FORAGING ECOLOGY OF THE WORLD'S ONLY POPULATION OF THE CRITICALLY ENDANGERED TASMAN PARAKEET (*CYANORAMPHUS COOKII*), ON NORFOLK ISLAND

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

Master of Science

in

Conservation Biology

at Massey University, Auckland, New Zealand.

Amy Waldmann

2016

The Tasman parakeet (*Cyanoramphus cookii*) Photo: L. Ortiz-Catedral©

ABSTRACT

I studied the foraging ecology of the world's only population of the critically endangered Tasman parakeet (*Cyanoramphus cookii*) on Norfolk Island, from July 2013 to March 2015. I characterised, for the first time in nearly 30 years of management, the diversity of foods consumed and seasonal trends in foraging heights and foraging group sizes. In addition to field observations, I also collated available information on the feeding biology of the genus *Cyanoramphus*, to understand the diversity of species and food types consumed by Tasman parakeets and their closest living relatives as a function of bill morphology. I discuss my findings in the context of the conservation of the Tasman parakeet, specifically the impending translocation of the species to Phillip Island. I demonstrate that Tasman parakeets have a broad and flexible diet that includes seeds, fruits, flowers, pollen, sori, sprout rhizomes and bark of 30 native and introduced plant species found within Norfolk Island National Park. Dry seeds (predominantly *Araucaria heterophylla*) are consumed most frequently during autumn (81% of diet), over a foraging area of ca. 90 hectares, at 6.94 m above the ground. During winter, consumption of dry seeds remains high (61%) however over less than half the foraging area of autumn (46 hectares). More importantly, foraging height during winter is significantly lower than any other season, at 2.16 m. Though overall 18% of all foraging registered occurs at ground level, the highest frequency occurs during winter (55.4%). I argue that this seasonal shift in foraging area and height has important consequences for the management of Tasman parakeets. In particular foraging close to the ground within a small area makes the world's only population of Tasman parakeets highly vulnerable to predation by introduced cats, thus intensification of cat control during this period is crucial for safeguarding this species *in situ*.

ACKNOWLEDGEMENTS

This study would not have been possible without the help of many individuals and organisations. Financial support for my visits to Norfolk Island was provided by Massey University, The Mohamed bin Zayed Species Conservation Fund, World Parrot Trust, WildMob and the Parrot Society of the UK. On Norfolk Island, staff from the Norfolk Island National Park provided logistical assistance, which greatly facilitated data collection and analysis. Thanks to all those who helped in the field including: Tansy Bliss, Mike Skirrow, Liz Whitwell, Rebecca Hamner, John Steemson, Luke Martin, Jess Barr, Akshya Ilangovan, Nat Sullivan, Emma Wells, Mark Delaney, and Daniel Waldmann.

Thanks to all those who have contributed towards the conservation of the Tasman parakeet. Without those who have gone before, I wouldn't have the privilege of studying them today.

Thanks to the New Zealand Federation of Graduate Women – North Shore Branch. Thank you for seeing the potential in the research of a young student and honouring me with a scholarship. The funds have been a huge benefit to my research, and often helped me afford to contact home on long field trips.

Many thanks to the Auckland War Memorial Museum for allowing me the use of their incredible collection. What wonders it holds. Thanks particularly to Jason Froggatt, and Brain Gill for facilitating my access.

Thanks to Emma Wells, and the rest of the Auckland Zoo staff, for welcoming me on the 2015 kakariki banding trip on Tiritiri Matangi. What a magical few days.

To the community of Norfolk Island, I have never felt so welcomed away from home. Your love for your beautiful Island home shone through in everyone I met. Heartfelt thanks to all of you who have contributed to the care of your precious green parrots in the past, successfully ensuring they are here for the next generations. To the Norfolk Island National Park team, Abi, Cass, Joel, Dids, Rosco, Kenny, and many others, thank you all for showing me the secret world of the green parrot, and the other world that is Phillip Island. To Margaret and Ken Christian, whose knowledge, passion for their Island is limitless. To Jan and Anne, and everyone who came and let me share my dancing knowledge with them, it was an honour to be welcomed in such a way. To all the girls at The Olive, for keeping up with my coffee addiction, and recognising me every time I came back. To Jenny, Helen, Mira and Graham for providing the beautiful cottages that became my home away from home, your generosity was unfailing. Thanks to Beryl Evans, for access to her records of the green parrot and sharing her wealth of knowledge over a cup of tea.
Norfolk Island truly is a pacific paradise. It is my hope this work will contribute to the conservation of your unique green parrot for the enjoyment of generations of Islanders to come. Thank you, everyone.

Thank you to Dianne Brunton for her feedback on an earlier version of this thesis, and for reminding me how to look on this work from the outside.

To Luis, my supervisor, without you I would have been lost. You have provided so much more than a student could ask for. You have given me opportunities and experiences that a 12 year old meeting her first kakariki on Tiritiri Matangi never dreamed of having. You have been an anchor in the maelstrom of self-doubt and self-discovery that is a thesis. Thank you for always checking on me, and keeping me focused. You have encouraged and pushed me to achieve more than I thought possible. I cannot thank you enough.

To all my family and friends. To my dear mother and father, you put in so much effort to ensure I came into this world, and then you continued to believe in me and encourage my love of nature and knowledge. Thank you for giving me such a strong base from which to grow. To my husband, thank you for holding me when I struggled and cheering me when I succeeded, and also for giving me the freedom to pursue this endeavour, you have given so much to allow me to complete this. I am forever blessed to have a man like you at my side, thank you. To Giselle, your friendship has been a blessing for many years, and I appreciate every drop of encouragement you have given me on this long journey. To my wider family, everyone has been so encouraging, and I’m looking forward to sharing this work with you. To my dancing family, especially Harry, Marie, Ian and Daniel, for ensuring I was not only a researcher but also part of another community, and giving me a goal to always strive for, thank you. To all my friends, you know who you are. Thank you for listening and encouraging me, and giving me a night off when I needed it.

To my Grandad, Oma, and Opa. You have all inspired me in your own ways, and though only one of you is here to see this, I know you are all proud.

Lastly, to the green parrot. After hours and hours spent trekking through Norfolk Island National Park I have seen some amazing sights. I have witnessed pairs courtship feeding, held babies that were days and weeks old, and even found a previously unknown nest in an unlikely punga and watched its young fledge. I have searched for hours in vain for one feeding observation, and also walked right past a parrot only for it to alert me to its presence. After all this, if there is one thing I have learned, life will always continue, and we can give it that chance.

Me reading the band of Tasman parakeet chick. July, 2014.

TABLE OF CONTENTS

ABSTRACT III

ACKNOWLEDGEMENTS IV

TABLE OF CONTENTS VIII

LIST OF TABLES AND FIGURES XIII

  TABLES xiii

  FIGURES xiv

CHAPTER ONE: GENERAL INTRODUCTION

1.1 PSITTACIFORMES: A HIGHLY THREATENED GROUP OF BIRDS 1

1.2 THE GENUS CYANORAMPHUS 4

1.3 STUDY SPECIES: THE TASMAN PARAKEET 8

1.4 STUDY SITE: NORFOLK ISLAND 10

1.5 AIMS OF THE PRESENT STUDY 15

1.6 THESIS OUTLINE 15

  1.6.1 Chapter One 15

  1.6.2 Chapter Two 16

  1.6.3 Chapter Three 16

  1.6.5 Chapter Four 16

  1.6.4 Chapter Five 16

1.7 REFERENCES 17

CHAPTER TWO: DIETARY NICHE AND BILL MORPHOLOGY IN CYANORAMPHUS

2.1 INTRODUCTION 25

2.1.1 Bill Morphology And Diet 25

2.1.2 The Genus *Cyanoramphus* 28

2.2 OBJECTIVES 30

2.3 METHODS 30

2.3.1 Definition Of Terms 30

2.3.2 Dietary Diversity And Analyses 32

2.3.3 Bill Morphology 33

2.4 RESULTS 35

2.4.1 Dietary Diversity 35

2.4.2 Bill Morphology 37

2.4.3 Bill Morphology And Seed Consumption 41

2.5 DISCUSSION 52

2.5.1 Dietary Diversity And Overlap 52

2.5.2 Bill Morphology 54

2.5.3 Bill Morphology And Seed Consumption 55

2.6 LIMITATIONS AND FUTURE DIRECTIONS 58

2.7 CONCLUSIONS 59

2.8 REFERENCES 59

CHAPTER THREE: SEASONAL CHANGES IN THE DIET OF THE TASMAN PARAKEET

3.1 INTRODUCTION 66

3.1.1 Generalities Of The Diet of *Cyanoramphus* Parakeets 69

3.2 OBJECTIVES 73

3.3 METHODS 73

3.3.1 Data Collection 73

3.3.2 Statistical Analyses 75

3.4 RESULTS 76

3.4.1 Seasonal Variation in Dietary Diversity 80

3.4.2 Seasonal Variation In Food Types 83

3.4.3 Foraging Height 84

3.4.4 Foraging Group Size 86

3.5 DISCUSSION 87

3.5.1 Seasonal Variation In Food Species 87

3.5.2 Non-Dietary Observation 89

3.5.3 Seasonal Variation In Food Types 89

3.5.4 Seasonal Variation In Foraging Height 90

3.5.5 Foraging Group Size 91

3.6 LIMITATIONS AND IMPROVEMENTS 92

3.7 CONCLUSION 93

3.7 REFERENCES 93

CHAPTER FOUR: SPATIO-TEMPORAL VARIATION IN FORAGING AREAS OF THE TASMAN PARAKEET: A PILOT STUDY

4.1 INTRODUCTION 100

4.2 OBJECTIVES 103

4.3 METHODS 103

- 4.3.1 Data Collection And Analysis 103

4.4 RESULTS 105

- 4.4.1 Inter-Seasonal Variation In Foraging Areas 105
- 4.4.2 Ground Feeding 110
- 4.4.2 Incidental Behavioural Observations 110

4.5 DISCUSSION 111

- 4.5.1 Preferred Areas Of Foraging 111
- 4.5.2 Targeted Predator Control 112
- 4.5.3 Potential Relationship Between Foraging And Nesting Locations 113
- 4.5.4 Weed Management And Restoration Of NINP 113
- 4.5.5 Incidental Behavioural Observations 114
- 4.5.6 Sampling Methodology 114

4.6 LIMITATIONS AND FUTURE DIRECTIONS 115

4.7 REFERENCES 115

CHAPTER FIVE: THE RELEVANCE OF THIS STUDY FOR THE CONSERVATION OF TASMAN PARAKEETS AND FUTURE RESEARCH NEEDS

5.1 CONSERVATION OF THE TASMAN PARAKEET 118

5.2 FUTURE RESEARCH 124

- 5.2.1 Competition With Crimson Rosellas (*Platycercus elegans*) 125
- 5.2.2 Competition For Food With Introduced Rodents 127
- 5.2.3 Habitat Use Of Tasman Parakeets And Resource Availability 128

5.3 REFERENCES 129

APPENDICES

A.1 APPENDIX 1 133

A.2 APPENDIX 2 154

- A.2.1 Raw Data For The Tasman Parakeet Diet 154

A.3 APPENDIX 3 156

- A.3.1 Tukey Honest Significant Differences 156

LIST OF TABLES AND FIGURES

TABLES

Chapter One

Table 1. Conservation status of *Cyanoramphus* parakeets according to IUCN. 5

Chapter Two

Table 1. Sample size of bill measurements from Auckland War Memorial Museum. 34

Table 2. Jaccards similarity coefficient for the diets of *Cyanoramphus* parakeet pairs. 36

Table 3. Means ± standard error and ranges of bill characteristics (mm). 38

Table 4. Tukey HSD 95% confidence intervals for mean difference in bill size characteristics of pairs of species (mm). 39

Table 5. Dietary items consumed by different *Cyanoramphus* species. 43

Chapter Three

Table 1. Species consumed by the Tasman parakeet as per accounts published prior to this study. 71

Table 2. Dietary items from voluntary reporting during 1977, 1982, and 1983. 72

Table 3. List of the 30 plant species consumed by the Tasman parakeet (*Cyanoramphus cookii*) in different seasons within the Norfolk Island National Park, including food type eaten. 78

