new species, both deliberate and accidental, has led to many cases of species extinctions and population declines of native species. These effects are caused most apparently by inter-trophic interactions, such as predation (Davis, 2003). Introduced species have been involved in approximately 86% of island extinctions since 500 A.D. (Bellard et al., 2016). However, introduced species cause increasingly more complicated and nuanced effects on ecological communities, especially through indirect competition. Although direct extinction caused by intra-trophic competition driven by niche overlap is uncommon, new introduced species can cause rapid declines in long-term native species, which can greatly increase native species vulnerability to extinction (Davis, 2003). In the Galapagos, endemic rodent extinction is correlated with the introduction and competition with the black rat (*R. rattus*). A study by Harris and Macdonald (2007) shows that an endemic population of Santiago rice rats (*Nesoryzomys swarthi*) are outcompeted for food resources due to black rats displaying more aggressive behaviour when encountering Santiago rice rats. Competitive impacts may be associated with indirect interactions of one species exploiting limited food resources more successfully than another, but also by aggressive encounters that interfere and prevent a species access to food resources (Macdonald et al, 2013). When studying these distinctions, food resources must first be limited to determine which mechanism is driving competition in the ecosystem (Harris and Macdonald, 2007). Carpenter (2005) demonstrates that interference or exploitive competition also depends on spatial factors of resources. Introduced and benthic dwelling virile crayfish (*Orconectes virilis*) who compete with native Colorado River basin fish have higher interference competition with flannelmouth suckers (*Catostomus latipinnis*) compared to that of Gila chub (*Gila intermedia*), which are a less benthic species (Carpenter, 2005).

Within parrots, 16.6% of species are highly invasive due to high proliferation around the world from historical trading and natural adaptive ability to new habitats and ecosystems (Menchetti & Mori, 2014). Across crimson rosellas distribution, there is a range of impacts on native birds (Menchetti & Mori, 2014). Norfolk Island crimson rosellas have long been attributed to out competing Tasman parakeets for nest sites and food resources (Duston, 2013; Hill, 2002). Body sizes of Tasman parakeets and crimson rosellas suggest they have the same preferences for nest cavities, although in some cases smaller introduced birds prefer the larger cavities of natives, such as European Starlings (*Sturnus vulgaris*) (Menchetti & Mori, 2014). Crimson rosellas on average are larger and more aggressive that Tasman parakeets, so have the potential to be interference and exploitative competitors. For instance, at Black Mountain reserve in Canberra, crimson rosellas exhibit strong intra-specific competition for nesting sites and in some cases can destroy eggs of conspecifics (Krebs, 1998). Similar behaviour has not been observed among *Cyanoramphus* parakeets in any of the available studies on their breeding biology (Greene, 2003; Ortiz-Catedral and Brunton, 2009; Ortiz-Catedral et al., 2010).

Until the introduction of Crimson rosellas, parakeets weren't the only "medium sized" parrot on Norfolk Island. Another species of parrot, the Norfolk Island kaka (*Nestor productus*) existed but was last recorded in the 1851 and quickly disappeared from over hunting and habitat destruction by settlers (Forshaw, 2010; Holdaway & Anderson, 2001). Norfolk Island kaka and Tasman parakeet co-evolution would have allowed the two parrots to exploit different niches. Other kaka species diets such as the New Zealand North Island kaka (*Nestor meridionalis septentrionalis*) on Kapiti Island and South Island kaka (*N. meridionalis meridionalis*) are more insectivorous than *Cyanoramphus* diets, and consume other diverse plant foods such as fruit, seeds and nectar (Moorhouse, 1997). To understand the role species have within an ecosystem, it is important to know how that species foraging varies across spatial, trophic and ecological levels. In this chapter, I describe a study on the dietary diversity of Tasman parakeets within

and outside the Norfolk Island National Park. Tasman parakeets and crimson rosellas have been sympatric for at least 140 years, but only anecdotal information for crimson rosellas about their role as competitors with Tasman parakeets for food resources has been given but has not been measured quantitatively. Previous research indicates that when resource niche overlap is high, constraints on species fitness increases and affects the species likelihood of persistence (DeCesare, 2010). My main interest is to examine the potential competition for food resources between Tasman parakeets and crimson rosellas to provide an understanding of the degree of dietary niche overlap in the National Park and Norfolk Island regional reserves. The aim of this analysis is to evaluate whether Tasman parakeets and crimson rosellas exhibit resource partitioning inside and outside the National Park, which would indicate low competition and niche overlap between habitats.

METHODS

Data collection

Dietary observations of Tasman parakeets and Crimson rosellas were collected in June and September 2019. This chapter includes a subset of feeding observations from the original data set collected on Tasman parakeet and crimson rosella behaviour in Chapter Two. For details on study species refer to Chapter One. Following sampling techniques described in Chapter Two, foraging observations were recorded alongside behavioural observations. Food species and type were recorded. For food consumed in the canopy of Norfolk Pines, techniques described by Magrath (1985) were implemented, where food items were observed through binoculars and estimated by debris dropped by feeding birds.

Data analysis

During this study, Tasman parakeets were not observed outside the National Park and were therefore omitted from the analysis. To determine the seasonal and spatial variability of food resources consumed by Tasman parakeet and Crimson rosella, I estimated Shannon-Wiener index of diversity of food resources for each season and location (Shannon and Weaver, 1949). This is calculated using the following formula:

$$H = -\sum_{i=1}^{S} p_i \ln p_i$$

Where S is the total number of species in the community and p_i is the proportion of S made up of the ith species.

To compare differences of food types in Tasman parakeets and crimson rosellas between seasons and locations, I conducted Chi-squared test. To determine differences in foraging heights, distances between seasons and locations, as well as foraging flock sizes between seasons, locations and species I conducted Welch's t-test. All results are presented as means ± standard error and sample size in parentheses. To estimate the degree of dietary niche overlap between Tasman parakeets and crimson rosellas by season, location and foods species, I used MacArthur's (1958) general niche overlap model, Levins (1968) niche breadth, and Pianka's (1986) niche overlap index. The underlying assumption of this study was that Tasman parakeets and crimson rosellas and would exhibit low resource competition (i.e. wide niche breadth and low niche overlap between food species and food type) as crimson rosella use habitats differently in the National Park. Statistical tests were carried out using R Studio Version 3.6.1.

RESULTS

Seasonal dietary variation

Of the 252 individual birds observed, 90 observations included feeding. Tasman parakeets were observed for 26 of these observations (29%) and crimson rosellas for 64 (71%). In total, 489 feeding events were made. Tasman parakeets fed on 10 plant species over winter and spring 2019 with varying importance (Table 7). Tasman parakeets had 7 unidentified observations, including one entry of a dead leaf, and bark from an unidentified plant species. Relatively important food species consumed included the Norfolk pine (*Araucaria heterophylla*), most commonly consumed species by Tasman parakeets in winter and spring (48.5% and 88.8%) (Fig. 14). In winter, parakeets spent 24.2% of observations feeding on guava (*Psidium cattleianum*), 12% on ironwood (*Nestegis apetala*), 9.1% on Niau palm (*Rhopalostylis baueri*), and 6.1% on sharkwood (*Dysoxylum bijugum*). In spring, Tasman parakeets also fed on ironwood (6.7%). Species the Tasman parakeets were observed feeding on that account for >5% of observations include devil's guts (*Capparis nobilis*), maple (*Elaeodendron curtipendulum*), *Meryta angustifolia* and oleander (*Pittosporum bracteolatum*).

Crimson rosellas fed on 15 species over winter and spring 2019 (Table 8). Rosellas had a total of 188 unidentified observations, 11 of which were unknown including an entry of a dead leaf, and bark from an unidentified plant species. The other unidentified observations were from circumstances of crimson rosella feeding at great distances from the observer on dense grass, weeds and associated seeds. These species were not able to be identified in the field but are included in the analysis because of the large percentage of diet they represent. In winter, crimson rosellas fed almost exclusively on Norfolk pine (*A. heterophylla*) (90.4%). In spring, crimson rosella fed on unidentified grass (63%), Norfolk pine (*A. heterophylla*) (16.8%) and capeweed (*Arctotheca calendula*) (12.4%).

Table 7. Diversity of Tasman parakeet diet in June and September 2019 (N = number of observations per species).

Common name	Family name	Scientific name	Season	Part eaten	N
Norfolk Pine	*Araucariaceae*	*Araucaria heterophylla*	Winter, Spring	Dry seed, bark	135
Ironwood	*Oleaceae*	*Nestegis apetala*	Winter, Spring	Bark, leaves, petiole, fleshy fruits	13
Guava	*Myrtaceae*	*Psidium cattleianum*	Winter	Fleshy fruit	8
Unidentified	-	-	Spring	-	7
Niau Palm	*Arecaeae*	*Rhopalostylis baueri*	Winter	Fleshy fruit	3
Sharkwood	*Meliaceae*	*Dysoxylum bijugum*	Winter	Bark	2
-	*Araliaceae*	*Meryta angustifolia*	Spring	Leaf petiole	2
Oleander	*Pittosporaceae*	*Pittosporum bracteolatum*	Spring	Dry seed, flower	2
Devils Guts	*Capparaceae*	*Capparis nobilis*	Spring	Dry fruit	1

Table 7. continued. Diversity of Tasman parakeet diet in June and September 2019 (N = number of observations per species).

Common name	Family name	Scientific name	Season	Part eaten	N
Maple	*Celastraceae*	*Elaeodendron curtipendulum*	Spring	Bark	1
Total					174

Table 8. Diversity of crimson rosella diet in June and September 2019. (N = number of observations per species).

Common name	Family name	Scientific name	Seasons	Part eaten	N
Unidentified grass	-	-	Spring	Leaves, dry seeds	216
Norfolk Pine	*Araucariaceae*	*Araucaria heterophylla*	Winter, Spring	Needles, dry seeds, strobili, bark	102
Capeweed	*Asteraceae*	*Arctotheca calendula*	Spring	Flowers, pedicel, leaves, dry seeds	43
Unidentified weeds	-	-	Spring	Leaves	13
White Oak	*Malvaceae*	*Lagunaria pat ersonia patersonia*	Spring	Bark, leaves	7
Unidentified	-	-	Winter, spring		6
Lichen	*Cladoniaceae*	-	Spring	Leaves	3
Maple	*Celastraceae*	*Elaeodendron curtipendulum*	Spring	Bark, leaves	3
Norfolk fern tree	*Cyatheaceae*	*Cyathea brownii*	Winter	Leaves	2

Table 8. continued. Diversity of crimson rosella diet in June and September 2019. (N = number of observations per species).

Common name	Family name	Scientific name	Seasons	Part eaten	N
Guava	*Myrtaceae*	*Psidium cattleianum*	Spring	Leaves, unripe fruits	2
Whitewood	*Cannabaceae*	*Celtis paniculata*	Winter	Leaf petiole	1
Ironwood	*Oleaceae*	*Nestegis apetala*	Spring	Bark	1
Oleander	*Pittosporaceae*	*Pittosporum bracteolatum*	Winter	Bark	1
Niau Palm	*Arecaeae*	*Rhopalostylis baueri*	Winter	Fleshy fruit	1
Native spinach	*Aizoaceae*	*Tetragonia tetragonoides*	Spring	Fleshy leaves	1
Total					406
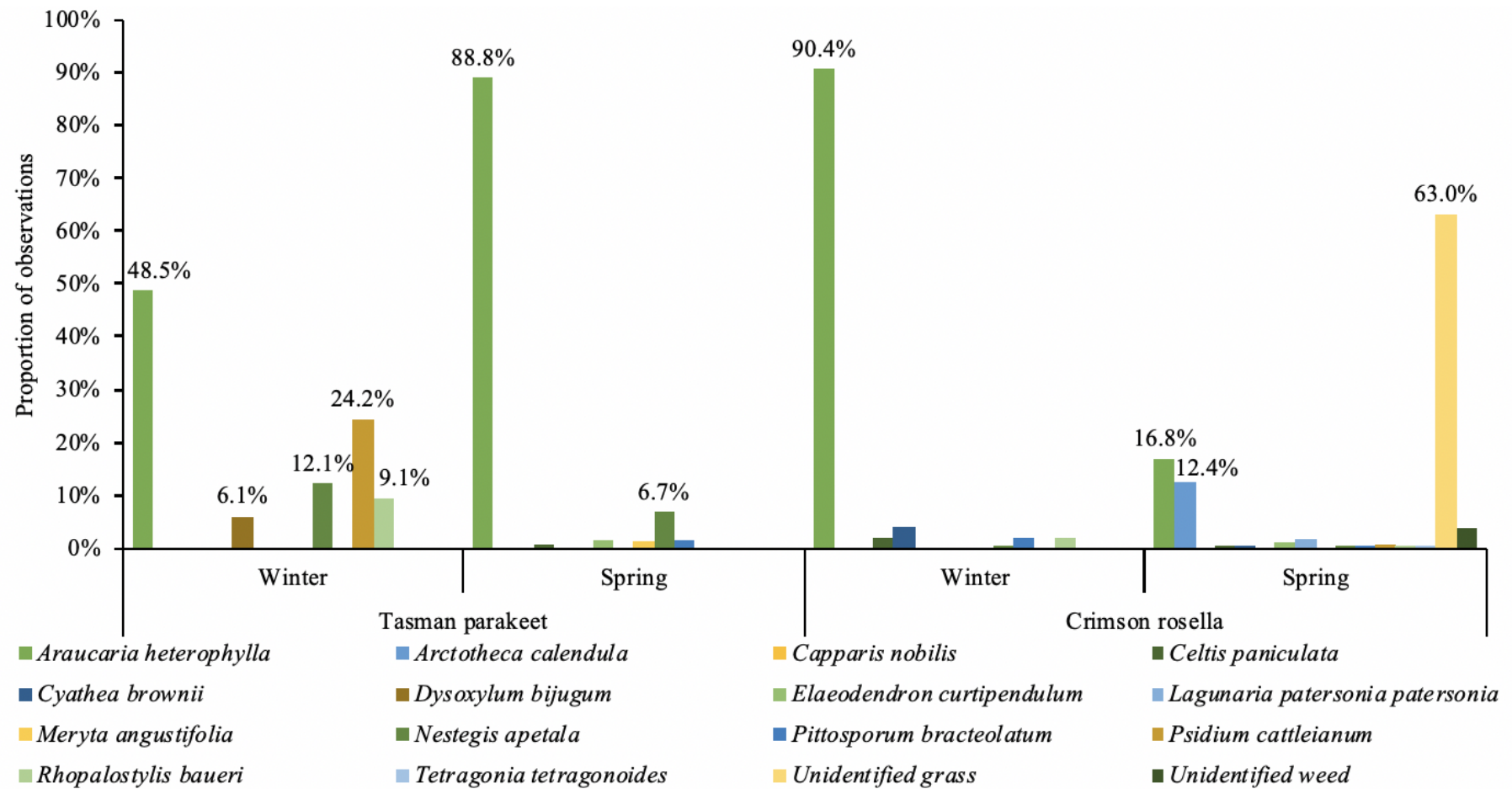
Figure 14. Seasonal diversity of plant species consumed by Tasman parakeets (Winter = 33, Spring = 134) and crimson rosellas (Winter = 52, Spring = 346)

Other species crimson rosella were observed feeding on that account for >5% of observations include unidentified weed, whitewood (*Celtis paniculata*), Norfolk fern tree (*Cyathea brownie*) maple (*Elaeodendron curtipendulum*), white oak (*Lagunaria patersonia patersonia*), ironwood (*Nestegis apetala*), oleander (*Pittosporum bracteolatum*), guava (*Psidium cattleianum*), Niau palm (*Rhopalostylis baueri*) and native spinach (*Tetragonia tetragonoides*).

Between the National Park and reserves, crimson rosella diet varies (Figure 15). Within the National Park, feeding observations were primarily made from Norfolk pine (65.2%), unidentified grass (17.4%), Norfolk fern tree (*Cyathea brownii*) (8.7%), and equally Niau palm (*Rhopalostylis baueri*) and oleander (*Pittosporum bracteolatum*) (4.3%). In reserves, crimson rosellas most commonly fed on unidentified grass (57.1%), followed by Norfolk pine (*Araucaria heterophylla*) (24%), and capeweed (*Arctotheca calendula*) (11.5%). The category of other includes five species than contribute less than 1%, when combined 2.1% these other species were only recorded in reserves.

Tasman parakeet and crimson rosella have varying seasonal diversity and richness of food species consumed (Table 9). Species richness for Tasman parakeet diet stayed relatively constant over winter (n = 5) and spring (n = 7), and also showed the highest index of diversity in winter. The lowest seasonal diversity indices are recorded in spring by Tasman parakeets (Table 10). Crimson rosellas have a lower dietary diversity in winter compared to spring, which also has the highest species richness between the two species (n = 12).
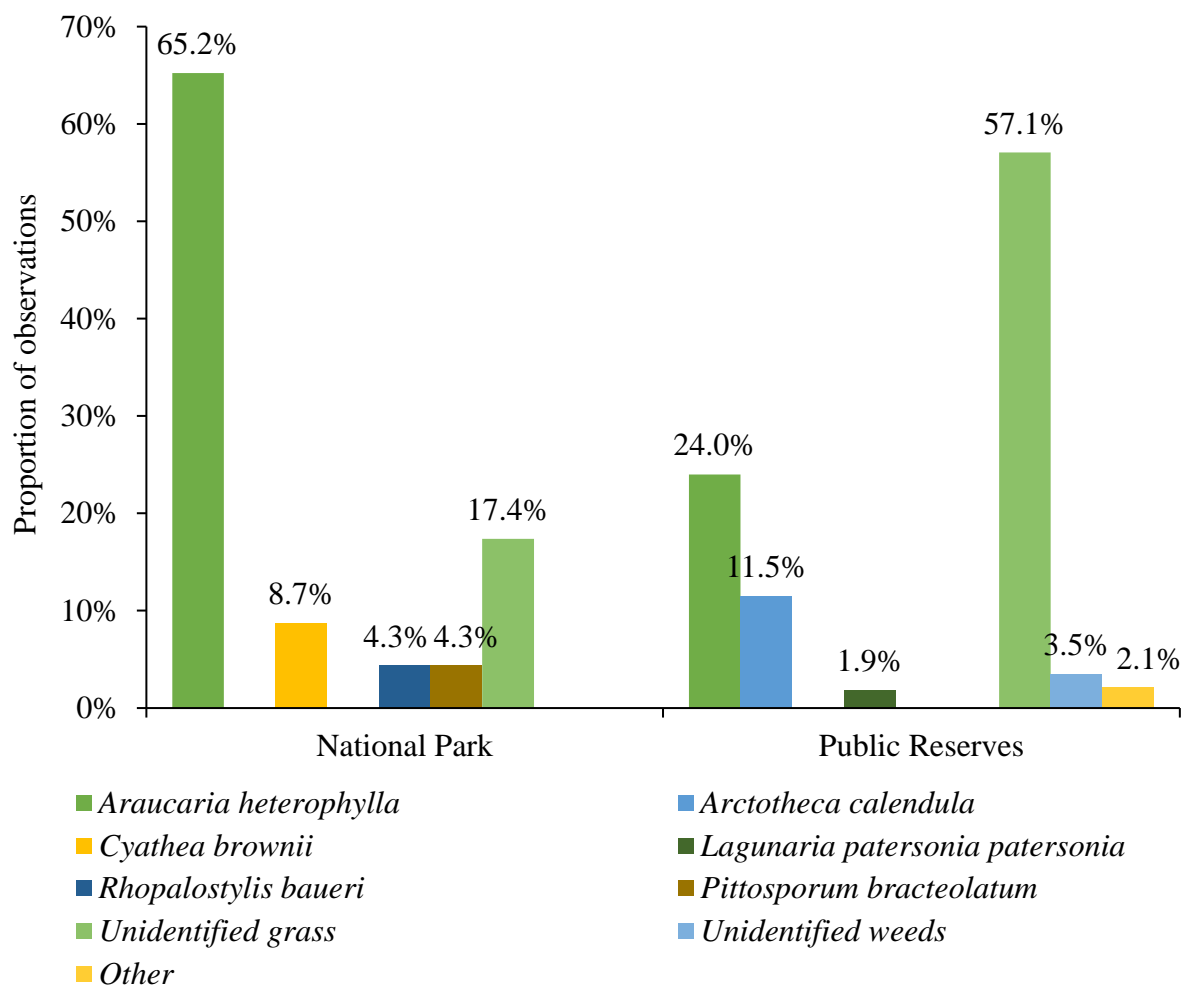
Figure 15. Diversity of plant species consumed by crimson rosellas in the National Park (n = 25) and regional reserves (n = 378). Other includes observations lower than 1% (*C. paniculate*, *E. curtipendulum*, *N. apetala*, *P. cattleianum*, *T. tetragonoides*).

Spatial dietary diversity is highest for crimson rosellas in regional reserves, however, does not differ vastly compared to diversity in the National Park (Table 10). They consumed twice as many species in reserves (n = 12) compared to the National Park (n = 6). Across the whole island, crimson rosella records the highest indices of diversity and species richness when National Park and reserves are combined. These differences are most likely driven by the proportion of which these species are consumed. Within the National Park boundaries, Tasman parakeets register a lower diversity index than crimson rosellas, although they consume higher richness of species. Within the National Park during winter, crimson rosella are only observed feeding on four species, of which Norfolk pine is consumed for half of the observations (50%, n = 4), followed by Norfolk tree fern (25%, n = 2), oleander (12.5%, n = 1) and niau palm (12.5%, n = 1) (Table 11). During spring, only two species were consumed. Likewise, Norfolk pine was ingested heavily, (73.3%, n = 11), in addition to unidentified grass species (26.7%, n = 4). In reserves during winter, crimson rosella dietary species is similarly small, where only Norfolk pine eaten significantly (97.7%, n = 43), and whitewood (*Celtis paniculata*) (2.3%, n = 1) were consumed. During spring, crimson rosella diet in reserves shows greatest diversity and richness. Of nine species consumed, unidentified grass is ingested significantly (64.7%, n = 214). Norfolk pine (14.2%, n = 47) and cape weed (13%, n = 43) are consumed in similar quantities, in addition to unidentified weed, white oak, maple, guava, ironwood and native spinach all contributing less than 5% of relative importance and sample sizes less than 10.

Table 9. Shannon-Weiner indices of food species seasonal diversity between Tasman parakeets and crimson rosellas in the National Park.

Species	Tasman parakeet		Crimson rosella	
Season	Winter	Spring	Winter	Spring
Shannon Index	1.34	0.34	1.21	0.58
Species richness	5	7	4	2
Sample size	33	141	8	15

Table 10. Shannon-Weiner indices of food species diversity by study sites between Tasman parakeets and crimson rosellas.

Species	Tasman parakeet	Crimson rosella	
Location	National Park	National Park	Reserves
Shannon Index	0.94	1.26	1.30
Species richness	10	6	12
Sample size	174	25	378

Table 11. Shannon-Weiner indices of crimson rosella food species diversity by study site and season.

Location	National Park		Reserve	
Season	Winter	Spring	Winter	Spring
Shannon Index	1.21	0.58	0.11	1.14
Species richness	4	2	2	9
Sample size	8	15	44	331

Levins' niche breadth, B, was narrower for Tasman parakeets ($B = 1.26$) than crimson rosellas ($B = 2.16$) (Table 12). Standardised Levins' niche breadth indicates that crimson rosella has a slightly wider niche breadth ($B_A = 0.12$) than Tasman parakeets ($B_A = 0.04$) and indicates both species have low niche overlap. MacArthur's resource partitioning model gave a narrower niche for Tasman parakeets ($M = 0.70$) than crimson rosellas ($M = 1.20$). Pianka's index indicates a strong similarity in their consumption of food types ($O = 0.91$).

Table 12. Food species niche breadth and overlap for Tasman parakeets and crimson rosellas

Location	Tasman parakeet	Crimson rosella
B	1.26	2.16
B_A	0.04	0.12
M	0.70	1.20
O	0.91	0.91
n	8	11

B = Levins' niche breadth

B_A = Standardised Levins' niche breadth

M = MacArthurs resource partitioning

O = Pianka's niche overlap index

Seasonal food type variation

Eight food types were recorded by Tasman parakeets and crimson rosella during feeding observations; bark, flowers, fruit pulp, unripe fruits, seeds, strobili (or pollen), and leaves (leaf blade, leaf petiole and pine needles). Tasman parakeet and crimson rosella diet relies heavily on seeds and leaves (Fig. 16). There is a significant difference between winter and spring in Tasman parakeet diet ($\chi^2_{df=9}$ 75.2, p = >0.0001). Tasman parakeets consumed seeds more than any other food type in winter (39.4%) and spring (88.2%). Parakeets consumed high proportions of fruit pulp (33.3%), bark (18.2%) and leaves (18.2%). In winter, parakeets also consumed leaves (8.1%), bark, fruit pulp and flowers (>1.5%). Overall, Tasman parakeets consumed 50% leaf petioles and 50% leaf blade, which were also consumed evenly over winter and spring.