Table 4. Shannon-Weiner indices of diversity for important food sources each season (species constituting more the 5% of seasonal observations). 81

Table 5. Breakdown of foraging height (m) for each season 85

Chapter Four

Table 1. Subset of observations of plant species consumed by the Tasman parakeet represented by GPS data per season (excluding non-dietary items). 109

Table 2. Subset of food type observations represented by GPS data per season. 110

Appendix 2

Table 1. Total number of observations of plant species consumed by the Tasman parakeet per season (excluding non-dietary items). 154

Table 2. Total number of observations for different food types per season. 155

FIGURES

Chapter One

Figure 1. A Tasman parakeet foraging on the ground on Norfolk Island. 5

Figure 2. Map showing the distribution of all *Cyanoramphus* parakeets (Boon, 2000) (including extinct taxa) in the South Pacific. 7

Figure 3. Map of Norfolk Island Group. 12

Figure 4. A) A Tasman parakeet emerging from the nest; B) Luis Ortiz-Catedral removing the predator-proof inspection hatch to check nest contents. 13

Chapter Two

Figure 1. Diagrams showing bill morphology measurements. 33

Figure 2. Dietary diversity of different *Cyanoramphus* species (as per published studies), including prevalence of seed consumption (measured by percentage of food species from which seed is consumed). 37

Figure 3. Linear regression (conducted in R© version 2.15.3) of bill surface area (BSA) and average body weights. 40

Figure 4. Relationship between BSA and prevalence of seeds in diet with reference of bill shapes for *Cyanoramphus* species. 41

Figure 5. Linear regression (conducted in R© version 2.15.3) of the prevalence of seed consumption in a parakeets diet (measured as % of richness) against average body weights (grams). 42

Figure 6. Linear regression (conducted in R© version 2.15.3) the prevalence of seed consumption in a parakeets diet (measured as % of richness) against average upper bill width (mm). 42

Chapter Three

Figure 1. Tasman parakeets feeding on fleshy fruits (f) or dry seeds (s) of the following species (from to left to right, then bottom left to right): peach[f] (*Prunus persica*), peach[s], shade tree[f] (*Meryta angustifolia*), African olive[f] (*Olea europea cuspidata*), Norfolk Island pine[s] (*Araucaria heterophylla*) and lilac[f] (*Melia azedarach*). 80

Figure 2. Food species as a percentage of diet per season. 82

Figure 3. Percentage of food types from all observations weighted for seasonal sampling effort. 83

Figure 4. Food types as a percentage of seasonal diet, sample sizes (Winter = 101, Spring = 214, Summer = 42, Autumn = 127). 84

Figure 5. Average foraging heights (m) per season, sample sizes (Winter = 101, Spring = 214, Summer = 42, Autumn = 127). 85

Figure 6. Percentage of observations for each group size per season (observations of groups of 5 and above are combined), sample sizes (Winter = 101, Spring = 214, Summer = 42, Autumn = 127). 86

Chapter Four

Figure 1. Some examples of food species for the Tasman parakeet. 102

Figure 2. Map of NINP walking tracks. 104

Figure 3. Locations of foraging Tasman parakeets in winter (2013 pale blue, n = 29; 2014 dark blue, n = 72). Area utilised = 46 hectares. 107

Figure 4. Locations of foraging Tasman parakeets in spring (2013 yellow, n = 47; 2014 white, n = 108). Area utilised = 74 hectares. 107

Figure 5. Locations of foraging Tasman parakeets in summer (2014, n = 42). Area utilised = 74 hectares. 108

Figure 6. Locations of foraging Tasman parakeets in autumn (2013, n = 30). Area utilised = 93 hectares. 108

Chapter Five

Figure 1. Long Valley on Phillip Island. 122

Figure 2. A crimson rosella perched in niau palm (*Rhopalostylis baueri*). 126

Figure 3. Two Pacific rats (*Rattus exulans*) eating fruits of *Meryta latifolia* in the Norfolk Island National Park. 127

A.3 Appendix 3

Figure 1. 95% confidence intervals for mean upper bill length (mm). 156

Figure 2. 95% confidence intervals for mean upper bill width (mm). 157

Figure 3. 95% confidence intervals for mean upper bill depth (mm). 157

Figure 4. 95% confidence intervals for mean lower bill basal width (mm). 158

Figure 5. 95% confidence intervals for mean lower bill distal width (mm). 158

Figure 6. 95% confidence intervals for mean lower bill length (mm). 159

Figure 7. 95% confidence intervals for mean lower bill width (mm). 159

CHAPTER ONE: GENERAL INTRODUCTION

1.1 PSITTACIFORMES: A HIGHLY THREATENED GROUP OF BIRDS

The order Psittaciformes (Parrots and cockatoos) includes 352 species divided into two families: Cacatuidae with 21 and Psittacidae with approximately 331 (Koutsos et al., 2001; Munshi-South & Wilkinson, 2006). Despite this taxonomic diversity and a wide variety of sizes and colouration, the order is morphologically distinct, and one of its most distinguishing features is a keratinous beak adapted primarily to crack and grind seeds (Forshaw & Cooper, 1981). Beak morphological similarity however, does not correspond to dietary uniformity within the order. Within this group it is possible to identify secondary beak and tongue adaptations for feeding on pollen and nectar as in the tribe Loriini, (genera *Chalcopsitta*, *Eos*, *Trichoglossus* and *Vini* (Forshaw & Cooper, 1989) or beak and digestive system adaptations for feeding exclusively on soft fruits as in the Pesquet's parrot (*Psittrichas fulgidus*) (Mack & Wright, 1998; Pryor et al., 2001).

Another remarkable feature of the order Psittaciformes is the high proportion of species threatened with extinction. Approximately 26% of all species are classified under an IUCN category of threat, from Vulnerable to Critically Endangered (Collar, 2000). Furthermore, 78% of all endangered parrots are single country endemics (Collar, 2000), such as the kakapo (*Strigops habroptilus*) from New Zealand (Powlesland & Lloyd, 1994), and the swift parrot (*Lathamus discolor*) from Australia (Saunders et al., 2007).

Parrots and cockatoos are threatened by a variety of factors including habitat loss (for example Australia's migratory swift parrot (*Lathamus discolour*) (Saunders et al., 2007), poaching for the pet trade (Wright et al., 2001), and the threats associated with inhabiting small geographic ranges and reduced population sizes (Collar, 2000). Others are threatened by competition with introduced species.

For instance, common brushtail possums (*Trichosorus vulpecula*) and introduced wasps (*Vespula* spp.) compete for honeydew with the New Zealand kaka (*Nestor meridionalis*), limiting the availability of this high-energy resource and affecting the productivity of kaka (Beggs & Wilson, 1991). Pathogens and diseases also represent a threatening factor for wildlife, particularly for small populations (Cleveland et al., 2002; Daszak et al., 2000). For parrots, the role of pathogens in threatening small populations is poorly understood. However, as a precautionary measure strict quarantine protocols are in place for small isolated populations to prevent transmission of highly contagious disease such as Psittacine Beak and Feather Disease (PBFD) (Jackson et al., 2014; Ortiz-Catedral et al., 2009c).

The impact of the threats mentioned above varies geographically. There is a much larger illegal trade in rare and endangered species of parrots in South America, for example (Marini & Garcia, 2005; Nóbrega Alves et al., 2013), than in Australasia (Pain et al., 2006). With regards to habitat loss and the impacts of introduced predators, island parrots (as well as other animal groups) are disproportionately affected when compared to mainland species (Blackburn et al., 2004; Didham et al., 2005). In fact 44% of parrot species threatened with extinction are island dwellers (Collar, 2000). Island ecosystems are particularly susceptible to the negative effects of introduced predators. For example, one of the most insidious introduced mammalian predators is the domestic cat (*Felis catus*), posing a major threat to many island vertebrates (Nogales et al., 2013), including parrots. For instance, domestic cats are considered one of the leading causes of local extinction of the Kermadec subspecies of red-fronted parakeet (*Cyanoramphus novaezelandiae cyanurus*) on Raoul Island (Ortiz-Catedral et al., 2009a). Also, domestic cats are likely to have caused the extinction of the Macquarie Island red-fronted parakeet (*Cyanoramphus erythrotis*) (Taylor, 1979).

The threatened status of many parrots has prompted research aimed at providing guidelines for management and conservation, to prevent the extinction of various species including the kakapo (Clout, 2006); eclectus (*Eclectus roratus*) and Pesquet's parrots (Igag, 2002); and Malherbe's parakeets (*Cyanoramphus malherbi*) (Ortiz-Catedral et al., 2012) to name a few. Nevertheless, there are still numerous gaps in knowledge that limit our ability to develop and implement management actions to improve the conservation status of many species (Collar, 2000).

The majority of studies on Psittaciformes to date focus on a single species and traditionally, on a single aspect of their ecology. For instance, diet (scaly-headed parrot *Pionus maximiliani* (Galetti, 1993); kaka (Moorhouse, 1997)); nesting biology (lilac-crowned amazon *Amazona finschi* (Renton & Salinas-Melgoza, 1999); red-fronted parakeet *Cyanoramphus novaezelandiae novaezelandiae* (Ortiz-Catedral, 2006)) or habitat use (Swift parrot (Saunders & Heinsohn, 2008)). Collectively, these studies have provided an overview of the variety of threats affecting wild parrots and cockatoos as well as insights into promising management actions to prevent their extinction. However, one of the most significant gaps in knowledge relates to the spatial and temporal variability of food resources utilised by wild parrots. Understanding the diversity of dietary items of a given threatened species can provide important information about critical resources for its survival and reproduction. For example, the Cape parrot (*Poicephalus robustus*) is a habitat and dietary specialist, feeding predominantly on the kernels of yellow-wood (*Podocarpus* spp.) species (Wirminghaus et al., 2002). Clearly, the conservation of this food resource is linked to the conservation of the Cape parrot across its range.

The dietary requirements of island parrots have received less attention when compared to mainland species. A notable example among island species relates to the food availability and reproductive output of the critically endangered kakapo, a species that only reproduces during "mast" seeding events on islands free of predators (Clout & Craig, 1995; Clout & Merton, 1998; Powlesland et al., 1995). These observations led to a successful supplementary feeding program for this species, albeit with the undesirable effect of biasing sex ratios towards males (Clout et al., 2002). The high proportion of threatened island parrot species (see above) and the scarcity of studies on their diet, warrants further investigations that can contribute towards saving critically endangered island species.

In this thesis, I describe the diversity of food resources used by of a critically endangered island parrot: the Tasman parakeet (*Cyanoramphus cookii*). I also document the temporal and spatial variability in foraging by this species and discuss the implications of these findings for the management and conservation of this island endemic.

1.2 THE GENUS CYANORAMPHUS

Tasman parakeets (Fig. 1) belong to the genus *Cyanoramphus*, a monophyletic group with 14 taxa (Boon, 2000) distributed across the South Pacific (Higgins, 1999). Four of these taxa are extinct (Boon et al., 2001), (see Fig. 2). Given that many *Cyanoramphus* parakeets are found on small, isolated islands they are considered vulnerable to extinction (Taylor, 1985). All extant members of the genus are classified under various categories of threat (Table 1) (Miskelly et al., 2008; Taylor, 1985).

Figure 1. A Tasman parakeet foraging on the ground on Norfolk Island. Photo: L. Ortiz-Catedral©.

Table 1. Conservation status of *Cyanoramphus* parakeets according to IUCN.

Common Name	Species	IUCN status
Yellow-fronted parakeet	*C. auriceps*	Near Threatened
Tasman parakeet	*C. cookii*	Critically Endangered*
Macquarie parakeet	*C. erythrotis*	Extinct
Chatham parakeet	*C. forbesi*	Endangered
Reischek's parakeet	*C. hochstetteri*	Not Recognised
Malherbes parakeet	*C. malherbi*	Critically Endangered
Red-fronted parakeet	*C. novaezelandiae*	Near Threatened
New Caledonian parakeet	*C. saisseti*	Not Recognised
Society parakeet	*C. ulietanus*	Extinct
Antipodes Island parakeet	*C. unicolor*	Vulnerable D2
Black-fronted parakeet	*C. zelandicus*	Extinct

*See also Chapter Four for a discussion on recent reviews of this status.