Crimson rosellas consume significantly different food types in winter and spring ($\chi^2_{df=13}$ 168.3 p = >0.0001). In winter, crimson rosella key food types include leaves (50%) and seeds (46.2%). Likewise, seeds are consumed in high amounts in spring (48.9%), followed by leaves (34.8%), flowers (9.5%), and bark and strobili, which comprise of less than less than 3% each of observations. Other food types include lichen and unripe fruits, which were only consumed by crimson rosellas in spring, and contribute less than 2% of their diet. Of leaf observation from crimson rosella, 65% are made up from leaf blades, 35% of pine needles and 1% of the leaf petiole. Crimson rosellas were the only birds observed eating pine needles (n = 194). Majority of pine needles were consumed in winter (88.5%) compared to spring (23.1%), whereas majority of leaf blades were consumed in spring (76.9%).
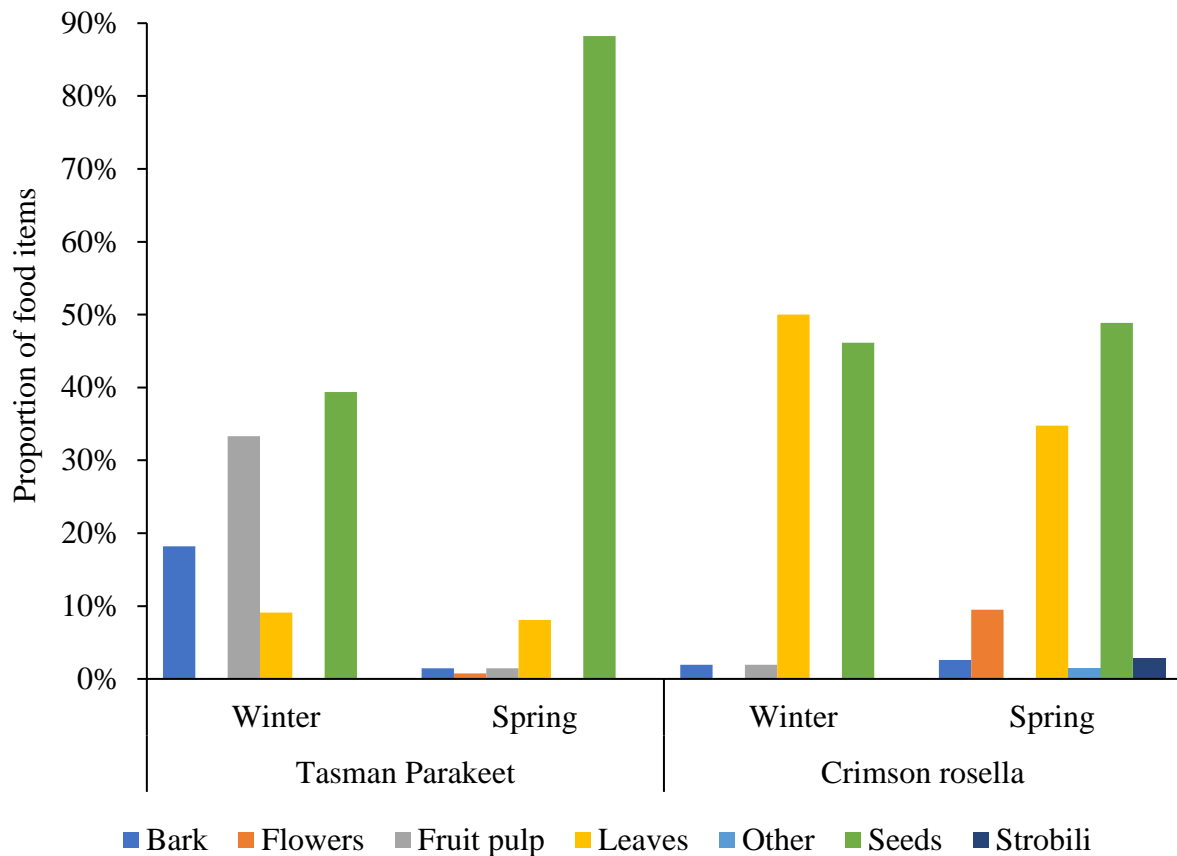
Figure 16. Seasonal diversity of food types consumed by Tasman parakeets and crimson rosellas. Crimson rosella: Winter = 52, Spring = 348; Tasman parakeet: Winter = 33, Spring = 136).

Crimson rosellas diet does not significantly differ between the National Park and regional reserves ($\chi^2_{\text{df} = 10}$ 140.1, p = 0.767), though there are differences in their relative proportions. Crimson rosella diet relies heavily on seeds (Fig. 17). Within the boundaries of the National Park, crimson rosellas diet consisted almost entirely of seeds (72.4%). Other food types in the National Park are fed on less than 10%, including leaves, fruit pulp, bark and flowers. Key food types for crimson rosellas in reserves include seeds (50.1%) and leaves (37.9%). Crimson rosellas ingest flowers more frequently in reserves (8.8%), as well as bark (2.4%) and lichen (0.8%).
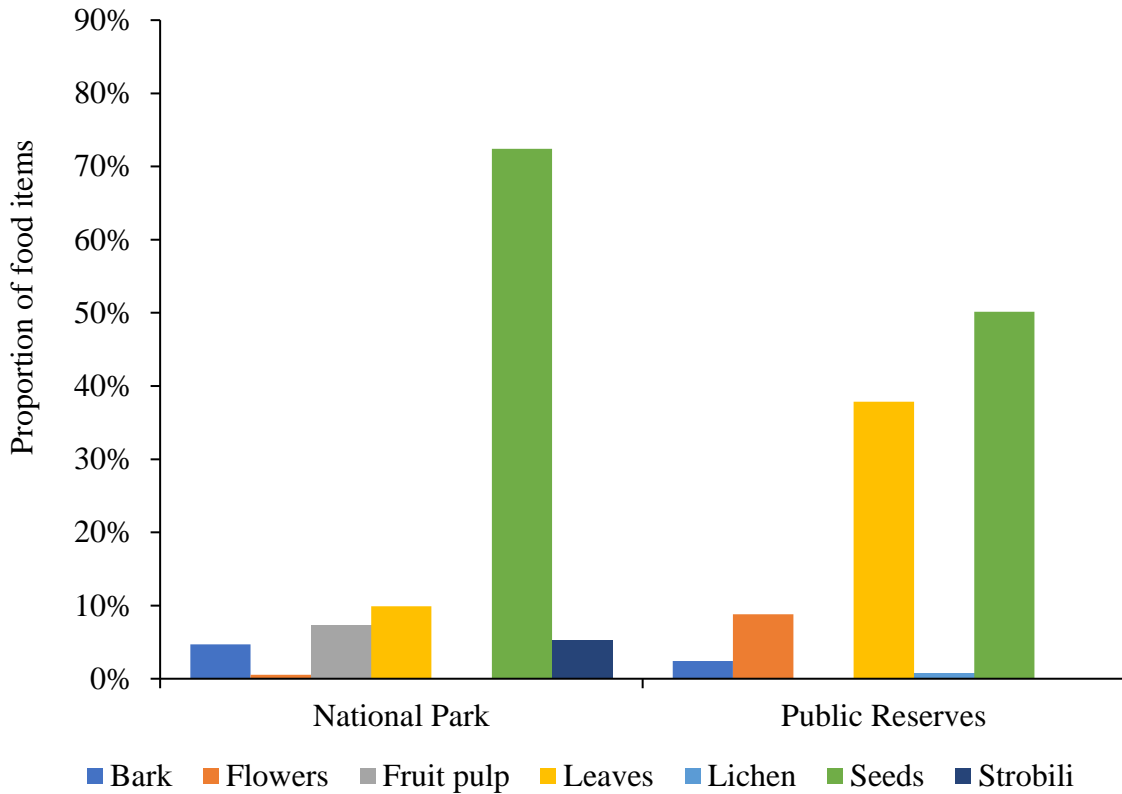
Figure 17. Spatial diversity of food type consumed by crimson rosellas in the National Park (n = 192) and regional reserves (n = 375).

Levins' niche breadth for food types consumed, B, was narrower for Tasman parakeets ($B = 1.47$) than crimson rosellas ($B = 2.63$) (Table 10). Similarly, standardised Levins' niche breadth indicates that crimson rosella have a slightly wider niche breadth ($B_A = 0.18$) than Tasman parakeets ($B_A = 0.09$) and indicates both species have low niche overlap. MacArthurs resource partitioning model is narrower for Tasman parakeets ($M = 0.67$) than crimson rosellas ($M = 1.21$). Pianka's index indicates a strong similarity in their consumption of food types ($O = 0.90$).

Table 13. Food type niche breadth and overlap for Tasman parakeets and crimson rosellas.

Location	Tasman parakeet	Crimson rosella
B	1.47	2.63
B_A	0.09	0.18
M	0.67	1.21
O	0.90	0.90
n	6	10

B = Levins' niche breadth

B_A = Standardised Levins' niche breadth

M = MacArthurs resource partitioning model

O = Pianka's niche overlap index

Foraging flock size variation

Tasman parakeet foraging flock size showed significant differences between seasons (p = 0.009, winter 1.37 ± 0.26, spring 2.33 ± 0.19), specifically they forage in larger groups of four or more in spring and feed in groups of one (75%) in winter (Fig. 18). Crimson rosella flock size differences between location is not significant (National Park 2 ± 0.38, reserves 2 ± 0.11) or between seasons (p = 0.21, winter 1.75 ± 0.27, spring 2.06 ± 0.12). Differences between flock sizes of species is not significant (p = 0.45, TP 2.15 ± 0.38, CR 2 ± 0.12).
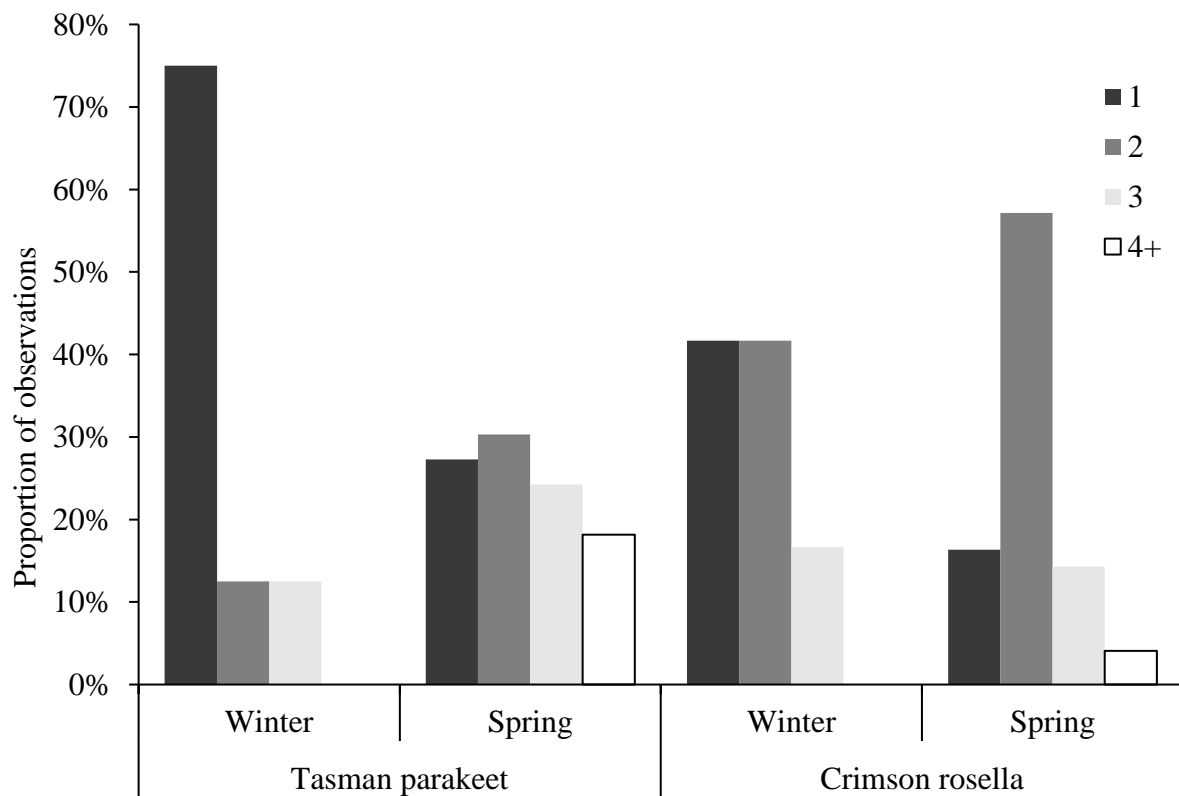
Figure 18. Foraging flock size proportions of Tasman parakeets (Winter = 8, Spring = 33) and crimson rosellas (Winter = 12, Spring = 49).