Cyanoramphus parakeets have been studied more intensely in New Zealand than in other localities in the South Pacific, and there are various studies addressing aspects of their ecology and breeding biology (Elliott et al., 1996; Greene, 1998; Kearvell et al., 2002; Ortiz-Catedral & Brunton, 2009). These studies have contributed towards refining translocation protocols to reintroduce *Cyanoramphus* parakeets to offshore island sanctuaries in New Zealand (Dawe, 1979; Miskelly & Powlesland, 2013; Ortiz-Catedral, 2009; Ortiz-Catedral & Brunton, 2008, 2010). Two common threats to all *Cyanoramphus* parakeets are depredation from introduced mammalian species (Elliott et al., 1996) and habitat loss (Ortiz-Catedral, 2010). A common management intervention aimed at expanding the geographic range and population size of various *Cyanoramphus* parakeets, is the translocation to offshore islands free of introduced mammalian predators (Miskelly & Powlesland, 2013). Although translocations have been successful and resulted in range expansion and population increase of red-fronted (Ortiz-Catedral & Brunton, 2010), yellow-fronted (*Cyanoramphus auriceps*) (Gaze & Cash, 2008) and orange-fronted parakeets (*Cyanoramphus malherbi*) (Ortiz-Catedral et al., 2012), a common shortfall in the wider conservation of *Cyanoramphus* parakeets has been the lack or limited assessment of dietary resources at release sites, which often fall outside the historical range of the target species. For example, orange-fronted parakeets were historically restricted to mainland beech (*Nothofagus* spp.) forests in the South Island (although there is some controversy regarding their precise historical range (Kearvell et al., 2003)); however, currently are being translocated to offshore islands with coastal forest and kanuka (*Kunzea ericoides*) / manuka (*Leptospermum scoparium*) patches (Ortiz-Catedral et al., 2009b). Both habitats are likely to exhibit marked differences in diversity of food items and their availability year-round, thus for effective conservation of *Cyanoramphus* parakeets translocation plans should include an understanding of the dietary items available at a given site and potential influence on the survival and lifespan of managed species.

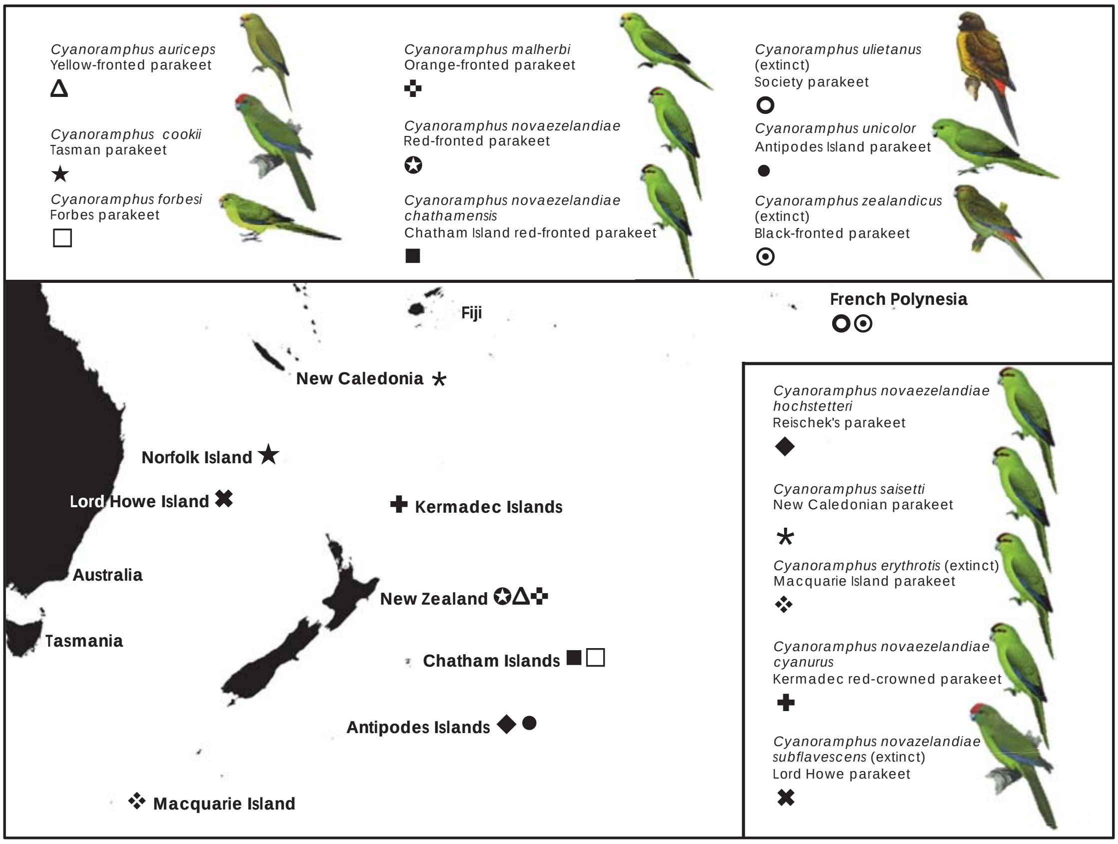

Figure 2. Map showing the distribution of all *Cyanoramphus* parakeets (Boon, 2000) (including extinct taxa) in the South Pacific. Map modified from Free Vector Maps © (freevectormaps.com). Bird illustrations modified from Handbook of the Birds of the World (hbw.com); BirdLife International (birdlife.com); Gros-Becs (grosbecs.net) and untitled Tasman parakeet painting, kindly donated by Mrs. Beryl Evans, resident of Norfolk Island.

The Tasman parakeet has been the subject of intense management since the 1970's (Hill, 2002), mostly focusing on provisioning of safe nesting sites, captive-breeding and control of introduced rats (*Rattus* spp.) and domestic cats (Hicks & Greenwood, 1989). Although this management has prevented the extinction of the species (Butchart et al., 2006), the population of Tasman parakeets remains in low numbers (Ortiz-Catedral, pers. comm.). An ambitious plan to leap forward in the conservation of this island endemic considers its translocation to nearby Phillip Island, a site free of introduced mammals but with a vastly different vegetation structure and composition (Coyne, 2009, 2011; Director of National Parks, 2008). To date no study has been aimed at documenting in detail the dietary requirements of the Tasman parakeet within the confines of the Norfolk Island National Park. The only available information comes from anecdotal observations of captive birds (see Chapter Three) and non-systematic records by residents and visitors of Norfolk Island (see Chapter Three). Thus the present study represents a significant contribution towards the integrated management of this species, by presenting the first detailed study on the diet of free-living Tasman parakeets.

1.3 STUDY SPECIES: THE TASMAN PARAKEET

The Tasman parakeet is similar in appearance to other *Cyanoramphus* parakeets, and like the red-fronted parakeet, it exhibits diagnostic bright green plumage with a blue leading edge of the wing (Forshaw & Knight, 2010). It additionally has a red crown and a small red patch behind the eyes, in contrast to the continuous eye stripe of the red-fronted parakeet. Adults display a bicolour beak that is blue-silver in the upper portion and black towards the tip (Higgins, 1999) (see Fig. 1).

For nearly 200 years, there has been taxonomic uncertainty surrounding the 'species' status of the Tasman parakeet. Most authors consider it a subspecies of the red-fronted parakeet due to the remarkable similarity in plumage (Higgins, 1999). Molecular evidence supports the recognition of the Tasman parakeet as a species under the phylogenetic species concept (Boon et al., 2001). In their analysis Boon et al. (2001) found strong evidence supporting the divergence of Tasman parakeets from the red-fronted parakeet clade. On the basis of this evidence the Tasman parakeet has been treated as a distinct species for over a decade (Christidis & Boles, 2008; Turbott, 1990). Despite these advances in molecular taxonomy, the debate continues (L. Ortiz-Catedral, pers. comm.). The recognition of the Tasman parakeet as a separate species is important beyond the traditional taxonomic debate. Norfolk Island, home to this island endemic, has a unique coastal forest type not found across the range of red-fronted parakeets in New Zealand. Thus, the diversity and availability of food items on Norfolk Island is unlikely to match that of other species. Clearly this has important consequences for management and conservation: taxonomic uncertainty might obscure important differences in feeding ecology (see Chapters Two and Three). For the remainder of this document, the Tasman parakeet will be considered a separate species following Boon et al. (2001) criteria.

The first detailed account of the behaviour of Tasman parakeets comes from Forshaw and Cooper (1981), who poetically describe the following: *"[Tasman parakeets] are active in the early morning, when pairs or small parties may be seen flying to or from favoured feeding areas. Once they have settled to feed, these parrots are extremely difficult to detect, so well does their green plumage blend with the foliage, and their presence is betrayed only by the continuous clicking of their mandibles, the steady stream of debris falling to the ground below and the occasional emission of their characteristic call notes (…) mainly arboreal, but will come to the ground where they forage for fallen seeds (…) They are not shy and will usually allow a close approach."* This short description refers to an important aspect of the biology of Tasman parakeets, namely their vulnerability when foraging at ground level (see Chapters Three and Five). Further, Forshaw and Cooper (1981) describe this species as extremely rare, and *"[A] classic example of island population declining under a number of pressures, notably loss of habitat, competition from introduced species, predation by rats and feral cats, and disease."*. Tasman parakeets have been considered under threat for a long time. In particular during the 1970's when the population experienced a historical low number with 17 birds (Hicks & Greenwood, 1989), which has prompted ongoing management involving the monitoring and predator-proofing of nests (Fig. 4).

Furthermore there is a baiting program in place targeting rats, and trapping targeting feral cats (Director of National Parks, 2008). Despite of all these actions, the world's only population of Tasman parakeets is still small and recent efforts to estimate its precise numbers have failed (Dutson, 2013). Ortiz-Catedral and Skirrow

(2015 in prep.) provide an estimate of approximately 100-250 individuals based on fixed point counts.

While ongoing predator control and protection of nesting sites has bolstered Tasman parakeet numbers, the long-term conservation of the species requires range expansion to two sites: Phillip Island, off the coast of Norfolk; and Lord Howe Island (Hutton et al., 2007) once introduced rats are removed. In this context the present study is timely because it provides information on the food types and feeding species of Tasman parakeets that can later be used to identify the most appropriate release sites based on vegetation characteristics.

1.4 STUDY SITE: NORFOLK ISLAND

Tasman parakeets are endemic to Norfolk Island (Fig. 3), where they are known locally as the “green parrot” (Chirstian, 2005). Until the 1800’s they also occurred on Lord Howe (see Fig. 2) (Director of National Parks, 2010). Unlike many other *Cyanoramphus* parakeets, Tasman parakeets do not exist in captive collections elsewhere in the world. During the 1940’s some Tasman parakeets were imported to Zoological collections like the Auckland Zoo (Museum specimen, see Chapter Two) but once theses individual died, no further specimens were sent abroad. Tasman parakeets are a micro-endemic species, with a single breeding population globally restricted to the Norfolk Island National Park (NINP, hereafter), a 465 ha area consisting of 30% ‘native forest’, 37% ‘weed infested native forest’ and 33% ‘exotic forest’ (Director of National Parks, 2010). The species occasionally ventures outside the boundaries of the NINP to feed on orchard trees (see Chapters Three and Five).

The Norfolk Island group comprises three main islands formed volcanically between 3.1 and 2.3 million years ago. They are located in the south pacific (29° 02’S, 167° 57’ E), with the nearest landmasses being over 800km away (New Caledonia and Lord Howe Island), whilst the nearest population and travel centres of Auckland (1,100km) and Sydney (1,700km) are further afield (Director of National Parks, 2010).

The main landmass of Norfolk Island is 3455ha of plateaus cut with deep valleys, bounded by sheer 100m cliffs. The two highest points on the island, which are also forested, are Mount Pitt (316m) and Mount Bates (318m) both in the northern part of the island.

Phillip Island, which is included in legislation as part of the National Park, is an entirely different environment. Phillip resides 6 km from the mainland, though at one stage the two were joined (Coyne, 2009), and has an area of 190ha with a peak of 280m at the precipitous Jacky Jacky ridge.

Phillip Island has been severely eroded due to vegetation loss in the presence of goats (*Capra hircus*), pigs (*Sus scrofa*) and rabbits (*Oryctolagus cuniculus*), which were introduced during the penal settlements to provide and alternate source of food in case of emergencies (Coyne, 2009). It is estimated that the soil has eroded 5m in some parts. Though this creates a stunning and unique landscape (sometimes referred to as the Uluru of the pacific), this has come at the price of endemic species, (insert list of which ones are extinct and which are threatened). Since the last rabbit was eradicated in 1986, the island has been slowly re-vegetating, accelerated in some areas by on-going restoration works. Phillip Island provides a unique conservation opportunity, as the island is predator free it has potential to be a refuge for translocated species from Norfolk Island, particularly the Tasman parakeet. While Norfolk and Phillip Islands were formed from volcanic activity, Nepean Island (10ha) was not but is rather a calcarenite formation, with little vegetation, making it a haven for seabirds. It is also reserved as conservation land.

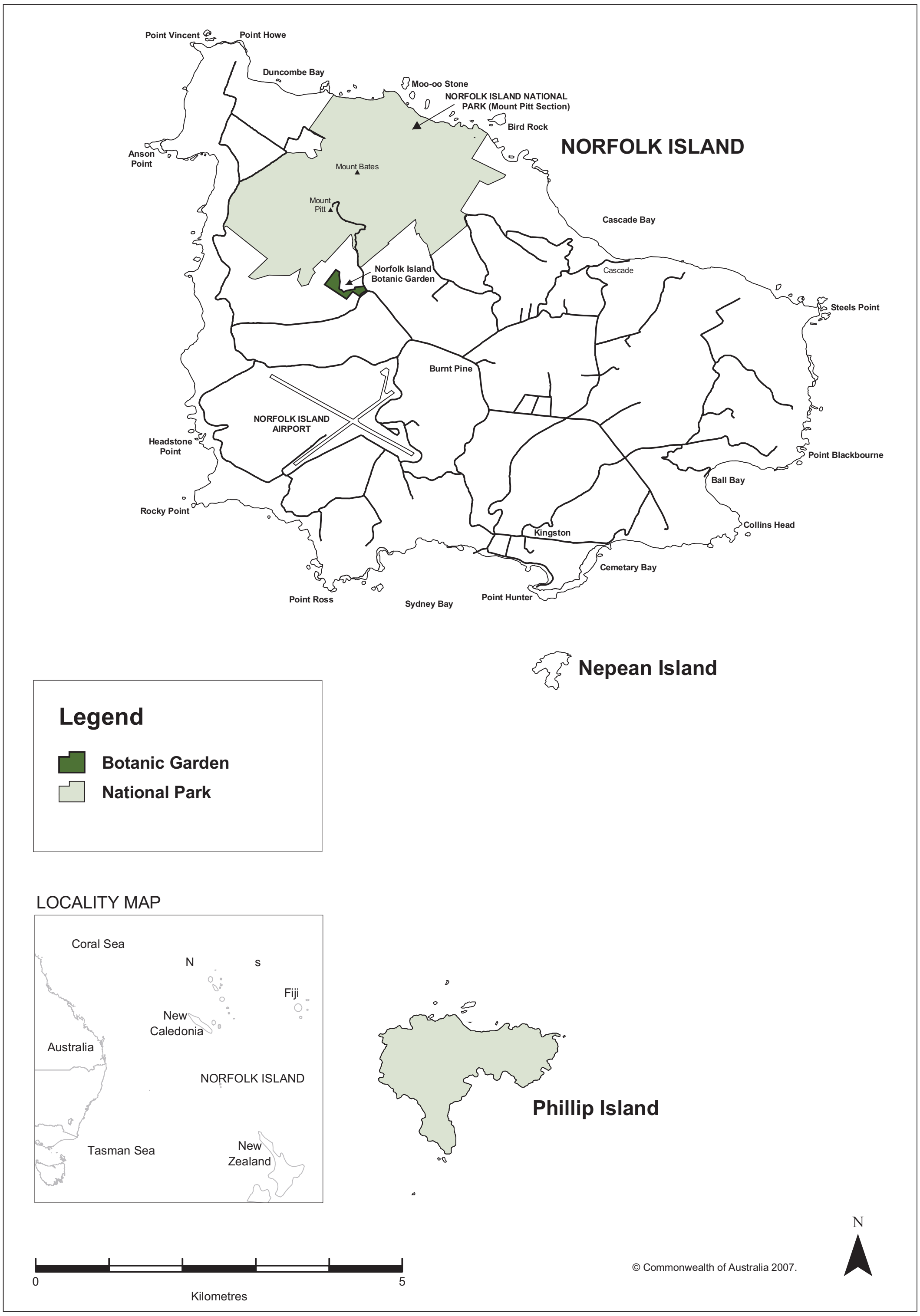

Figure 3. Map of Norfolk Island Group. Map modified from: (Director of National Parks, 2008)

Figure 4. A) A Tasman parakeet emerging from the nest; B) Luis Ortiz-Catedral removing the predator-proof inspection hatch to check nest contents. (Photos courtesy of Luis Ortiz-Catedral© and Mark Delaney©).

The climate of Norfolk Island is subtropical with dry summers and heavy rainfall in winter, typical patters for a subtropical oceanic island. Under the Köppen-Geirger classification it has a warm temperate, fully humid, with a hot summer (Cfa), comparable to the eastern coast of Australia (Kottek et al., 2006). Norfolk Island experiences an average annual rainfall of 1320mm, peaking in the winter months. Average temperatures range from minimums of 11 – 23.4 °C and maximums 15.8 – 26.5 °C (Director of National Parks, 2010). As the island is an erosional remnant with a friable clay layer mass soil movements are common (Abell & Falkland, 1991; Director of National Parks, 2010). There is little surface water on Norfolk island, though there is plenty of ground water, with residence times of up to 25 years (Stow & Dirks, 1998).

The vegetation of NINP is characterised by an emergent canopy stratum of Norfolk pine (*Araucaria heterophylla*) up to 30 m; a thick understory of niau

(*Rhopalostylis baueri*) and a variety of woody plants including ironwood (*Nestegis apetala*); bloodwood (*Baloghia inophylla*) and white oak (*Lagunaria patersonia*). Other notable species include maple (*Elaeodendron curtipendulum*), ake ake (*Dodonaea viscosa*) and *Meryta* spp. A number of woody introduced plants are also found throughout NINP, including cherry guava (*Psidium cattleianum*), African olive (*Olea europea cuspidata*) and tobacco (*Solanum mauritianum*) (see (Coyne, 2011) for a detailed account of plant species).

The prevailing view regarding human occupation of Norfolk Island is that Polynesians settled there temporarily around 500 years ago. However, by the time of the islands rediscovery by Captain James Cook in October 1774 there was no evidence of permanent dwellings, and no Polynesians living on the island (Anderson, 1996). Hence, their occupation has been inferred from the presence of bones of two animal species commonly associated with the diaspora of Polynesians across the South Pacific: the Pacific rat or kiore (*Rattus exulans*) and the domestic dog (*Canis familiaris*) (Anderson, 1996), as well as bananas (*Musa* spp.) and stone adzes (Director of National Parks, 2010).

Shortly after Cooks discovery, Norfolk Island was settled in 1788. Early accounts from settlers described very dense vegetation, and a great abundance of pines. In the first 75 years of settlement much of this forest was cleared for agriculture (Director of National Parks, 2010). The anthropological history of Norfolk Island is fascinating, as it was settled twice as a penal colony, once from England, and a second time receiving prisoners from New South Wales. Following these periods of settlement the land was finally settled by the Pitcairn Islanders, descendants of the Bounty mutineers, as their population size had outgrown Pitcairn, and Queen Victoria had offered them a place on the newly vacant land. Arriving in 1856, 194 people made the island their permanent home (Christian, 1982).

Today the island is home to approximately 2000 residents made up of native islanders, and Australian and New Zealand immigrants. The island also has a floating population of around 300 tourists at any time.

1.5 AIMS OF THE PRESENT STUDY

The research presented here represents two years of data collected in the field, primarily by me, with the help of volunteers and fellow scientists. I also had access to six months of data collected using the same methodology by my thesis supervisor Dr. Luis Ortiz-Catedral from June to December 2013. These data were part of the pilot phase of this project. This project was designed to document the diversity of food items consumed by Tasman parakeets in the wild, and to describe the temporal changes in dietary diversity between seasons. Additionally I present a pilot study on the seasonal variation in foraging areas, using data gathered in the field. The overall aim of this research was to integrate published information and field data on the diet of Tasman parakeets to present an overview of the temporal variability of the foraging ecology of the species and its relevance for conservation management. To achieve this aim, I obtained information from published studies and field observations.

1.6 THESIS OUTLINE

1.6.1 Chapter One

The present chapter provides a general introduction into the conservation of Psittaciformes and the relevance of diet studies to advance the conservation of island parrot species. It highlights the need for research using the critically endangered Tasman parakeet as a study species and includes a description of the study species and site. Finally, this chapter summarises the content and sequence of all chapters.

1.6.2 Chapter Two

In chapter two, I explore the dietary diversity of *Cyanoramphus* parakeets using published studies and information collected from Museum specimens. Specifically I was interested in determining if there is a relationship between bill morphology (a variable feature among *Cyanoramphus*) and the prevalence of seed consumption. In this chapter I discuss the state of knowledge about the dietary diversity of *Cyanoramphus* parakeets, and how the diet of the Tasman parakeet compares to this genus.

1.6.3 Chapter Three

The focus of chapter three is an analysis of the seasonal changes in the food types and food species of wild Tasman parakeets in the Norfolk Island National Park. I also investigated the inter-seasonal differences in foraging heights and foraging group size to produce the first detailed study on the feeding ecology of this critically endangered species.

1.6.5 Chapter Four

Chapter four focuses on a pilot investigation of seasonal variation in foraging locations of Tasman parakeets using incidental spatial information obtained during my field research, and a brief discussion how further investigation of these patterns can aid conservation of the Tasman parakeet. I also describe some interesting foraging behaviours observed in the field.

1.6.4 Chapter Five

In this chapter I discuss conservation management of the Tasman parakeet in relation to other *Cyanoramphus* species, and how my findings can help to reduce the extinction risk of this critically endangered species.

My research was conducted under full approval by: Norfolk Island National Park and Department of Environment Australia (Appendix 1).

1.7 REFERENCES

Abell, R. S., & Falkland, A. C. (1991). The hydrology of Norfolk Island South Pacific Ocean. *Bulletin - Bureau of Mineral Resources, Geology & Geophysics, Australia, 234*.

Anderson, A. (1996). Discovery of a prehistoric habitation site on Norfolk Island. *The Journal of the Polynesian Society, 105*(4), 479-486. doi: 10.2307/20706684

Beggs, J. R., & Wilson, P. R. (1991). The kaka *Nestor meridionalis*, a New Zealand parrot endangered by introduced wasps and mammals. *Biological Conservation, 56*(1), 23-38. doi: 10.1016/0006-3207(91)90086-O

Blackburn, T. M., Cassey, P., Duncan, R. P., Evans, K. L., & Gaston, K. J. (2004). Avian extinction and mammalian introductions on oceanic islands. *Science, 305*(5692), 1955-1958. doi: 10.1126/science.1101617

Boon, W. M. (2000). *Molecular Systematics and Conservation of the Cyanoramphus Parakeet Complex and the Evolution of Parrots.* (Doctor of Philosophy Unpublished doctoral dissertation), Victoria University, Wellington, New Zealand.

Boon, W. M., Daugherty, C. H., & Chambers, G. K. (2001). The Norfolk Island Green Parrot and New Caledonian Red-crowned Parakeet are distinct species. *Emu, 101*(2), 113-121.

Butchart, S. H. M., Stattersfield, A. J., & Collar, N. J. (2006). How many bird extinctions have we prevented? *ORYX, 40*(3), 266-278. doi: 10.1017/S0030605306000950

Chirstian, M. L. (2005). *Norfolk Island... The birds.*: Green Eyes Publications.

Christian, G. (1982). *Fragile Paradise: the discovery of Fletcher Christian Bounty mutineer*. London: Hamish Hamilton Ltd.

Christidis, L., & Boles, W. (2008). *Systematics and taxonomy of Australian birds*: Csiro Publishing.