Foraging spatial and seasonal variation

Foraging heights and distance of Tasman parakeets are not related significantly to seasons, though differences in height at observation is near significance ($p = 0.06$; Table 14). When comparing crimson rosellas inside the National Park, there is a significant difference between foraging distance and season ($p = 0.0007$, winter 17.8 ± 33.1 m, spring 4.09 ± 2.33 m) where feeding occurs at greater distances in winter (Table 14). Additionally, 60.9% of Tasman parakeet observations were from individuals foraging on the ground, which was most common in spring (73%). In all ground observations, Tasman parakeets fed on Norfolk pine (*A. heterophylla*) seeds.

Crimson rosellas have a significant spatial difference between height at first sight ($p = 0.05$, National Park 22.1 ± 6.89 m, reserves 5.6 ± 1.76 m) and height at observation ($p = 0.04$, National Park 22.1 ± 6.89 m, reserves 4.93 ± 1.75 m) (Table 15). There is no significant difference between distance and study site for crimson rosellas. For crimson rosellas over all sample observations, there is no significant seasonal difference between foraging heights or foraging distances (Table 16). 82.7% of all crimson rosella foraging observation were from the ground. Ground foraging in crimson rosellas was similar between seasons and higher in reserves (86.5%) compared to the National Park (24%). Comparatively, majority of ground observations in reserves are made up of unidentified grass (63.1%) and 18.9% from *A. heterophylla*. Ingestion of seeds and leaves from *A. heterophylla* observation in reserves are relatively even, whereas consuming seeds from unidentified grass was more common (67.6%) followed by leaves (32.4%).

Table 14. Tasman parakeet foraging height and distance between seasons.

	Height at first sight (m)	Height at observation (m)	Distance at observation (m)
Tasman parakeet			
Winter (8)	5.75 ± 1.84	7.19 ± 2.22	8.63 ± 1.31
Spring (33)	2.34 ± 0.85	2.18 ± 0.90	8.80 ± 1.01
Crimson rosella			
Winter (12)	9.42 ± 4.02	8.75 ± 6.81	17.8 ± 33.1
Spring (49)	7.36 ± 2.31	4.17 ± 2.30	4.09 ± 2.33

Foraging heights and distance are related significantly between Tasman parakeets and crimson rosellas (Table 17). Height at first sighting and height at start of observation is higher for crimson rosellas ($p = 0.01$, CR 7.77 ± 2.33 m; $p = 0.03$, CR 7.19 ± 2.24). Feeding also occurs at greater distances by crimson rosellas ($p = 0.0001$, CR 30.1 ± 2.50).

Table 15. Crimson rosellas foraging height and distance between study sites.

	Height at first sight (m)	Height at observation (m)	Distance at observation (m)
National Park (8)	22.1 ± 6.89	22.1 ± 6.89	24.2 ± 6.41
Reserves (53)	5.6 ± 1.76	4.93 ± 1.75	31.0 ± 2.38

Table 16. Crimson rosella foraging height and distance between seasons from the National Park and regional reserves.

	Height at first sight (m)	Height at observation (m)	Distance at observation (m)
Winter (8)	5.75 ± 1.84	7.19 ± 2.22	8.63 ± 1.31
Spring (33)	2.34 ± 0.85	2.18 ± 0.90	8.80 ± 1.01

Table 17. Tasman parakeet and crimson rosella foraging heights and distances including observations within the National Park.

	Height at first sight (m)	Height at observation (m)	Distance at observation (m)
Tasman parakeet (41)	3.01 ± 1.80	3.16 ± 2.00	8.77 ± 1.93
Crimson rosella (61)	7.77 ± 2.23	7.19 ± 2.24	30.1 ± 2.50

DISCUSSION

Interspecific competition for resources plays an integral role in niche partitioning, potential local extinction and conservation of endangered species (Davis, 2003). Species that are closely related and share resources will often differentiate phenotypically or behaviourally to coexist. Diet of red-crowned parakeets (*C. novaezelandiae novaezelandiae*) and yellow-crowned parakeets (*C. auriceps*) on Little Barrier Island, New Zealand, were compared and found to differ significantly (Greene, 1998). Red-crowned parakeets were observed feeding across diverse habitats and species, feeding on 57 different food species, and foraging on ground in open habitats, whilst yellow-crowned foraged arboreally and fed on less diverse foods (17 species). Diet overlaps are more likely to occur in highly modified habitats (Newton, 1967). Populations of sympatric species, orange-fronted parakeet (*C. malherbi*) and yellow crowned (*C. auriceps*) parakeet, are found in the same remnant forest, South Island, New Zealand. Although each species was observed feeding for 20% of foraging time at different forest stratums, their diet overlaps in species and food type, specifically on beech seeds summer (90%) (Kearvell, 2002). Ecological competition between interspecies species less commonly focused on, especially between introduced and native species within *Cyanoramphus*. Introduced species are more likely to exploit ecological opportunities that most native species rarely use, and as long as key vegetation that both species feed on is not in short supply, species are less likely compete (Kearvell, 2002).

Tasman parakeets and crimson rosellas are found to use National Park forest differently (Simmonds, 2019). Crimson rosella and Tasman parakeets are thought to compete little for food resources within the National Park. As the population of Tasman parakeets continues to increase, more incidental observations of Tasman parakeets outside the National Park are

reported, including observations foraging on lilac (*Melia azedarach*) trees on rural roadsides and reserves near the National Park (Luis Ortiz-Catedral, pers. comm., 2019).

Dietary variation

In this study, Tasman parakeets display higher dietary diversity in winter, whereas crimson rosellas exhibit high diversity in spring (Table 9). Within the National Park, crimson rosellas exhibit higher diversity than Tasman parakeets, though they feed on less species in the National Park (Table 10). This illustrates that although Tasman parakeets feed on a higher richness of species, crimson rosellas consume resources in greater volumes, and therefore are represented as having a higher diversity. Sample sizes may limit the conclusions from diet diversity and inherently bias results in winter or for crimson rosellas found in the National Park. Between the National Park and reserves, crimson rosella dietary diversity is highest in reserves (Table 10).

Within in the boundaries of the National Park, Tasman parakeet diet indicates several key species to winter and spring (Figure 1). The Norfolk pine (*A. heterophylla*) is a significant dietary species for Tasman parakeets in both seasons. Guava (*P. cattleianum*) is a key species in winter. An exotic to Norfolk Island, guava is originally from brazil and is a particularly weedy species, growing thickly in northern and eastern sections of the National Park (Coyne, 2011). This species is regularly removed inside the National Park to make room for managed regeneration of native plants (pers. obs). On majority of the island, expansion of introduced weedy species in the National Park, public and private land is a recorded issue as it decreases biodiversity of native species (Hill, 2002). Other key species in winter include, ironwood (*N. apetala*), niau palm (*R. baueri*) and sharkwood (*D. bijugum*). In spring, aside from Norfolk pine, the other key species in Tasman parakeets' diet is ironwood. Ake ake (*Dodonaea viscosa*)

is not recorded during my study but is reported to be commonly consumed by Tasman parakeets and crimson rosellas. Simmonds (2019) suggests there is likely to be competition for this species as it was the most important food source for both species in spring 2017.

Over the island as a whole, during winter crimson rosella had a lower species diversity of dietary species eaten. During winter, crimson rosellas fed almost exclusively on Norfolk pine (90.4%). The rest of their diet in winter consists of species that are less than 5% of their diet; Norfolk tree fern (*C. brownie*), whitewood (*Celtis paniculate*), oleander (*P. bracteolatum*) and niau palm. In spring, crimson rosella diet is more varied, made up of three species, unidentified grass, Norfolk pine and Norfolk tree fern and is reflected by a higher diversity index. Cape weed (*A. calendula*) makes up the majority of observations is an introduced weed listed as a noxious weed under the Noxious Weed Act 1916 (2013) and therefore mandated to be eradicated if land becomes infested. Notably, crimson rosella was observed feeding on native spinach. Niche overlap indicates that crimson rosellas and Tasman parakeets consume high volumes of similar species, although crimson rosellas have a wider niche breadth and consume a wider diversity than that of Tasman parakeets (Table 12).

Tasman parakeets consume significantly different seasonal food types. Pine seeds are most important in winter and spring. All Tasman parakeet seed ingestion consists Norfolk pine seeds. Fruit pulp and bark also makes up a large quantity of food types consumed. Similarly, crimson rosella exhibits significant differences in food types consumed in winter and spring. In previous studies, Waldman (2016) also observed Tasman parakeets consuming invertebrates and grit. As a non-dietary item, grit and bark is thought to function as a form of geophagy, hypothesised to aid in taste and digestion of poisonous and bitter tasting secondary compounds of food types, seen also in the orange-fronted parakeet (*C. malherbi*) (Diamond, Bishop & Gilardi, 1999; Ortiz-Catedral & Burton, 2009).

Crimson rosellas eat significant quantities of seeds and leaves, however there is no major difference between food type and the location they are eaten. Seeds are eaten in the highest proportion in the National Park, while seeds and leaves are similarly relied on in reserves. Crimson rosella are known to feed extensively on seeds, mainly from grasses, weeds, shrubs and trees (Higgins, 1999). Crimson rosellas exhibit a wider niche breadth than Tasman parakeets and insert themselves into Norfolk Island exploiting these same resources in reserves. This highlights the ecological importance of seeds in both species diet, and the maintenance of vegetation species that both species consume to avoid increasing foraging competition. Crimson rosella exhibits a wider niche breadth of food types than Tasman parakeet, however, there is high niche overlap among food type. This most likely driven by both species' large consumption of seeds, although, a large proportion of seeds is made up of grass seeds in spring (Table 13). Leaves also make up significant proportions of crimson rosella diet in winter and spring (Fig. 13). Therefore, Tasman parakeet and crimson rosellas only share key food types over winter; whereas the rest of crimson rosellas diet is made up of resources from broader habitats, such as grass seed which accounts for more than 50% of its diet in reserves, those that the Tasman parakeet is not regularly exploiting.

In the National Park, Tasman parakeets appear to forage lower to the ground more frequently than crimson rosellas. On the mainland, crimson rosellas spend 36% of their time foraging on the ground, and the rest in shrubs and trees (Higgins, 1999). The ability for crimson rosellas to forage higher may place the species at an advantage, reducing predation risk from feral cats and rats. This spatial difference, in addition to crimson rosellas wider niche, suggests that there is a difference and breadth of separation for foraging competition, although they forage on high proportions of the same species.

Tasman parakeets and crimson rosellas feed in varying flock sizes, although they were never observed in close proximity with one another. Tasman parakeets forage in significantly larger flocks in winter. This can be attributed to Tasman parakeet breeding season where family groups are more common (pers. comm. Luis Ortiz-Catedral).

Competition with crimson rosella

Many examples of interspecific competition between native and introduced species applies to nest competition (Arendt, 2000). Tasman parakeets and crimson rosellas are known to compete for nesting sites, largely exacerbated by the removal of viable cavities by deforestation. Conservation approaches to enhance nesting success have included creation of nesting boxes to increase likelihood of Tasman parakeets successfully breeding (Hill, 2002). Similarly, the vulnerable eastern Regent parrot (*Polytelis anthopeplus*) in Australia which competes with the yellow rosella (*Platycercus elegans flaveolus*) for nest cavities has been advised to strategically place nest boxes in protected flight corridor habitats (Lewis et al., 2019). While breeding competition can be managed by these measures, food resource competition is often mitigated with supplemental feeding. This is a measure that could be implemented in reserves and corridors to encourage Tasman parakeets to enlarge their distribution when population numbers allow it. This should only be undertaken when predator control can be implemented to the same or similar degree in reserves as it is in the National Park. Reserves in close proximity to the National Park and those that have similar habitats and key seasonal resources could be targeted for this kind of predator management. Within the National Park, crimson rosellas are regularly eradicated, therefore reducing nest competition (pers. comm. Matt Upton, Norfolk Island National Park pest management). The continued eradication of crimson rosellas has aided the Tasman parakeet recovery and should continue at its current pace (Skirrow, 2018).

Limitations and further studies

During this study, I was not able to complete a comprehensive seasonal analysis and equal survey effort for sample sizes (See Chapter 2). This limits the conclusions I can make to describe each species diet composition and the full degree to which they may overlap.

The managed introduction of Tasman parakeets into wider habitat such as regional reserves and Philip island would benefit from estimations of food species and seed availability for Tasman parakeets in reserves based on known dietary diversity. This is necessary to understand the full scope of competition present for Tasman parakeets dispersing out of the National Park.

Conclusions

Tasman parakeet consistently forage at lower heights and closer distances than crimson rosellas in the National Park. Crimson rosellas forage at significantly higher altitudes in the National Park compared to reserves. It is likely that Tasman parakeets and crimson rosellas overlap on seeds of Norfolk pine in winter in the National Park, however crimson rosella niche breadth is wider and more diverse. Crimson rosellas exploit more diverse food species and types in regional reserves, whereas Tasman parakeets do not rely on these resources in the National Park.

CHAPTER FOUR: FUTURE RESEARCH PRIORITIES TO ENHANCE THE CONSERVATION OF THE TASMAN PARAKEET.

Figure 19. View of Anson Bay Reserve, Norfolk Island. Photo: L. Ortiz-Catedral.

ABSTRACT

The long-term conservation of the Tasman parakeet (*Cyanoramphus cookii*) hinges on sustained predator control and safe nest provisioning within the Norfolk Island National Park, however, as the population of parakeets increases, forested areas beyond the National Park might play a significant part on the conservation of the species. In this thesis I have presented the first comparative analysis of behavioural responses of Tasman parakeets and crimson rosellas (*Platycercus elegans*). I was unable to measure the responses of Tasman parakeets outside the National Park boundaries but based on the significant difference in response to disturbance (presence of an observer) it seems likely that Tasman parakeets will remain vulnerable outside the National Park boundaries. In coming years, the eradication of rodents and cats might be feasible, following on the experiences on Lord Howe Island, to effectively remove the predation pressure on Tasman parakeets and other native species (see Chapter 3). In the meantime, there are significant gaps in knowledge on the biology of parakeets that need to be addressed to maintain a growing population. In this chapter I outline some of these gaps which hopefully can be addressed in coming years. Besides efforts towards better understanding patterns of habitat use by Tasman parakeets, it is important to critically evaluate the most recent taxonomic change for the species, advocated by BirdLife International and the IUCN, namely the merging of all "red-crowned" populations of *Cyanoramphus* under the polyphyletic *Cyanoramphus novaezelandiae*.

INTRODUCTION

The potential of roadside mature tree stands as corridors for Tasman parakeets

The road network on Norfolk Island consists of 50 paved roads and vehicle tracks adding up to approximately 78 km (WorleyParsons Services, 2015). The majority of these roads are fringed by large trees such as Norfolk Pines (*Araucaria heterophylla*), Lilac (*Melia azedarach*) (Fig. 22, Fig. 23, Fig. 24), African olive (*Olea europea cuspidata*), Guava (*Psidium cattleianum*) Wattle (*Acacia dealbata*) Gum trees (*Eucalyptus* spp.) as well as a number of fruiting trees like Bananas (*Musa* x *paradisiaca*), Lemons (*Citrus jambhiri*). In some areas, there is also a thick undergrowth of shrubby species like wild tobacco (*Solanum mauritianum*). Norfolk pines and lilacs in particular, provide large amounts of fruits eaten by Tasman parakeets, and records prior to this study include groups of up to five birds foraging on these trees away from the National Park boundaries. It is possible that these tree stands act as corridors to connect patches of vegetated areas for Tasman parakeets, but this has not been explored in detail. The closely related Red-fronted parakeet (*Cyanoramphus novaezealandiae*) can fly long distances, up to 65 km (Ortiz-Catedral, 2010). So it is likely that the flying capacity of Tasman parakeets falls within this range. Similarly, juvenile red-fronted parakeets in the Wellington area have been reported dispersing ca. 3 km outside Zealandia, a fenced sanctuary (Irwin, 2017). One potential approach to better understand the importance of roadside fruiting trees on the dispersal and establishment of Tasman parakeets would be the use of radio-telemetry to monitor movements of different age and size classes of parakeets.

Radio-telemetry has been successfully used to track other *Cyanoramphus* species like the Orange-fronted parakeet (*Cyanoramphus mahlerbi*) (Ortiz-Catedral, 2012), the aforementioned red-fronted parakeet (Ortiz-Catedral et al., 2010) and even Tasman parakeets.

Figure 20. From top left: SW edge of the Norfolk Island National Park, view from Mission Road; Example of roadside vegetation; Bottom from left: Fruiting melia on edge of private property; Roadside Norfolk pines near Middlegate. Photos: L. Ortiz-Catedral.
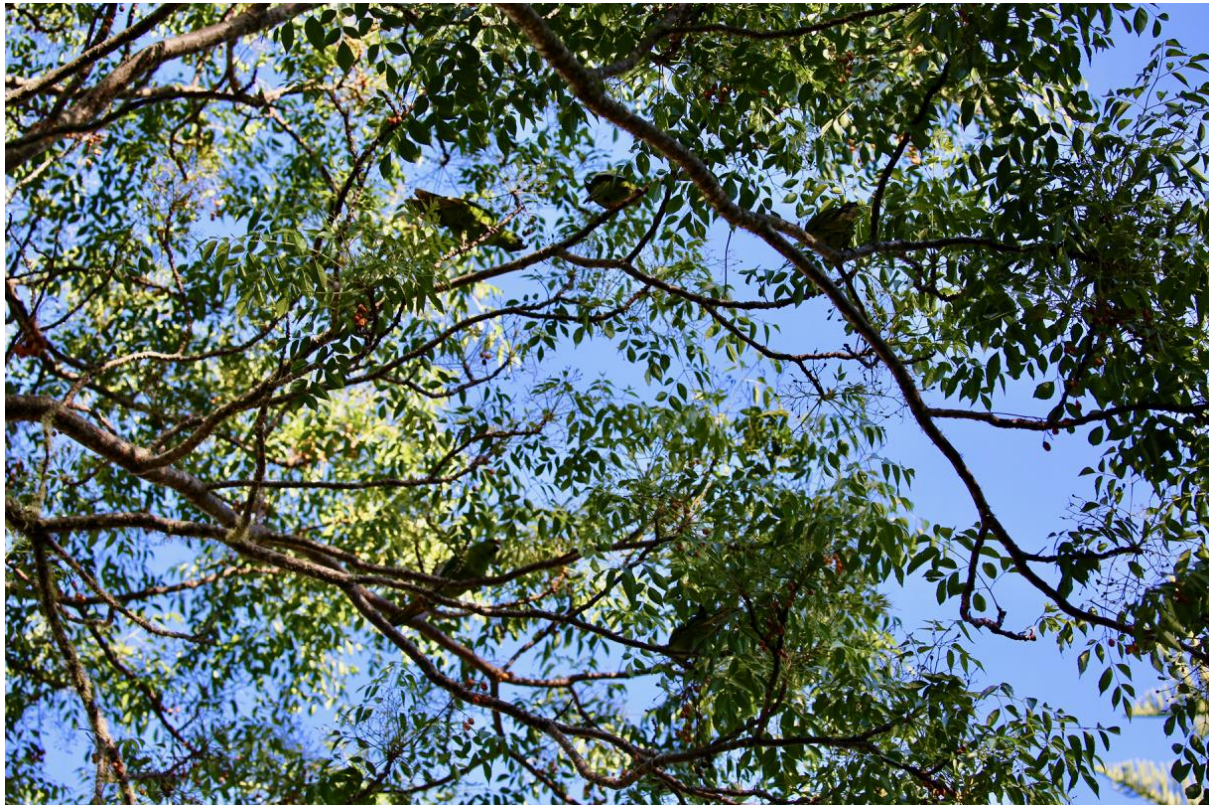
Figure 21. Group of five Tasman parakeets foraging on lilac (*Melia azedarach*) fruits, in a private property 600 m away from the nearest boundary of the Norfolk Island National Park. Photo: L. Ortiz-Catedral.

In 2016-2017 the Norfolk Island National Park conducted a pilot study looking at the dispersal capability of juvenile Tasman parakeets (C. Jones, pers. Comm.). During this research I collected preliminary observations on tree density of two species, Norfolk Pines and melia, along the roads of Norfolk Island. The densities of these trees in particular Norfolk pines is comparable to areas within the Norfolk Island National Park (Simmonds, 2020). Norfolk pines reach sexual maturity and start producing seeds at 10-15 years of age (Fullaway, 1972).

Figure 22. Group of five Tasman parakeets perched on a Norfolk Pine, some 0.45 km away from the nearest edge of the Norfolk Island National Park. Prior to the photograph being taken the birds were foraging on seeds in the lower branches. Photo: L. Ortiz-Catedral.

Although they only produce seeds during late May to early September this coincides with the breeding season of parakeets and represents an important food source for dispersing juveniles (Ortiz-Catedral, pers. comm.).

Future studies should therefore quantify fruit availability of roadside vegetation as well as degree of use by Tasman parakeets. Targeted restoration work, for instance replanting along edges with fruiting native vegetation could enhance the quality of these potential corridors by providing a wider range and seasonal availability of fruits for Tasman parakeets. Incorporating native plants to private gardens and farms could also provide a breadth of native plants for Tasman parakeets.

Bio-security approaches to prevent the establishment of crimson rosellas, and management of other nest competitors on Phillip Island

One of the most ambitious milestones in the conservation of the Tasman parakeet consists of the reintroduction of the species to Phillip Island, which is part of its former distribution (Mills, 2012). An initial attempt to reintroduce eight juveniles failed in 2018 (Simmonds, 2020). Translocations often fail initially and as lessons of the process are incorporated into additional planning, eventually succeed. For instance, attempts at reintroducing red-fronted parakeets to mainland New Zealand in the 1970s (Dawe, 1979) and 1990s (McMillan, 1990) failed. In 2010, attempts to reintroduce the species to Tawharanui, a mainland site (Ortiz-Catedral, 2010) were successful. The reintroduction template to re-establish these birds has not been successfully applied at other mainland sanctuaries including Zealandia (Irwin, 2017). In coming years further attempts to reintroduce Tasman parakeets to Phillip Island are likely (Ortiz-Catedral et al., 2018) but substantial work is needed prior to this. In particular, efforts should be made to prevent the establishment of crimson rosellas on Phillip Island, and potential control of introduced cavity nesters like starlings (*Sturnus vulgaris*). The available evidence suggests that crimson rosellas and starlings displace Tasman parakeets from to occupy nests. Crimson rosellas are strong competitors for nest cavities and in their natural range, can destroy clutches and broods of conspecifics (Krebs, 1998). Given the limited nests available on Phillip Island (Ortiz-Catedral, pers. comm.) it is important to maintain the nesting space available for Tasman parakeets.