Cleveland, S., Hess, G.P., Dobson, A.P., Laurenson, M.K., McCallum, H.I., Roberts, M.G., & Woodroffe, R. (2002). The role of pathogens in biological conservation. In P.

Hudson, A. Rizzoli, B. Grenfell & H. Heesterbeek (Eds.), *The ecology of wildlife diseases* (pp. 139-150). Oxford: Oxford University Press.

Clout, M. N. (2006). A Celebration of kakapo: progress in the conservation of an enigmatic parrot. *Notornis, 53*(1).

Clout, M. N., & Craig, J. L. (1995). The conservation of critically endangered flightless birds in New Zealand. *Ibis, 137*(Suppl. 1), 181-190.

Clout, M. N., Elliott, G. P., & Robertson, B. C. (2002). Effects of supplementary feeding on the offspring sex ratio of kakapo: A dilemma for the conservation of a polygynous parrot. *Biological Conservation, 107*(1), 13-18. doi: 10.1016/S0006-3207(01)00267-1

Clout, M. N., & Merton, D. V. (1998). Saving the kakapo: the conservation of the world's most peculiar parrot. *Bird Conservation International, 8*(3), 281-296.

Collar, N. J. (2000). Globally threatened parrots: criteria, characteristics and cures. *International Zoo Yearbook, 37*(1), 21-35. doi: 10.1111/j.1748-1090.2000.tb00704.x

Coyne, P. (2009). *Incredible! : the amazing story of the birth and rebirth of a natural treasure Phillip Island, South Pacific*. Belconnen, A.C.T.: Petaurus Press.

Coyne, P. (2011). *Norfolk Island's Fascinating Flora*. Belconnen, ACT: Petaurus Press.

Daszak, P., Cunningham, A. A., & Hyatt, A. D. (2000). Emerging infectious diseases of wildlife - threats to biodiversity and human health. *Science, 287*, 443-449.

Dawe, M. R. (1979). Behaviour and ecology of the red-crowned parakeet (*Cyanoramphus novaezelandiae*) in relation to management. *Unpublished M. Sc. thesis, University of Auckland, Auckland, New Zealand*.

Didham, R. K., Ewers, R. M., & Gemmell, N. J. (2005). Comment on "Avian extinction and mammalian introductions on oceanic islands". *Science, 307*(5714).

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

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

Dutson, G. (2013). Population densities and conservation status of Norfolk Island forest birds. *Bird Conservation International, 23*(3), 271-282.

Elliott, G. P., Dilks, P. J., & O'Donnell, C. F. J. (1996). The ecology of yellow-crowned parakeets (*Cyanoramphus auriceps*) in *Nothofagus* forest in Fiordland, New Zealand. *New Zealand Journal of Zoology, 23*(3), 249-265.

Forshaw, J. M., & Cooper, W. T. (1981). *Australian parrots* (2nd ed.). Melbourne: Lansdowne Editions.

Forshaw, J. M., & Cooper, W. T. (1989). Parrots of the World. *Willoughby, Landsdowe, Australia*.

Forshaw, J. M., & Knight, F. (2010). *Parrots of the World*: Princeton University Press.

Galetti, M. (1993). Diet of the scaly-headed parrot (*Pionus maximiliani*) in a semideciduous forest in southeastern Brazil. *BIOTROPICA, 25*(4), 419-425.

Gaze, P. D., & Cash, B. (2008). A history of wildlife translocations in the Marlborough Sounds (pp. 24). Nelson, New Zealand: Department of Conservation.

Greene, T. C. (1998). Foraging ecology of the red-crowned parakeet (*Cyanoramphus novaezelandiae novaezelandiae*) and yellow-crowned parakeet (*C. auriceps auriceps*) on Little Barrier Island, Hauraki Gulf, New Zealand. *New Zealand Journal of Ecology, 22*(2), 161-171.

Hicks, J., & Greenwood, D. (1989). Rescuing Norfolk Island’s parrot. *Birds international, 1*(4), 34-47.

Higgins, P.J. (Ed.). (1999). *Handbook of Australian, New Zealand and Antarctic Birds.* (Vol. Volume 4: Parrots to Dollarbird.). Melbourne: Oxford University Press.

Hill, R. (2002). Recovery plan for the Norfolk Island Green Parrot (*Cyanoramphus novaezelandiae cookii*): Natural Resource Management, Environment Australia.

Hutton, I., Parkes, J. P., & Sinclair, A. R. E. (2007). Reassembling island ecosystems: the case of Lord Howe Island. *Animal Conservation, 10*, 22-29.

Igag, P. (2002). *The conservation of large rainforest parrots: A study of the breeding biology of palm cockatoos, eclectus parrots and vulturine parrots.* The Australian National University.

Jackson, B., Lorenzo, A., Theuerkauf, J., Barnaud, A., Duval, T., Guichard, P., Bloc, H., Baouma, A., Stainton, D., Kraberger, S., Murphy, S., Clark, N., Dillon, C., Knight, T., & Varsani, A. (2014). Preliminary surveillance for beak and feather disease virus in wild parrots of New Caledonia: Implications of a reservoir species for Ouvea Parakeets. *Emu, 114*(3), 283-289. doi: 10.1071/MU14029

Kearvell, J. C., Grant, A. D., & Boon, W. M. (2003). The orange-fronted parakeet (*Cyanoramphus malherbi*) is a distinct species: A review of recent research into its taxonomy and systematic relationship within the genus *Cyanoramphus*. *Notornis, 50*(1), 27-35.

Kearvell, J. C., Young, J. R., & Grant, A. D. (2002). Comparative ecology of sympatric orange-fronted parakeets (*Cyanoramphus malherbi*) and yellow-crowned parakeets (*C. auriceps*), South Island, New Zealand. *New Zealand Journal of Ecology, 26*(2), 139-148.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift, 1*, 259-263.

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

Mack, A. L., & Wright, D. D. (1998). The vulturine parrot, *Psittrichas fulgidus*, a threatened New Guinea endemic: Notes on its biology and conservation. *Bird Conservation International, 8*(2), 185-194.

Marini, M. Â, & Garcia, F. I. (2005). Bird conservation in Brazil. *Conservation Biology, 19*(3), 665-671. doi: 10.1111/j.1523-1739.2005.00706.x

Miskelly, C. M., Dowding, J. E., Elliott, G. P., Hitchmough, R. A., Powlesland, R. G., Robertson, H. A., Sagar, P. M., Scofield, R. P., & Taylor, G. A. (2008). Conservation status of New Zealand birds, 2008. *Notornis, 55*(3), 117-135.

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

Moorhouse, R. J. (1997). The diet of the North Island kaka (*Nestor meridionalis septentrionalis*) on Kapiti Island. *New Zealand Journal of Ecology, 21*(2), 141-152.

Munshi-South, J., & Wilkinson, G. S. (2006). Diet influences life span in parrots (Psittaciformes). *Auk, 123*(1), 108-118.

Nóbrega Alves, R. R., De Farias Lima, J. R., & Araujo, H. F. P. (2013). The live bird trade in Brazil and its conservation implications: An overview. *Bird Conservation International, 23*(1), 53-65. doi: 10.1017/S095927091200010X

Nogales, M., Vidal, E., Medina, F. M., Bonnaud, E., Tershy, B. R., Campbell, K. J., & Zavaleta, E. S. (2013). Feral cats and biodiversity conservation: The urgent prioritization of island management. *BioScience, 63*(10), 804-810. doi: 10.1525/bio.2013.63.10.7

Ortiz-Catedral, L. (2006). *Breeding ecology of a translocated population of red-crowned kakariki (Cyanoramphus novaezelandiae) on Tiritiri Matangi Island, New Zealand.* MSc. thesis, Massey University.

Ortiz-Catedral, L. (2009). Some observations on the behaviour of the critically endangered orange-fronted parakeet (*Cyanoramphus malherbi*) on Maud Island, New Zealand. *Notornis, 56*(3), 165-166.

Ortiz-Catedral, L. (2010). *Aspects of the biology of managed populations of Cyanoramphus parakeets in New Zealand.* (PhD), Massey University, Auckland.

Ortiz-Catedral, L., & Brunton, D. H. (2008). Clutch parameters and reproductive success of a translocated population of red-crowned parakeet (*Cyanoramphus novaezelandiae*). *Australian Journal of Zoology, 56*(6), 389-393.

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

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

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

Ortiz-Catedral, L., Kearvell, J. C., & Brunton, D. H. (2012). Population increase of critically endangered Malherbe's parakeet (*Cyanoramphus malherbi*) introduced to Maud Island, New Zealand. *Conservation Evidence, 9*, 54-57.

Ortiz-Catedral, L., Kearvell, J. C., Hauber, M. E., & Brunton, D. H. (2009b). Breeding biology of the critically endangered Malherbes parakeet on Maud Island, New Zealand, following the release of captive-bred individuals. *Australian Journal of Zoology, 57*(6), 433-439.

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

Ortiz-Catedral, L., & Skirrow, M. (2015). *Observing elusive populations: Finding an efficient method for sampling Tasman parakeets (Cyanoramphus cookii)*. Massey University.

Pain, D. J., Martins, T. L. F., Boussekey, M., Diaz, S. H., Downs, C. T., Ekstrom, J. M. M., Garnett, S., Gilardi, J. D., McNiven, D., Primot, P., Rouys, S., Saoumoé, M., Symes, C. T., Tamungang, S. A., Theuerkauf, J., Villafuerte, D., Verfailles, L., Widmann, P., & Widmann, I. D. (2006). Impact of protection on nest take and nesting success of parrots in Africa, Asia and Australasia. *Animal Conservation, 9*(3), 322-330. doi: 10.1111/j.1469-1795.2006.00040.x

Powlesland, R. G., & Lloyd, B. D. (1994). Use of supplementary feeding to induce breeding in free-living kakapo *Strigops habroptilus* in New Zealand. *Biological Conservation, 69*(1), 97-106.

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

Pryor, G. S., Levey, D. J., & Dierenfeld, E. S. (2001). Protein requirements of a specialized frugivore, Pesquet's Parrot (*Psittrichas fulgidus*). *Auk, 118*(4), 1080-1088.

Renton, K., & Salinas-Melgoza, A. (1999). Nesting behavior of the Lilac-Crowned parrot. *The Wilson Bulletin, 111*(4), 488-493. doi: 10.2307/4164133

Saunders, D., Brereton, R., Tzaros, C., Holdsworth, M., & Price, R. (2007). Conservation of the Swift Parrot *Lathamus discolor* - Management lessons for a threatened migratory species. *Pacific Conservation Biology, 13*(2), 111-119.

Saunders, D. L., & Heinsohn, R. (2008). Winter habitat use by the endangered, migratory Swift Parrot (*Lathamus discolor*) in New South Wales. *Emu, 108*(1), 81-89. doi: 10.1071/MU07033

Stow, C. D., & Dirks, K. N. (1998). High-resolution studies of rainfall on Norfolk Island Part 1: The spatial variability of rainfall. *Journal of Hydrology, 208*(3-4), 163-186. doi: 10.1016/S0022-1694(98)00154-1

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

Taylor, R. H. (1985). Status, habits and conservation of *Cyanoramphus* parakeets in the New Zealand region *In 'Conservation of Island Birds'* (pp. 195-211): (Ed. P.J. Moors).

Turbott, E. G. (1990). *Checklist of the birds of New Zealand and the Ross Dependency, Antarctica*: Random Century in association with Ornithological Society of New Zealand Inc.

Wirminghaus, J. O., Downs, C. T., Symes, C. T., & Perrin, M. R. (2002). Diet of the Cape Parrot, *Poicephalus robustus*, in Afromontane forests in KwaZulu-Natal, South Africa. *Ostrich, 73*(1-2), 20-25.