Revision of the taxonomic placement of the Tasman parakeet

Taxonomic placement is important to conservation. The *Cyanoramphus* genus is typically made up of 12 species (See Chapter 1). Many *Cyanoramphus* species resemble similar morphological characteristics (Figure of heads). Red-crowned parakeets have traditionally been classified as those which were green bodied with a red crown and were separated into subspecies according to variations in distributions and appearance (Boon et al., 2001a). Although the Tasman parakeet has been recognised as a distinct species based on molecular evidence (Boon et al., 2001b), the IUCN and BirdLife International recently grouped the Tasman parakeet with the Red-fronted parakeet (*C. novaezelandiae*), a change that affects the conservation classification of the species. Boon et al., (2001b) distinguishes *C. cookii* and *C. saisetti* as two monotypic species (no recognised subspecies), and *C. n. novaezelandiae* and *C. n. chathamensis*, as two polytypic species. Forshaw (2017) argues that keeping Tasman parakeet classification as a subspecies should not change its conservation importance, however, this classification elevation is significant for the species to maintain genetic diversity and more research should be investigated to corroborate how other aspects of their biology can support this scientific claim to help make better management decisions. Other *Cyanoramphus* species have had taxonomic changes due to advancing molecular and phylogenetic techniques. Forbes's parakeet *C. forbesi* has also been elevated to species status after it was evaluated to be genetically distinct from the mainland species of Yellow-crowned parakeets (Triggs & Daugherty, 1996) and thus conservation management to prevent further hybridization of the species is attempted as well as setting up an insurance population (Chan et al, 2006), similar to the endeavour of translocating Tasman parakeets to Phillip and Howe Island (Ortiz-Catedral et al., 2018). Further research into how Tasman parakeets differ from closely related species by aspects of their biology, behaviour and diet, will be useful to gaining full species recognition and conservation efforts.

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APPENDICES

APPENDIX I

Permit from the Norfolk Island National Park / Departmnet of Environment, to conduct research on Tasman parakeets and Crimson rosellas.

Australian Government

Director of National Parks

Environment Protection and Biodiversity Conservation Regulations 2000

PERMIT FOR AN ACTIVITY IN A COMMONWEALTH RESERVE

Reserve for which this Permit is issued	**Norfolk Island National Park & Botanic Garden**	

Date of issue	**10 /9/2019 (backdated from 25/9/2019)**	*Date of expiry*	**20/6/2020**

Name/address of principal permittee and each person/group to whom permit issued	**principal permittee:** Dr Luis Ortiz-Catedral, Massey University, NZ 0210733351 l.ortiz-catedral@massey.ac.nz

Provision of the *Environment Protection and Biodiversity Conservation Act 1999* and the *Environment Protection and Biodiversity Conservation Regulations 2000*	Part 12 Permit to conduct Scientific Research

Activity permitted	Observation and quantification of behavioural traits of Green Parrots and Crimson Rosellas along the visitor tracks of the Mount Pitt Section of the Norfolk Island National Park. This includes filming and photography of those species.

Failure to adhere to the attached conditions is an offence and may also result in suspension or cancellation of this permit.

....
Delegate of the Director of National Parks

(A /g)
Park Manager NINP

OFFICIAL USE ONLY
NINP- 2019 / 09 /10

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Australian Government

Director of National Parks

Dr. Luis Ortiz-Catedral
Massey University
NZ

25th September 2019

Dear Dr. Ortiz-Catedral

PERMIT TO CONDUCT SCIENTIFIC RESEARCH IN
NORFOLK ISLAND NATIONAL PARK

Your recent application for a permit to conduct scientific research in Norfolk Island National Park has been approved. Permits to conduct activities in a Commonwealth reserve are a requirement of the *Environment Protection & Biodiversity Conservation Act 1999*.

Please find enclosed permit number NINP 2019/09/10, valid for the period 10 September, 2019 to 20 June 2020.

You will also find enclosed a copy of your permit conditions. To ensure your activity remains compliant with Australian Government regulations, I remind you of these conditions and reporting requirements to which you have agreed.

If there is any further information you require please contact the Norfolk Island National Parks office 22695 or by email: norfolkislandnationalpark@environment.gov.au

Yours sincerely

Nigel Greenup
Park Manager, Norfolk Island National Park
Delegate of the Director of National Parks
PO Box 310
Norfolk Island 2899

NORFOLK **ISLAND**

NORFOLK ISLAND REGIONAL COUNCIL

PUBLIC RESERVES ACT 1997

PERMIT

TO CARRY OUT A CONTROLLED ACTIVITY IN A PUBLIC RESERVE

No. 35/2019

I, James Castles, Senior Environmental Officer, hereby grant a permit under Section 26 of the *Public Reserves Act 1997* for Georgia Brett of Massey University Oteha Rohe, Albany Highway, Albany 0632, email georgiamichellebrett@gmail.com, phone 02102989384 to observe wild birds, specifically the green parrot and crimson rosella, for the completion of Georgia Brett's Master of Science qualification with Massey University, New Zealand. Participants of the activity are Georgia Brett, fieldwork leader, and Millie Ahlstrom, fellow post-graduate student from Massey University. Participants will require visitation of Reserves to observe behavioural states of birds in their natural environment. Data collected from these visits will be used to help answer questions of Georgia's thesis to quantify similarities or differences between endemic and introduced birds that could provide insights into bird conservation on Norfolk Island. Participations will access reserves via public entries, gather observational data from public walkways and will be respectful and vigilant of reserve vegetation, wild life and other visitors of the reserve. Behavioural data collection will not require any wildlife handling. Observations of birds will be made incidentally while walking through reserves. Once a bird has been identified, participants will qualify the behavioural states presented in 30 second intervals for up to 15 minutes. These activities will occur between times of 7am – 12pm and 2pm – 5pm during weekdays and weekends.

This activity will be conducted between 6 September 2019 to 20 September 2019 in the following reserves – Anson Bay Reserve, Bumbora Reserve, Hundred Acres Reserve, Selwyn Reserve and Two Chimneys Reserve.

This activity will be subject to the following conditions:

1. The permit holder shall ensure that all reasonable measures are taken to prevent injury to any person, and shall ensure at least one of the permit holder's staff present at the permitted activity holds a current Senior First Aid certificate, has access to an adequate first aid kit and has an operational mobile phone

2. The permit holder shall as soon as practicable notify the Senior Environmental Officer of the details of any hazardous circumstance and of any occurrence of personal injury associated with activities carried out pursuant to this permit

3. The permit holder shall ensure that no damage is done to the land or to native flora or fauna in a public reserve

4. The permit holder shall prior to erecting any marquee or other structure:

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(a) inspect the site with the Commonwealth Heritage Manager, or the Senior Environmental Officer; and

(b) receive specific approval from the Commonwealth Heritage Manager, or the Senior Environmental Officer to erect such structures on the proposed site

5. The permit holder shall not interfere with any natural feature or any structure, including footings and other structures under the ground, or attach or allow to be attached, anything to any historic structure, will not excavate the land or dig any holes unless otherwise approved by the Senior Environmental Officer and shall ensure that all activities are conducted in a manner consistent with the conservation and heritage status of structures and other features in the Reserve

6. The permit holder shall ensure that all existing structures, including footings and other structures under the ground, are used in a manner consistent with their heritage status

7. The permit holder shall as soon as practicable notify the Senior Environmental Officer of the details of any potentially historical artefact found or discovered during the course of the permit holder's activities pursuant to this permit. **NOTE:** It is an offence to interfere with any artefact without a permit. An "artefact" is any man-made object, thing or item, including any man-made object, thing or item that can reasonably construed to be or to have been the property of a person or persons unknown; "interfere" has the same meaning as "interfere" in section 42 of the *Public Reserves Act 1997*

8. The permit holder shall exercise control over the parking of spectators' vehicles to ensure the safety of persons and prevent any damage to the reserves

9. Vehicles operated by the permit holder in conducting activities pursuant to this permit may access only those parts of public reserves as directed by the Senior Environmental Officer, and shall not access any part of a public reserve not otherwise designated for vehicular access as set out in the Plan of Management for that public reserve; no vehicle is to be taken into or operated within any area from which vehicles are normally excluded

10. The permit holder shall not park any vehicle or allow any vehicle operated by any other person undertaking activities pursuant to this permit to be parked on or in the immediate vicinity of any historical structures or building footings or foundations. NOTE: A plan of the location of known historical structures in the area(s) that may be used by the permit holder pursuant to this permit may be obtained from the Commonwealth Heritage Manager or the Senior Environmental Officer

11. The permit holder shall not permit any activity which is contrary to the Plan of Management for any reserve in which any activity under this permit is carried out or is to be carried out or which is contrary to any law of or applicable to Norfolk Island

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12. The permit holder shall provide sufficient equipment, tables and seating to cater for all of the persons to whom the permit holder is providing lunches, dinners or any other activity conducted pursuant to this permit

13. The permit holder shall not prevent any other person having access to and use of any facility (including barbeques, tables and seats) in a public reserve

14. The permit holder shall not interfere with the enjoyment of any Reserve by other members of the public

15. The permit holder shall not provide any food or alcoholic beverage in any public reserve without having the required licences and permits to do so

16. The permit holder shall remove from the Reserve all rubbish and wastes associated with activities conducted pursuant to this permit

17. The permit holder shall only place or display signs approved by the Senior Environmental Officer.

18. The permit holder shall not hold themselves or allow anyone else engaged in any activity under the permit to hold themselves out to be a ranger or employee or agent of the Norfolk Island Regional Council or law enforcement officer or agent/employee of the Norfolk Island Regional Council in any way where no such appointment or employment is actually held by the permit holder or the person concerned

19. The permit holder and all persons, firms, associations and corporations undertaking any activities under this permit shall immediately comply with all notices and/or directions (whether written or oral) issued or given under or pursuant to the *Public Reserves Act 1997* or under or pursuant to any other law applicable to Norfolk Island

20. The permit holder shall immediately cease any activities in a reserve and shall leave or cause any person engaged in any activity under the permit in a reserve to leave that reserve immediately upon declaration of any closure of such reserve either permanently or temporarily at any time during the period of the permit

21. The permit holder shall immediately notify the Senior Environmental Officer where

    (a) the permit holder or any person engaged in any activity under the permit is convicted of an offence against the *Public Reserves Act* or regulations; and

    (b) the permit holder or any person engaged in any activity under the permit has contravened any condition to which the permit is subject;

22. The permit holder, in accordance with the indemnity provided on the application for the permit, fully and irrevocably indemnifies and saves harmless the Senior Environmental Officer all rangers, the Norfolk Island Regional Council together with all employees servants and agents thereof, the Administrator of Norfolk Island, the Crown and the Commonwealth of Australia jointly and severally from any and all liability and claims whatsoever arising in any way out of or in connection with or as a result of any activities carried out or conducted or

Norfolk Island Regional Council expressly denies any liability for any injury occurring to any person who may conduct any activity pursuant to this permit

proposed to be carried out or conducted under the permit or the involvement of any person firm or corporation in any way in regard to any activity carried out or to be carried out under the permit

23. The permit holder is to immediately notify the Senior Environmental Officer of any claim for compensation or damages or any legal proceeding made against the permit holder in respect of any activity or person engaged in any activity under the permit

24. The grant of a permit does not establish any relationship of master and servant, bailor and bailee, principal and agent, employer and employee, insurer and insured, guarantor and guarantee, protector and protectee, person in *loco parentis* and child, guardian and child, teacher and student, nor any like relationship or duty of care as between the Senior Environmental Officer and the permit holder and/or any person acting on behalf of or under the direction or control of the permit holder engaged or to be engaged in any activity under the permit and/or in respect of any vehicles, equipment or materials used or to be used under the permit

25. A permit holder shall not have any expectation or belief that a permit will be granted or extended or renewed or continued as of right or as a mere formality even if any commercial activities conducted or to be conducted under a permit may be at risk if a permit is not granted or extended or renewed or continued by the Senior Environmental Officer; and

26. Senior Environmental Officer retains the right to cancel or suspend the permit at any time in accordance with the *Public Reserves Act 1997*.

Dated   **5 September 2019**

James Castles
Senior Environmental Officer

Norfolk Island Regional Council expressly denies any liability for any injury occurring to any person who may conduct any activity pursuant to this permit

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APPENDIX III

Acceptance letter from New Zealand Journal of Zoology

New Zealand Journal of Zoology

Decision Letter (NZJZ-2020-0002)

From: jim.briskie@canterbury.ac.nz

To: l.ortiz-catedral@massey.ac.nz

CC:

Subject: New Zealand Journal of Zoology - Decision on Manuscript ID NZJZ-2020-0002

Body: 27-Feb-2020

Dear Luis:

Re: NZJZ-2020-0002 Behaviour of Tasman parakeet (*Cyanoramphus cookii*) in the Norfolk Island National Park.

I have now received the referees' reports for the above manuscript. Some revision is required to address points raised by the referees. I am, therefore, returning the paper to you for minor revision, together with copies of the referees' reports.

Your revised paper should be resubmitted within 2 months of this letter (by 27-Apr-2020) otherwise the manuscript will be treated as lapsed and withdrawn from our system.

The revised manuscript must be submitted in Word, with changes marked using track changes or coloured text. Also, please upload a separate document responding to all the queries raised by the reviewers and the editor, and must explain or justify any suggested revisions the author is not prepared to make.

Please make sure that figure files are saved separately from the manuscript in an acceptable format (TIFF, JPEG, PS, EPS, AI or SVG files) and with the correct resolution (1200 dpi for line art, 600 dpi for grayscale and 300 dpi for colour). Provide a list of figure captions after the references section of the manuscript. Do not embed the figure caption in the figure file. Number the figures according to their sequence in the text and use a logical naming convention.

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Yours

Jim Briskie
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Reviewer(s)' Comments to Author:

Referee: 1

Comments to the Author
Some points to consider.
The whole article needs a much more rigorous edit, re grammar and sentence construction. It is a little too verbose.
The Title seems too generalist in nature. Perhaps more along the lines of the behaviours/ reliance upon Niau consumption and its significance with regard to survival in face of other species consumption; The importance of Niau fruit to .....

In the Abstract the word spring suddenly appears, so needs explanation. There is very little mention in the Abstract about the recorded behaviours, even though they formed a substantial part of the data collected. Perhaps the emphasis of the Abstract should move more along the lines of the effect upon the parakeet's survival, because of its reliance at times upon the fruit.....and this reflected in a slight Title change.
The Introduction lacks, for me, more detailed Genus references/discussion. Such as the work done by Greene on the C. novaezelandiae (Notornis 2003, NZ Jour Zool 1999, 1998), Kearvell on C. auriceps/C. malherbi (NZ Jour Ecology 2002), Nixon (Notornis 1994) and others. It would give the Research paper greater relevance and context. I very much like the mention of the importance of behavioural studies and their importance to a successful conservation outcome;

perhaps this can be given more emphasis.

I do not think the Methods needs the first paragraph and it might be better placed in the Introduction. You say you selected the sampling during the 'busiest' periods of parakeet activity; from a previous study. This means the sampling is biased to that period and this should be declared, as there may be behaviours/feeding that are different during this period. I like the instantaneous sampling method, but, are the parakeets marked in some way, leg bands, so that repeat sampling can be avoided; a real problem when dealing with rare birds. If not, then this also must be declared as it is a biased sample. Did you move on for a fixed distance before sampling again, in order to avoid repeat sampling.....it must be stated what was done to avoid this, or state in results this is an issue. Especially in light of the seeming small sample size, ie 31 foraging bouts. As stated earlier the results don't seem to be fully reflected in the Abstract, especially in relation to the 'behaviours' results. But generally the results section seems to be well set out. There is no mention of the samplers recording other species recorded on the fruit; needs explanation unless none were seen of course.

The Discussion section again, to me, lacks the context of the other genus studies along the same lines. There are opportunities to contextualise the Discussion much better, using these references. It might be worth considering shifting the emphasis, caused by the parakeets seeming reliance, at times, upon the Niau fruit. But care must be taken with the issues mentioned above, re the possible bias sampling; needs elaboration.

The References used in the text are all recorded in the Reference section.

Referee: 2

Comments to the Author
This is an important paper – one of the few on a species of high conservation value. This contribution will add considerably to our knowledge of this parrot's basic biology and to its conservation. I would like to see this published, but it does require some (but not overly major) revisions.
The manuscript is well written, clear and accessible. However, a really good edit is required for tenses, plurals and quite a few typos throughout (eg. Ln 67 'decribed'). I have not captured all of these in my comments as a spellcheck should easily pick these up.
There are some limitations to the study that should be acknowledge in the discussion. Any biases/differences in observations given behaviour data was collected by different people? Training?
Some justification/explanation required for why observations were taken from tracks and whether this might create a bias in the data collected. At least some acknowledgement of this in the discussion, with implications for conservation if this data are biased.
Detailed Comments
• Ln 52-53 – needs editing for clarity
• Ln 55-56 – reads like Cyanoramphus are a genus who don't exhibit some behaviours in captivity (ie. following on from previous sentence). Not sure this was meant by authors?
• Ln 62 – replace 'thanks to' with 'as a result of'?
• Ln 64 – behavioural?
• Ln 70 – re-write: 'to improve'?
• I don't think seasons should be capitalised throughout, nor 'niau'
• Ln 80 – might read better as 'two periods of critically low population…'
• Ln 123 – ripe fruit only?
• Ln 131 – usually indicate which author by initials when pers. obs.
• Ln 154 – 'feeding species' – not sure whether this is bird or plant – re word
• Ln 159 – instead of significantly different, much more helpful to read to indicate direction in text e.g 'significantly higher'
• Ln 155-158 – would be helpful here to state the result that niau made up 44% of the diet/observations (Table 1)
• Table 1 – the species should be ordered in some helpful way – eg highest proportion of diet obs to lowest
• There are significance tests on height differences – but no mention in methods of how height was measured. Given differences in observers, if height was estimated – then how significant are these differences in heights likely to be?
• Not sure how helpful the 2nd column in Table 3 is, given its just the inverse of column one.
• Ln 210-212 –needs to be broken into 2 sentences.
• Any observations of other species (eg rosellas or rats) consuming fruit? Are rats primarily eating them on the ground or one the tree? Perhaps a statement saying quantification needed for these other species to see if indeed they are limiting this important food source for the parakeets

Reviewer: Margaret Stanley

Date Sent: 27-Feb-2020

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APPENDIX IV

The importance of Niau (*Rhopalostylis baueri*) in the diet of the Tasman parakeet (*Cyanoramphus cookii*) in the Norfolk Island National Park.

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Keywords: Parrot, conservation, diet, island species.

ABSTRACT

The Tasman parakeet is a recovering threatened species, and much of its conservation planning in the last 40 years has occurred with little information about its behaviour in the wild. In this study, we quantified the relative frequency of behaviours and diversity of food items for the species during autumn and winter. We also collected information on the availability of one of their main foods: Niau (*Rhopalostylis baueri*) fruits. Parakeets fed on fruit pulp and seeds of eight plant species and but niau fruits represented 44% of total feeding bouts indicating that this is an important food item during winter-spring. The most common behavioural state during our observations was feeding (30% of behavioural states). Our estimate of niau fruit availability in the core area of Tasman parakeet occurrence indicates approximately 1,185,234 fruits during the peak of fruiting in spring. Our results indicate that Tasman parakeets are generalists, but niau fruits represent an abundant and important resource. Although niau are common and

produce large quantities of fruit, introduced rats (*Rattus* spp.), potentially represent significant competitors to Tasman parakeets, because they also feed on niau fruits. Ongoing control of rats is thus critical to maintain large quantities of native fruits to sustain a growing population of Tasman parakeets.

INTRODUCTION

Animal behaviour research can be useful to assist in the recovery of rare species (Caro 1999; Butler 2006). For instance, observations of nesting attempts by captive-bred individuals of the critically endangered Puerto Rican parrot (*Amazona vittata*), showed decreased nesting attendance by females, which led to higher rates of hatching and nestling failure (Wilson et al. 1997). This pattern of deficient nest attendance can alert conservation biologists to intervene via cross-fostering of eggs from captive-bred pairs to wild pairs to boost hatching success. Studies on conservation behaviour and ecology are difficult when species are rare and have small population sizes, or when critical periods of their biology are virtually unknown. For example, the critically endangered (possibly extinct) Hawaiian Po'ouli (*Melamprosops phaeosoma*), had low population sizes since its discovery in 1973 and was reduced to three individuals by 1998 (Butchart et al. 2018). Researchers attempted a recovery translocation but such a small population size meant a large set of unknowns about the dispersal biology of the species. As a result, translocated Po'ouli returned to their original home ranges without creating a successful pair bond (Groombridge et al. 2004). These examples highlight the difficulties of obtaining substantial behavioural information once populations decline to extreme low numbers.

Parrots (*Psittaciformes*) are an extinction-prone, highly endangered group of birds (Bennett and Owens 1997; Parr and Juniper 2003). Worldwide, parrots are threatened by

habitat destruction, bird trade and hunting, thus limiting their natural ranges and decreasing population sizes (Snyder and McGowan 2000). Recent studies have shown the importance of behavioural ecology in species conservation planning. For instance, the vulnerable eastern Regent Parrot (*Polytelis anthopeplus monarchoides*) exhibits nearly 50% nest failure, of which 16% is due to nest abandonment (Cantor et al. 2019). Early identification of abandoned clutches and broods via nest cameras, could assist in hatching eggs or rearing chicks in captivity for subsequent release into the wild. Nevertheless, critical behavioural information for several highly endangered species remains undocumented or unstudied in the wild. In many cases, threatened parrots are studied in captivity, for instance Kea (*Nestor notabilis*) (Gajdon et al. 2004). However, captive parrots might not exhibit the full range of behaviours one might encounter in the wild.

The Tasman parakeet (*Cyanoramphus cookii*; *sensu* Boon et al., 2001) is a threatened recovering species restricted to 350-400 hectares of protected subtropical rainforest within the Norfolk Island National Park on Norfolk Island, in the South Pacific. Tasman parakeets have undergone cycles of population decline and recovery since the 1970s, with two periods of critically low population numbers: 1970s when it was reduced to fewer than 50 individuals (Silva 1989; Forshaw and Cooper 2002) and 2013 when the population was estimated at 50-100 individuals (Ortiz-Catedral et al. 2018). Since 2013, the species has recovered to a population of approximately 400 individuals as a result of ongoing assisted breeding via provisioning of safe nesting sites (Ortiz-Catedral et al. 2018). The key threats for the species are depredation by introduced cats (*Felis catus*) and rats (*Rattus norvegicus* and *R. rattus*) and shortage of safe nesting sites (Forshaw and Cooper 2002; Ortiz-Catedral et al. 2018). Although population sizes of Tasman parakeets have increased, the species remains extinction prone and requires sustained management. Management of the species to date has focused on behavioural information from nesting pairs which has successfully produced numerous chicks, but there is

limited information on the diet and diversity of species consumed and the availability of these in the Norfolk Island National Park. Likewise, their non-nesting behaviours have not been described. As the population size increases there are now opportunities to better understand the diversity of foods consumed by Tasman parakeet, their seasonal variability in diet and associated changes in behaviours to improve management and long-term conservation of the species.

Here we present an analysis of the behavioural states of Tasman parakeets in autumn and winter, the diversity of food consumed in these seasons and a preliminary analysis of annual changes in fruit availability for a key feeding resource: niau (*Rhopalostylis baueri*) fruits.

METHODS

Behavioural observations

We analysed behavioural observations of Tasman parakeets collected by volunteers and the senior author in the Mount Pitt section of the Norfolk Island National Park (29°01'13.19" S, 167°56'22.09" E) during autumn 2015 (8-14th March, 29-31st, May, 23-29th) and winter 2015 (June, 23-29th; August, 1-10th). We walked along the visitor track network of the Norfolk Island National Park between 06:30 h and 12:00 h and again from 14:00 h to 17:30 h; during previous visits to Norfolk Island, we estimated these as the periods of greater Tasman parakeet activity (Waldmann 2016). We conducted this study when the population of Tasman parakeets was estimated at approximately 200-250 individuals (Skirrow, 2018), and encounters with the species were not very common. At the time of this study, Tasman parakeets were not banded to distinguish between individuals. Therefore we cannot rule out repeat sampling of individuals. Although this could represents bias in sampling, our interest was to broadly

characterise the behaviours of Tasman parakeets rather than conducting inter-individual comparisons. Thus we consider our sampling adequate considering the rarity of the species and small population size at the time of our sampling.

For behavioural observations we followed a modified version of the instantaneous sampling method described by Magrath and Lill (1983). In short, we registered single behavioural events for individual Tasman parakeets using 30 second intervals alternated with a 30 second period of no records. This modification was necessary to maximise the number of useful observation events, for a cryptic species occurring in low numbers in order to describe its behaviours. Rather than measuring the duration of behaviours of individual birds, we were interested in sampling as many individuals as possible and into calculating the relative frequency of behaviours representative of the species. We continued our sampling for a maximum of 15 minutes per individual. The behaviours registered were assigned to eight pre-defined categories: agonistic behaviour (chases, fights); climbing or walking (either on a branch or on the ground); feeding (includes handling fruits, nibbling, biting and ingesting edible matter); flying (short flights from a branch to another, not flights departing the area or arriving into visual field of observers); preening; resting (perching motionless on a branch, not calling); resting alert (perching, calling, moving head); courtship feeding (food transfers between pairs).