Wright, T. F., Toft, C. A., Enkerlin-Hoeflich, E., Gonzalez-Elizondo, J., Albornoz, M., Rodríguez-Ferraro, A., Rojas-Suárez, F., Sanz, V., Trujillo, A., Beissinger, S. R., Vicente Berovides, A., Xiomara Gálvez, A., Brice, A. T., Joyner, K., Eberhard, J., Gilardi, J., Koenig, S. E., Stoleson, S., Martuscelli, P., Meyers, J. M., Renton, K., Rodríguez, A. M., Sosa-Asanza, A. C., Vilella, F. J., & Wiley, J. W. (2001). Nest poaching in Neotropical parrots. *Conservation Biology, 15*(3), 710-720. doi: 10.1046/j.1523-1739.2001.015003710.x

CHAPTER TWO: DIETARY NICHE AND BILL MORPHOLOGY IN *CYANORAMPHUS*

2.1 INTRODUCTION

The bill is an important feature of all birds and, along with feathers, can be considered one of the most diagnostic features of this group of vertebrates. The primary purpose of the bill is food selection and feeding (Soobramoney & Perrin, 2007). Bills perform a range of other functions and constitute an additional appendage used for constructing nests (Hansell, 2000), helping birds move through the canopy (i.e. parrots) (Juniper & Parr, 1998), preening and plumage maintenance (Barbosa, 1996), and heat exchange (for example thermoregulation in toucans (Tattersall et al., 2009)). The bill exhibits a remarkable morphological radiation across the class Aves, from the primitive Paleognathae bill of Ratites and Tinamous (Dyke & Leonard, 2001) to the more derived Neognathae bill plan that includes simple seed-crushing bills as in finches (Herrel et al., 2005) to highly specialised structures; for example, the sword-billed hummingbird (*Ensifera ensifera*), which due to the exaggerated length of the pollen tubes of its food species possesses a bill longer than its body (Lindberg & Olesen, 2001)).

2.1.1 Bill Morphology And Diet

Bill morphology has a strong impact on diet. Different selective pressures have resulted in diverse bill morphology even among closely related species (Herrel et al., 2010). The resulting differences in size and shape allow for differentiation of the dietary niche, where individuals or species with overlapping distributions exploit different resources to reduce competition (Hardin, 1960). The huia (*Heteralocha acutirostris*) is a classic example of sexual dimorphism in bill morphology (Burton, 1974) allowing dietary niche differentiation within the same species, specifically the size and shape of the bill allowed male and female huia to probe for invertebrates at different depths in decaying wood (Jamieson & Spencer, 1996; Moorhouse, 1996). The structure of the bill strongly correlates to the resources a given species uses. For instance Darwin's finches (Geospizinae) show speciation from selection on differences in bill size and shape which are suited for different feeding modes (Herrel et al., 2010) including seed crushing species (*Geospiza* spp.), insect feeding species (*Certhidia* spp.), fruit feeding species (*Camarhynchus* spp.) and even foliage and leaf eaters (*Platyspiza crassirostris*) (De León et al., 2014).

Sympatric crossbills (*Loxia* spp.) show dietary niche differentiation: with smaller-billed species (*L. curvirostra*) responding to phenological changes in availability of conifer seeds (feeding on spruce (*Picea abies*) and larch (*Larix* spp) through summer and winter, then taking advantage of opening cones of Scots pine (*Pinus sylvestris*) in spring and early summer), and larger-billed species (*L. pytyopsittacus*) feeding on Scots pine year round (Marquiss & Rae, 2002). Additionally white-winged crossbills (*Loxia leucoptera*) and red crossbills (*Loxia curvirostra*) show differences bill structure which relate to differences in seed foraging efficiencies (Benkman, 1987).

Some parrot species are dietary specialists due to their bill structure. For example, Pesquet's parrot (*Psittrichas fulgidus*) feeds largely on figs (*Ficus* spp.) using its long slender bill (Juniper & Parr, 1998), and occasionally other soft fruits (Mack & Wright, 1998). Flowerpiercers (*Diglossa* spp. and *Diglossopis* spp.) possess a specialised hook on the maxilla that enables them to exploit the same resource: nectar. Size of the hook is variable and among sympatric species there is dramatic difference in relative hook sizes which facilitates coexistence (Mauck & Burns, 2009).

Food selection and feeding methods are well studied in granivorous birds (Koves Hrabar & Perrin, 2002), most notably finches (E.g. Fringillidae and Emberezidae (Diaz, 1990), Fringillidae and Estrildidae (Van der Meij & Bout, 2006)) partly because they are easy to study in captivity as well as in the field. Because of their taxonomic diversity and overlapping geographic distributions they offer an opportunity to study various aspects of their feeding ecology such as resource partitioning between closely related species (Pulliam & Enders, 1971); bio-mechanics (for example there is a significant positive correlation between bill dimensions (especially width) and bite force (Koves Hrabar & Perrin, 2002) and ecological speciation (Herrel et al., 2009) and vocal evolution (Podos & Nowicki, 2004). Within species, besides the well studied Darwin's finches, polymorphism in bill morphology facilitates resource partitioning for the Black-bellied seedcracker (*Pyrenestes ostrinus*), particularly during the dry season when food resources are low (Smith, 1987, 1990).

Among passerines, niche differentiation is well studied, and there is evidence indicating that this is due to changes in body size and bill size, which have measurable impacts on foraging behaviour (Benkman, 1991). Further, sympatric species posses greater differences in bills the allopatric species (Schoener, 1965). For example, in Vanuatu, finches (*Erythrura* spp.) occupy different feeding niches between fig specialists (*E. cyaneovirens regia*) to seed generalists in open habitat (*E. trichroa cyanofrons*) and there are marked morphological differences between taxa that experience these dietary changes (Diamond & Marshall, 1977). In the Vinous-throated parrotbill (*Paradoxornis webbianus*) birds with larger more slender bills feed at a higher trophic level than those with smaller less slender bills, and therefore populations with greater bill-size variation also show greater variation in trophic niche, (Hsu et al., 2014).

Studying differences in bill morphology of closely related species with diverse dietary niches can be useful to determine the relationship between bill morphology and resources used. Passeriformes (perching birds) have been the focus of much study on this relationship as outlined above, however one group that remains unstudied is the order Psittaciformes (parrots and cockatoos). The morphological diversity of parrot and cockatoo bills has received little attention, possibly because of the perceived general morphological uniformity of the group (see Chapter One).

However, as more field studies are conducted it becomes clear that parrot and cockatoos use a wider range of resources (Boyes & Perrin, 2009; Galetti, 2013) and form part of more intricate food webs than previously acknowledged (for example the New Zealand Kaka (*Nestor meridionalis*) feeding on honey dew from beach scale insects (Beggs & Wardle, 2006)). As outlined in Chapter One, as a group parrots are morphologically uniform. Despite this, their high diversity warrants an investigation into the associations between bill size and shape and feeding niche. One group of parrots, with various sympatric species, that can serve as a model to explore these topics is the genus *Cyanoramphus* that includes the New Zealand species commonly referred to as “kakariki”.

2.1.2 The Genus *Cyanoramphus*

The genus *Cyanoramphus* has its centre of diversity in New Zealand, with a few species on other islands of the South Pacific (see Fig. 2, Chapter One). This genus belongs to the tribe Platycercini, a group that contains other diverse genera like *Platycercus* and *Psephotus* (Higgins, 1999). *Cyanoramphus* parakeets are very similar in size and colour and for many years the actual number of species has remained obscured. The development of molecular techniques has helped solve the identity of some taxa. For instance, until the year 2000 the orange-fronted parakeet (or Malherbe’s parakeet) (*Cyanoramphus malherbi*) was considered a morph of the more widespread yellow-fronted parakeet (*Cyanoramphus auriceps*) (Boon et al., 2000). Besides obscuring the actual diversity of any animal group, incomplete taxonomies might also obscure significant differences in resource use, niche differentiation and feeding ecology. This has profound consequences for conservation management of *Cyanoramphus* parakeets since a commonly used tool for protecting species involves their translocation to predator-free sites ((Miskelly & Powlesland, 2013), see also Chapter One). These predator-free sites often have a very different habitat structure and composition than the original species’ range (for example, orange-fronted parakeets, see Chapter One). Thus, understanding the variability among and within species in *Cyanoramphus* and its relationship to the feeding ecology of this group of birds has relevance in a conservation context (see Chapters Three and Four).

The bill morphology of *Cyanoramphus* has received a lot of attention in studies describing sexual dimorphism (with males having longer bills (Elliott et al., 1996; Higgins, 1999)) and morphological traits of the various species (for example despite sexual dimorphism yellow-fronted (*C. auriceps*) and orange-fronted parakeets (*C. malherbi*) can be reliably differentiated by bill length (Young & Kearvell, 2001)). The degree of sexual dimorphism in *Cyanoramphus* parakeets means they can be sexed by sight in the field, as observed in Chatham Island red-fronted parakeets (*Cyanoramphus novaezelandiae chathamensis*) (Nixon, 1982).

Cyanoramphus parakeets exhibit a broad generalist diet that consists of seeds, leaves, flowers, nectar, etc. Of all food types they consume however there is a marked reliance on seeds across species. For example, seeds constituted over 70% of the autumn diet of the red-fronted parakeet on Little Barrier Island/Hauturu during a survey in 1987 (Greene, 1998). This reflects generally the diet of other species in the tribe Platycercini (Cannon, 1981; Higgins, 1999).

Previous studies have established that sympatric *Cyanoramphus* species occupy different feeding niches. On Little Barrier Island/Hauturu in the Auckland region red-fronted parakeets (*C. novaezelandiae*) and yellow-fronted parakeets (*C. auriceps*) feed on various plant species and invertebrates, but yellow-fronted parakeets consumed significantly more invertebrates (Greene, 1998). Unique amongst parrots, the Antipodes Island parakeet (*Cyanoramphus unicolor*; which has the largest bill of the genus), has been reported to depredate grey-backed storm petrels (*Oceanites nereis*) (Greene, 1999).

This dietary and bill morphological diversity make the *Cyanoramphus* genus an ideal model to explore the relationships between bill morphology, dietary diversity and prevalence of seed consumption, especially as *Cyanoramphus* parakeets are distributed across the pacific with both sympatric and allopatric species available for comparison.

In this Chapter, I explore the differences in dietary diversity among *Cyanoramphus* species using published information on diet and my own measurements on bill morphology. My study represents the first attempt at synthesising existing dietary knowledge for this diverse genus, integrating all available published studies. I propose that *Cyanoramphus* parakeets offer a model to understand dietary overlap and bill morphology for a diverse South Pacific group of Psittaciformes.

2.2 OBJECTIVES

The general objective of this chapter is to explore the diversity of bill morphology across the *Cyanoramphus* genus. I also attempt to identify trends between dietary diversity, bill morphology and the prevalence of consumption of the predominant food type (seeds) using information available in the literature. The specific objectives developed in this chapter are:

1. Quantify and describe the bill morphology across *Cyanoramphus* species.
2. Determine the diversity of food species consumed by *Cyanoramphus* species as a proxy for dietary niche using published and unpublished datasets.
3. Explore the relationship between bill morphology and the prevalence of consumption of the predominant food type (seeds) among *Cyanoramphus* species.

2.3 METHODS

2.3.1 Definition Of Terms

Dietary Diversity: The number of different plant species consumed by a given *Cyanoramphus* parakeet. This is measured as plant species richness in a given parakeet diet, but note it does not take into account the relative importance or frequency of consumption of a given plant species in the overall dataset. This is because many studies simply report "presence" of a given plant species in a Cyanoramphus species diet, without providing data on frequency of consumption, often during short periods of observation. I considered this measure a useful for comparison because even the most basic studies on parakeet diet include a list of species consumed. I focused on plant species because often where animal material was observed as part of the diet the species was not determined. I considered this a reasonable approach given that overall, the consumption of animal matter (invertebrates, carcass, etc.) was less common, and has not been thoroughly documented among *Cyanoramphus* parakeets..

Dietary Overlap: The percentage or degree of overlap in dietary diversity (or the number of species consumed) by pairs of *Cyanoramphus* species relative to their dietary diversity. I used the Jaccard similarity coefficient (Jaccard, 1912) as it is a measure that can easily be obtained from datasets using simple species richness (see above).

For the diet of two given species, A and B:

$$J = \frac{M_{11}}{M_{01} + M_{10} + M_{11}}$$

M_{11} represents the total number of attributes where A and B both have a value of 1.

M_{01} represents the total number of attributes where the attribute of A is 0 and the attribute of B is 1.

M_{10} represents the total number of attributes where the attribute of A is 1 and the attribute of B is 0.