On September 1st to 10th 2015 and September 3rd 2016 we also conducted observations on the feeding behaviour of Tasman parakeets consuming niau (*Rhopalostylis baueri*) and calculated the duration of individual foraging events (bouts) to the nearest second. Whenever a Tasman parakeet was found ingesting niau fruits, we recorded its location, visually estimated its foraging height (to nearest 0.5 m) and recorded the number of fruits picked from rachillae, that were crushed and ingested for a maximum of 15 minutes. We contrasted the rate of niau

fruit intake between the two sampling events 2015 and 2016. To minimise observer bias in height estimation, observers used baiting station markers as a reference for 1 m height. These markers, are coloured fibre-glass poles sticking 1-1.2 m off the ground in a 50 x 50 m grid across the Norfolk Island National Park.

Further, we estimated the daily change in fruit availability of niau fruits for Tasman parakeets. Niau have 30-60 cm long paniculate inflorescences divided into rachis and rachillae. To estimate the number of fruits per individual niau, we counted the number of green fruits on five random rachillae of 22 fruiting niau and multiplied the average by the number of rachillae bearing fruit on each tree. Fruit counts on the 22 niau were completed in a single day. The selection of this sample of niau followed the following criteria: mature individuals with visible fruiting rachis, location within known Tasman parakeet foraging grounds and accessibility to count fruits accurately within 5-6 hours. This criteria was deemed adequate to estimate fruit availability on the first and eight day of fruit counting. These estimates of availability refer only to fruits on rachis, not to fallen fruits on the ground. Tasman parakeets rarely consume niau fruits on the ground (LO pers. obs.), therefore we deemed these estimates of fruit availability representative of the ecology of the species.

Finally, we estimated the proportion of fruiting niau on a sample of 925 individual trees along a 1000 x 10 m transect along three sections of the visitor tracks in the Norfolk Island National Park: Mount Bates Track, Red Road Track and Palm Glen Track. We only included niau 3 m high, or above which represent the fruiting size class observed in the field. The transect location was chosen because it is an active area of foraging of Tasman parakeets, where over 60% of the records of Tasman parakeets have been registered in 2013-2015 (Skirrow 2018; Simmonds 2019). Individual niau were classified as "no seed set" (absence of visible fruits in any of the rachillae) or "seed set" (at least dozens of fruits in rachillae). To estimate

the availability of fruits along the transect, the senior author counted the fruits on 10 rachillae of 25 niau on 5th September 2015 and 1st September 2016, and multiplied the average by the number of fruit-bearing rachillae per niau along the transect. We used these estimates of fruit availability to roughly calculate the overall number of fruits, on the section surveyed between years.

We tested the normality of data using the Anderson-Darling test. For normal data, we used paired t-test. For non-normal data and data with unequal sample sizes, we used Welch's t-test (unequal variances t-test). This parametric test is easy to use and performs well when applied to non-normal datasets (Ruxton 2006). Results are presented as means $\pm$ SD.

RESULTS

Food species and feeding height

We recorded a total of 68 feeding events (48 in autumn, 20 in winter). Tasman parakeets ingested the fruit pulp, seeds and bark of eight plant species, 44% feeding events were on niau fruits (Table 1). In 10 instances, the species of fruit pulp consumed by parakeets could not be identified to species (Table 1). This was because the external characteristics of fruits (colour, texture, etc.) used to identify species were not visible. Parakeets fed at significantly higher heights in autumn than in winter (autumn 7.02 m; winter 4.31 m; Welch's $t = 2.365$ $p = 0.021$). In most instances, parakeets feed individually, with only 22% of records consisting of two or more birds.

Duration of foraging events on niau fruits

We recorded a total of 31 foraging bouts on niau fruits, 21 bouts in September 2015 and 10 bouts in September 2016. The duration of feeding bouts was similar between years: 2015 mean duration 3.88 ± 3.50 min, n = 21; 2016 mean duration 2.55 ± 2.59 min, n = 10; Welch's t-test= 1.187, p = 0.13. The rate of fruit intake was also comparable between years: 2015 fruit intake 6.12 ± 2.44 fruits per minute; 2016 fruit intake 5.55 ± 1.88 fruits per minute, Welch's t-test= 0.714, p = 0.250.

Behavioural states

We recorded a total of 792 behavioural states: 555 in autumn (81 parakeets) and 237 in winter (31 parakeets). On average, observations on Tasman parakeets lasted 3.28 ± 3.64 min in autumn, and 4 ± 3.83 min in winter (Welch's t-test t = -0.90, p = 3.71, n.s.). Behavioural states were recorded at significantly different heights between seasons, in autumn parakeets were observed higher on perches 8.53 ± 8.06 m, while in winter, they were observed at significantly lower heights, 6.11 ± 4.34 m in winter (Welch's t test t =2.04, p = 0.04). The distance from the observer at which parakeets were detected did not vary significantly between seasons (autumn 8.50 ± 9.45 m, winter 7.19 ± 18.49, Welch's t test t = 0.38, p = 0.71).

Tasman parakeets exhibited a similar frequency of behavioural states between autumn and winter 2015 (Table 2), with feeding being the most frequent behaviour (28% in autumn, 29% in winter), followed by climbing or walking (19% in autumn, 17% in winter). The least common behavioural states between seasons were agonistic behaviours, accounting for 1% in both seasons (Table 2). Courtship feeding behaviour represented 3% of behavioural states in autumn and 1% in winter. None of the differences in the frequency of each behavioural state was significantly different between autumn and winter after Bonferroni correction for Welch's t test.

Change in daily niau fruit availability

Over a period of seven days, we estimated a total loss of 18960 ± 3644 fruits from rachis of 22 fruiting niau. This indicates an approximate daily change in fruit availability (on rachillae) per individual niau of 123 ± 166 fruits. Both the number of rachillae bearing fruits and the average number of fruits per rachis decreased significantly between days one and seven (Rachillae bearing fruit day one: 52 ± 32, rachillae bearing fruit on day eight: 36 ± 19, paired t-test t = 2.04, p = 0.03; fruits per rachis on day one: 1859 ± 1502, fruits per rachis on day eight: 997 694, paired t-test t = 2.16, p = 0.02).

Change in percentage of niau fruiting trees

Between years, there was a 10% decrease in the proportion of fruiting niau along the 1000x10 m transect; in 2015 (n = 925) 460 niau (49.7%) had rachis with fruits, and 465 (50.3%) had no fruits. In 2016 (n = 917) 361 niau (39.4%) had rachis with fruits and 556 (60.6%) had no fruits. The average number of fruits per niau between years did not vary significantly: in 2015 we estimated 2471 ± 2217, in 2016 2457 ± 1693.01 (paired t-test 0.03, p = 0.97, n = 25). Assuming that the fruit counts on 25 niau trees per year are representative of the average fruit volume of the niau found along the transect, the mean fruit availability for 2015-2016 along this section of the Norfolk Island National Park during the first week of September would be in approximately 1, 185 ,234 fruits on rachis (Table 3). At the estimated rate of fruit loss (123 fruits per day), it would take approximately 24 days to approach near zero fruit availability on rachis on the sampled area.

DISCUSSION

Our field observations of Tasman parakeets indicate that, like other members of *Cyanoramphus*, spend up to 30% of their daytime activities foraging, like other *Cyanoramphus* species (Ortiz-Catedral 2010). Tasman parakeets are regarded as a food generalist, much like most *Cyanoramphus* species (Ortiz–Catedral and Brunton 2009; Waldmann 2016) and do not feed exclusively on niau fruits but these represented approximately 44% of feeding bouts registered during the present study. This suggests niau fruits are an important food item during the winter-spring period. Tasman parakeets show seasonal dependency on niau, suggesting the impacts of its reduction could be high. Compared to continental species, island species generally have narrower diets and are less likely to adapt to alternative food sources when seasonal food supplies are limited (O'Donnell and Dilks 1994). The effects on populations are higher when food supply and nest sites are removed at the same time (O'Donnell and Dilks 1994). Breeding success can likewise be affected when breeding seasons rely on abundance of a specific food source; Yellow-crowned parakeet numbers increase when beech (*Nothofagus* spp.) seeds are abundant (Elliott et al. 1996b).

Consumption of bark was recorded on two occasions during this study, and has been previously described for the species (Forshaw and Cooper 1973; Waldmann 2016). Other parrot species are known to ingest bark and other non-dietary items such as grit and dirt, including the orange fronted parakeet (*Cyanoramphus malherbi*) (Ortiz–Catedral and Brunton 2009). Though the purpose of consuming these items is unknown, it's function could be related to geophagy for detoxification (Gilardi et al. 1999).

Based on our calculations of niau fruit intake per minute, a 40% of time actively foraging on niau fruits would represent 350 niau fruits per parakeet per day. Assuming no differences in niau fruit ingestion between sexes and age classes, this would mean an

approximate requirement of 122,535 niau fruits per day for an estimated population of 300-350 parakeets at the time of our observations. Our estimate of niau fruit availability in the core area of Tasman parakeet occurrence indicates approximately 1,185,234 fruits during the peak of fruiting in Spring. Besides Tasman parakeets, introduced crimson rosellas (*Platycercus elegans*), introduced rats (*Rattus norvegicus* and *R. rattus)*, and blackbirds (*Turdus merula*) also consume niau fruits, so despite the estimated high abundance of this resource, Tasman parakeets might have access to a smaller subset, since population sizes of these introduced species are much higher. Predator-prey population densities often coincide with changes in the abundance of seasonal foods. For example, in high mast-seeding cycles, trophic patterns often show an increase of rodents which predate on increased bird populations from consumption of surplus seeds (Elliott et al. 1996a; Bogdziewicz et al. 2016). In these seasons, rigorous pest control is implemented. Rats have been recorded feeding on closely related *Rhopalostylis* species including Nikau palm (*Rhopalostylis sapida*) flowers, fruit and leaves in New Zealand and many offshore islands (Cowan 1991; Campbell and Atkinson 2002). Therefore, ongoing rat control is critical to control large quantities of niau fruits to sustain growing population of Tasman parakeets. Future research should focus on Tasman parakeet dispersal beyond the boundaries of the Norfolk Island National Park, as well as the distribution of significant food resources found in non-protected areas for the species.

ACKNOWLEDGEMENTS

Table 1. Plant species and food types ingested by Tasman parakeets between Autumn and Winter (2015) on Norfolk Island.

Species	Type	Season	Total proportion of diet
African olive (*Olea europea cuspidate*)	Fruit pulp	Winter	0.11
Cherry guava (*Psidium cattleianum*)	Fruit pulp	Autumn	0.02
Niau palm (*Rhopalostylis baueri*)	Fruit pulp	Autumn, Winter	0.44
Broad-leaved Meryta (*Meryta latifolia*)	Fruit pulp	Autumn	0.01
Norfolk pine (*Araucaria heterophylla*)	Seeds	Autumn, Winter	0.17
Tobacco (*Solanum mauritianum*)	Fruit pulp	Autumn	0.01
Beech	Fruit pulp	Winter	0.02

(*Myrsine ralstoniae*)

Bloodwood	Bark	Winter	0.02
(*Baloghia inophylla*)			
Unidentified	Fruit pulp	Autumn, Winter	0.14

Table 2. Frequency of Tasman parakeet behavioural states between Autumn and Winter 2015 on Norfolk Island.

	Feeding	Resting	Resting alert	Preening
Autumn	0.28	0.15	0.14	0.12
Winter	0.29	0.16	0.15	0.15
	Climbing/walking	Flying	Agonistic	Courtship feeding
Autumn	0.19	0.08	0.01	0.03
Winter	0.17	0.09	0.01	0.01

Table 3 Proportion of fruiting Niau rachis in Spring on Norfolk Island.

	Rachis with fruits (%)	Rachis with no fruits (%)	Average number of fruits
2015	49.7	50.3	2471 ± 2217
2016	39.4	60.6	2457 ± 1693.01

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