This measure has been used in other analyses of dietary similarity in other parrot groups (Sosa-Asanza, 2000).

2.3.2 Dietary Diversity And Analyses

To determine the dietary diversity of the genus *Cyanoramphus* I used published accounts to compile a database of all plant species consumed by six species: Antipodes Island parakeet (*Cyanoramphus unicolor*), Forbes' parakeet (*Cyanoramphus forbesi*), orange-fronted parakeet (*Cyanoramphus malherbi*), red-fronted parakeet (*Cyanoramphus novazelandiae*), Tasman parakeet (*Cyanoramphus cookii*), and the yellow-fronted parakeet (*Cyanoramphus auriceps*).

Data for the Tasman parakeet includes observations made during this study (see Chapter Three). Observations on the Chatham Island red-fronted parakeet (*C. novaezelandiae chathamensis*) from Nixon (1982, 1994) were combined with the red-fronted parakeet, as well as data for the Kermadec red-fronted parakeet (*C. novazelandiae cyanurus*) from Higgins (1999). Reischek's parakeet (*C. hochstetteri*) and the New Caledonian parakeet (*C. saisetti*) were excluded from the final analysis due to a lack of published information on these species. I also excluded extinct species (For extinct species see Fig. 2, Chapter One).

I recorded all published plant species consumed by the different species of parakeet and I also classified if seed from that species is consumed. I excluded records where the species of plant consumed was not specified or was given only to the genus level. I then compared the dietary richness with the prevalence of seed consumption, determining the proportion of richness accounted for by seeds in each species diet. I used a proportional measure to limit bias introduced by differences in level of knowledge of richness and consumption of seeds created by differing levels of study effort between species. To compare these proportions, I used Fisher exact test on R© version 2.15.3, StatView © and SAS© Version 9.4.

To determine the degree of overlap in species consumed by different parakeet species I used Jaccard's similarity coefficient (described above), which provides a useful measure of similarity for qualitative datasets of ecological communities (Jaccard, 1912). For my analysis, I used this coefficient as an extension of its classical use to compare between pairs of "communities" (i.e. number of plant species consumed per parakeet species).

To investigate if there is a relationship between bill morphology and the prevalence of seeds in the diet, I conducted simple linear regressions using the software packages mentioned above.

2.3.3 Bill Morphology

To characterise the bill morphology in the genus *Cyanoramphus* I measured seven characteristics, using specimens held at the Auckland War Memorial Museum (aucklandmuseum.com). I used digital callipers to obtain all measurements. The bill characteristics I considered include: upper mandible; length, width, depth and for the lower; basal width, distal width, length, and depth (Fig. 1).

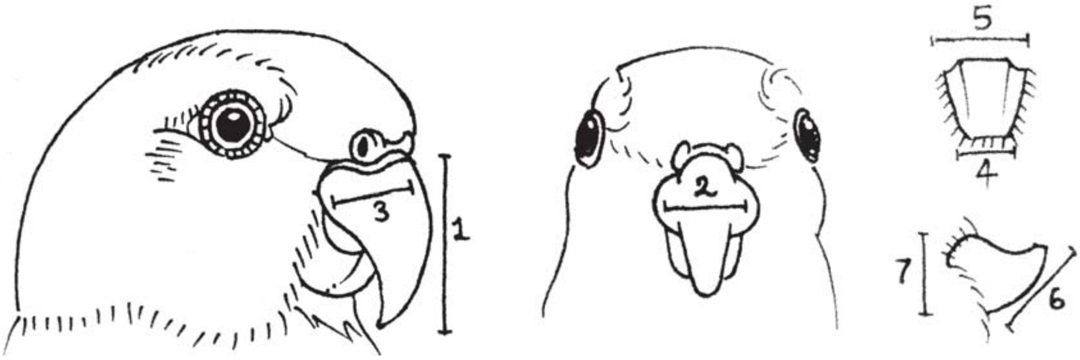

Figure 1. Diagrams showing bill morphology measurements. 1) Upper mandible length; 2) Upper mandible width; 3) Upper mandible depth; and 4) Lower mandible basal width; 5) Lower mandible distal width; 6) Lower mandible length; 7) Lower mandible depth. (Drawing courtesy of Giselle Keenleyside©)

These specimens are kept in a humidity and temperature controlled environment. They vary in age with some as old as 1889, ranging through to recently collected specimens. I measured a total of 122 specimens from the Platycercini tribe, of which 78 were *Cyanoramphus* species (64%). I then reduced the final dataset to the six species for which information on dietary diversity was available. The final dataset includes 65 of these museum specimens. I did not distinguish between sex of birds because often this data was not recorded on museum specimens and I was unable to conduct molecular analyses to determine the sex of birds where it was not specified, and because I wanted to determine dietary trends for species as a whole.

Table 1. Sample size of bill measurements from Auckland War Memorial Museum.

Common Name	*Species*	n
Antipodes Island Parakeet	*Cyanoramphus unicolor*	5
Forbes' Parakeet	*Cyanoramphus forbesi*	1
Orange-fronted or Malherbe's Parakeet	*Cyanoramphus malherbi*	1
Red-fronted Parakeet	*Cyanoramphus novaezelandiae*	38
Tasman Parakeet	*Cyanoramphus cookii*	3
Yellow-fronted Parakeet	*Cyanoramphus auriceps*	17

Due to logistical difficulties I did not have access to more specimens from other museum collections. Also, it was not possible to obtain measurements from specimens held at other museums or collections by a third party; hence the present analysis is restricted to a limited sample size. Further, this restricted sample size precluded the use of transformations such as principle components analysis (PCA).

To determine differences in bill size I used Tukey's honest significant difference (HSD, hereafter) test, using R© version 2.15.3, to perform multiple comparisons to test for significant differences in means of the seven bill characteristics between pairs of *Cyanoramphus* species. I used this test because it accounts for the increase chance of type I error caused by multiple comparisons, and the method is conservative when there are unequal sample sizes. For these comparisons I used measurements for the yellow-fronted parakeet, red-fronted parakeet, Tasman parakeet and Antipodes Island parakeet, as they had a large enough sample size (Table 1).

As a PCA was not viable, I decided to combine the measurements for the upper mandible into a composite measure “bill surface area” (BSA) to compare the bill morphology with the prevalence of seed in a *Cyanoramphus* parakeets diet across species, instead of using multiple linear measurements. To this end I used the following formula, which has been used in previous studies on Australian parrots (Campbell-Tennant et al., 2015; Greenberg et al., 2012):

$$BSA = (depth+width)/4*length$$

I used the average length, depth and width from the upper mandible (see Fig. 1) of each species to obtain a BSA measurement that would describe the average size of the bill for each species, to reduce the impact of variation introduced by the sex of specimens.

I used all upper bill morphological data in the calculation of bill surface area. For the Forbes’ parakeet additional data used to calculate a robust bill surface area (BSA) was obtained from individuals captured and measured as part of the 2014 annual monitoring activities in the Chatham Islands by staff of the New Zealand Department of Conservation, bringing the sample size for the BSA of the Forbes’ parakeet to 65.

2.4 RESULTS

2.4.1 Dietary Diversity

The six species considered in this analysis (Table 1) consume food items from a total of 214 plant species, within 141 genera and 72 families (Table 4). Dietary diversity ranged from 10 species for Forbes parakeet (*C. forbesi*) (Nixon, 1982); to 145 for red-fronted parakeets (*Cyanoramphus novaezelandiae*) (Dawe, 1979; Greene, 1998; Higgins, 1999) (see Fig. 2).

Of the 214 plant species recorded 38 are consumed by more than one *Cyanoramphus* species. Dietary overlap ranged from 0% to 34.15% between pairs of species (Table 2). The orange-fronted and yellow-fronted parakeets showed the greatest degree of overlap (34.15%), while several pairings showed no overlap (Table 2). For sympatric species dietary overlap ranged from 3.05% to 34.15%. While for species without overlapping distributions the range was 0%-8%. The highest degree of overlap between allopatric species was between the Antipodes Island parakeet and Forbes' parakeet (8%, Table 2).

Table 2. Jaccards similarity coefficient for the diets of *Cyanoramphus* parakeet pairs. (species pairs with overlapping distributions are highlighted).

Species	*C. auriceps*	*C. forbesi*	*C. malherbi*	*C. novaezelandiae*	*C. unicolor*	*C. cookii*
C. auriceps	-	0%	34.15%	6.02%	0%	0%
C. forbesi	-	-	0%	6.16%	8.00%	0%
C. malherbi	-	-	-	3.05%	0%	1.96%
C. novaezelandiae	-	-	-	-	1.25%	0.58%
C. unicolor	-	-	-	-	-	0%
C. cookii	-	-	-	-	-	-

Of the 214 plant species that are consumed by the different *Cyanoramphus* species, 89 have seeds consumed by at least one (Table 5). The prevalence of seed consumption in a given parakeets diet ranged from 17% (orange-fronted parakeet) to 70% (Forbes parakeet). Intermediately prevalence of seed consumption increased from 26% (yellow-fronted parakeet), 39% (red-fronted parakeet), 47% (Antipodes Island parakeet), and 54% (Tasman parakeet) (Fig. 2).

The prevalence of seed consumption for the six *Cyanoramphus* species differed significantly from what would be expected by chance (Chi-sq test (X-squared = 16.4, p-value = 5.8 e^{-03}); Fishers exact test (p= 0.004)).

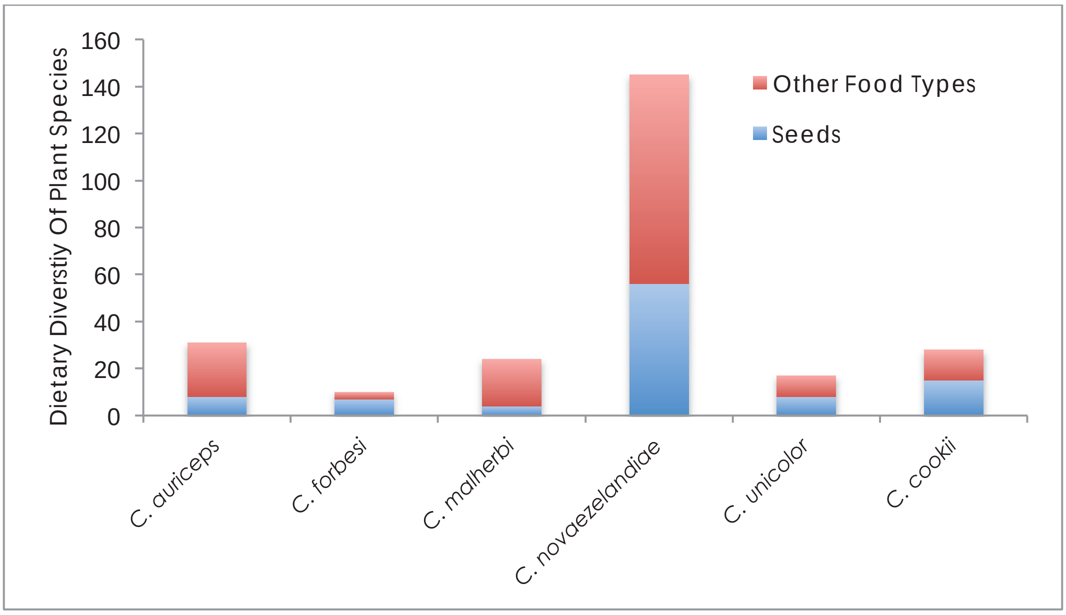

Figure 2. Dietary diversity of different *Cyanoramphus* species (as per published studies), including prevalence of seed consumption (measured by percentage of food species from which seed is consumed).

2.4.2 Bill Morphology

The bill of the yellow-fronted parakeet is significantly smaller than that of the Antipodes Island parakeet in all characteristics (Tukey HSD test: all p-values ≤ 0.01), and the bill of the Tasman parakeet (Tukey HSD test: p-values ≤ 0.005, except upper depth p = 0.37) The bill of the yellow-fronted parakeet was smaller than the red-fronted parakeet in four characteristics; upper width (*C. auriceps* = 8.39 ± 0.17 mm, *C. novazelandiae* = 9.85 ± 0.15 mm, Tukey HSD test: p = < 0.0001), lower basal width (*C. auriceps* = 8.15 ± 0.3 mm, *C. novazelandiae* = 9.76 ± 0.33 mm, Tukey HSD test: p = 0. 018), lower distal width (*C. auriceps* = 8.86 ± 0.21 mm, *C. novazelandiae* = 9.98 ± 0.2 mm, Tukey HSD test: p = < 0.005), and lower length (*C. auriceps* = 8.84 ± 0.41 mm, *C. novazelandiae* = 10.71 ± 0.28 mm, Tukey HSD test: p = < 0.001) (see Tables 3 and 4).

The red fronted parakeet has a smaller bill than the Antipodes Island parakeet in five characteristics; upper length (*C. novazelandiae* = 15.29 ± 0.32 mm, *C. unicolor* = 20.33 ± 0.26 mm, Tukey HSD test: p = <0.0001), upper width (*C. novazelandiae* = 9.85 ± 0.15 mm, *C. unicolor* = 13.27 ± 0.09 mm, Tukey HSD test: p = <0.0001), upper depth

(*C. novazelandiae* = 12.98 ± 0.51 mm, *C. unicolor* = 19.92 ± 0.36 mm, Tukey HSD test: p = <0.0001), lower distal width (*C. novazelandiae* = 9.98 ± 0.2 mm, *C. unicolor* = 12.21 ± 0.25 mm, Tukey HSD test: p = < 0.0001), lower depth (*C. novazelandiae* = 9.46 ± 0.21 mm, *C. unicolor* = 11.75 ± 0.57 mm, Tukey HSD test: p = < 0.003). The Tasman parakeet is larger than the red-fronted parakeet in four characteristics; upper length (*C. cookii* = 19.33 ± 1.09 mm, *C. novazelandiae* = 15.29 ± 0.32 mm, Tukey HSD test: p = < 0.003), upper width (*C. cookii* = 12.33 ± 1.09 mm, *C. novazelandiae* = 9.85 ± 0.15 mm, Tukey HSD test: p = <0.0001), lower distal width (*C. cookii* = 11.92 ± 0.22 mm, *C. novazelandiae* = 9.98 ± 0.2 mm, Tukey HSD test: p = 0.023), and lower length (*C. cookii* = 14.75 ± 0.88 mm, *C. novazelandiae* = 10.71 ± 0.28 mm, Tukey HSD test: p = <0.001).. The Tasman parakeet and Antipodes Island parakeet differ in lower length; which is shorter in the Antipodes Island parakeet (*C. cookii* = 14.75 ± 0.88 mm, *C. unicolor* = 11.57 ± 0.24 mm, Tukey HSD test: p = 0.05), and upper depth; which is shallower in the Tasman parakeet (*C. cookii* = 11.08 ± 0.96 mm, *C. unicolor* = 19.92 ± 0.36 mm, Tukey HSD test: p = <0.001). (See Tables 3 and 4 for ranges and non-significant comparisons)

Table 3. Means ± standard error and ranges of bill characteristics (mm). Numbers for measurement in parentheses correspond to Fig. 1 see Table 1 for common names. Sample size in parentheses.

Measurement	Species	*C. auriceps* (17)	*C. cookii* (3)	*C. novaezelandiae* (38)	*C. unicolor* (5)
Upper Length	Mean	14.16 ± 0.4	19.33 ± 1.09	15.29 ± 0.32	20.33 ± 0.26
(1)	Range	10.93-17.15	18-21.5	11.85-18.38	19.88-21.28
Upper Width	Mean	8.39 ± 0.17	12.33 ± 1.09	9.85 ± 0.15	13.27 ± 0.09
(2)	Range	7.09-9.42	11-14.5	8.06-11.75	13.11-13.6
Upper Depth	Mean	13.76 ± 0.36	11.08 ± 0.96	12.98 ± 0.51	19.92 ± 0.36
(3)	Range	11.2-16.9	10-13	7-17.6	19-20.68
Lower Basal Width	Mean	8.15 ± 0.3	12.17 ± 1.69	9.76 ± 0.33	11.34 ± 0.29
(4)	Range	6.72-11	10-15.5	7.41-18.75	10.6-12.03
Lower Distal Width	Mean	8.86 ± 0.21	11.92 ± 0.22	9.98 ± 0.2	12.21 ± 0.25
(5)	Range	7.13-10.76	11.5-12.25	7.9-13	11.48-13
Lower Length	Mean	8.84 ± 0.41	14.75 ± 0.88	10.71 ± 0.28	11.57 ± 0.24
(6)	Range	6.68-12.77	13.75-16.5	7.92-16	11.08-12.2
Lower Depth	Mean	8.90 ± 0.29	11.17 ± 1.42	9.46 ± 0.21	11.75 ± 0.57
(7)	Range	7.05-11.25	9.5-14	6.9-11.64	10.83-13.96

Table 4. Tukey HSD 95% confidence intervals for mean difference in bill size characteristics between pairs of species (mm). Numbers for measurement in parentheses correspond to Fig. 1, see Table 1 for common names. Sample size: *C. auriceps* = 17, *C. cookii* = 3, *C. novaezelandiae* = 38, *C. unicolor* = 5. (For visual comparisons see Figs 1-7, Appendix 3)

Upper Length (1)	Lower 95%	Mean Difference	Upper 95%	P-value
C. cookii-C. auriceps	2.16	5.17	8.18	<0.001
C. novaezelandiae-C. auriceps	-0.28	1.13	2.53	0.16
C. unicolor-C. auriceps	3.72	6.16	8.61	<0.0001
C. novaezelandiae-C. cookii	-6.93	-4.04	-1.16	<0.003
C. unicolor-C. cookii	-2.52	0.99	4.51	0.88
C. unicolor-C. novaezelandiae	2.75	5.04	7.33	<0.0001

Upper Width (2)	Lower 95%	Mean Difference	Upper 95%	P-value
C. cookii-C. auriceps	2.46	3.95	5.43	<0.0001
C. novaezelandiae-C. auriceps	0.77	1.46	2.15	<0.0001
C. unicolor-C. auriceps	3.68	4.89	6.09	<0.0001
C. novaezelandiae-C. cookii	-3.90	-2.48	-1.06	<0.0001
C. unicolor-C. cookii	-0.79	0.94	2.67	0.48
C. unicolor-C. novaezelandiae	2.30	3.42	4.55	<0.0001

Upper Depth (3)	Lower 95%	Mean Difference	Upper 95%	P-value
C. cookii-C. auriceps	-7.03	-2.68	1.68	0.37
C. novaezelandiae-C. auriceps	-2.81	-0.78	1.24	0.74
C. unicolor-C. auriceps	2.62	6.16	9.70	<0.001
C. novaezelandiae-C. cookii	-2.28	1.89	6.06	0.63
C. unicolor-C. cookii	3.76	8.84	13.91	<0.001
C. unicolor-C. novaezelandiae	3.64	6.94	10.25	<0.0001

Lower Basal Width (4)	Lower 95%	Mean Difference	Upper 95%	P-value
C. cookii-C. auriceps	1.01	4.02	7.03	0.005
C. novaezelandiae-C. auriceps	0.21	1.61	3.02	0.018
C. unicolor-C. auriceps	0.75	3.20	5.64	0.005
C. novaezelandiae-C. cookii	-5.29	-2.41	0.48	0.13
C. unicolor-C. cookii	-4.34	-0.82	2.69	0.92
C. unicolor-C. novaezelandiae	-0.71	1.58	3.87	0.27

Lower Distal Width (5)	Lower 95%	Mean Difference	Upper 95%	P-value
C. cookii-C. auriceps	1.24	3.05	4.87	<0.001
C. novaezelandiae-C. auriceps	0.27	1.12	1.96	<0.005
C. unicolor-C. auriceps	1.88	3.35	4.82	<0.0001
C. novaezelandiae-C. cookii	-3.67	-1.94	-0.20	0.023
C. unicolor-C. cookii	-1.82	0.30	2.41	0.98
C. unicolor-C. novaezelandiae	0.85	2.23	3.61	<0.001

Lower Length (6)	Lower 95%	Mean Difference	Upper 95%	P-value
C. cookii-C. auriceps	3.18	5.91	8.64	<0.0001
C. novaezelandiae-C. auriceps	0.60	1.87	3.14	<0.001
C. unicolor-C. auriceps	0.51	2.73	4.94	0.01
C. novaezelandiae-C. cookii	-6.65	-4.04	-1.42	<0.001
C. unicolor-C. cookii	-6.37	-3.18	0.00	0.05
C. unicolor-C. novaezelandiae	-1.22	0.85	2.93	0.69
Lower Depth (7)	Lower 95%	Mean Difference	Upper 95%	P-value
C. cookii-C. auriceps	0.10	2.27	4.44	0.037
C. novaezelandiae-C. auriceps	-0.45	0.57	1.58	0.45
C. unicolor-C. auriceps	1.09	2.85	4.61	<0.001
C. novaezelandiae-C. cookii	-3.78	-1.71	0.37	0.14
C. unicolor-C. cookii	-1.95	0.58	3.11	0.93
C. unicolor-C. novaezelandiae	0.64	2.28	3.93	<0.003

There is a near-significant relationship between BSA and body mass (linear regression: F-statistic = 7.29, p-value = 0.05, Fig. 3, conducted in R© version 2.15.3). Increase in body mass predicts an increase in BSA with an increase in surface area of 0.85 mm^2 for every additional gram of body weight. However, as body weight only explains 65% of variation other factors are involved.

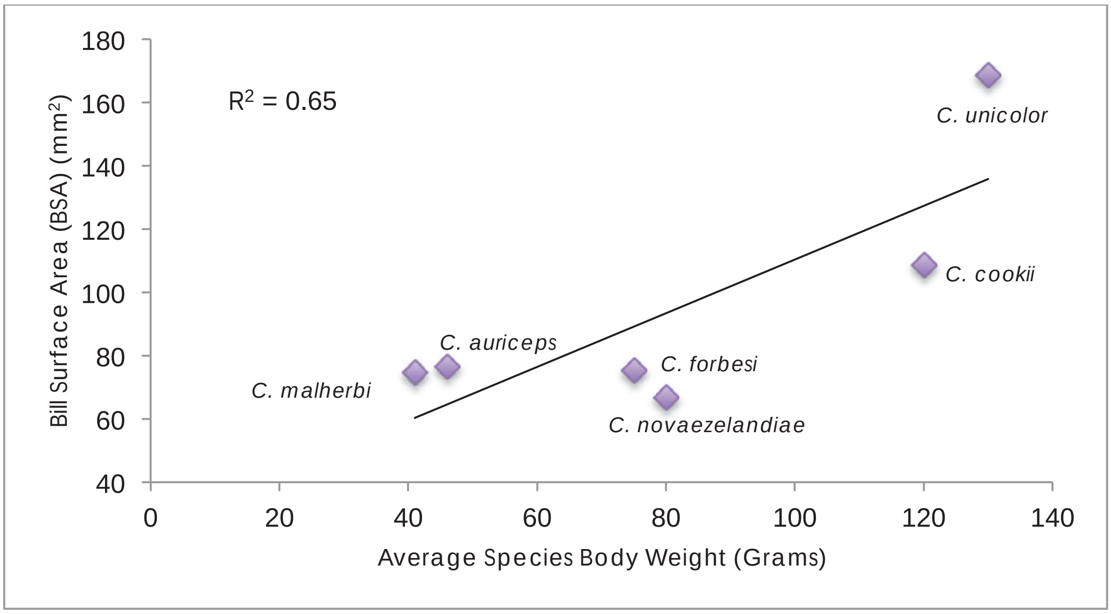

Figure 3. Linear regression (conducted in R© version 2.15.3) of bill surface area (BSA) and average body weights. (Body weight data from: nzbirdsonline.org.nz, and field data for the Tasman parakeet (Ortiz-Catedral, unpublished)) Sample size for BSA measure: *C. auriceps* = 17, *C. cookii* = 3, *C. novaezelandiae* = 38, *C. unicolor* = 5, *C. forbesi* = 65, *C. malherbi* = *1*.

2.4.3 Bill Morphology And Seed Consumption

I found no relationship between bill surface area (BSA) and the prevalence of seeds in the diet of a given *Cyanoramphus* parakeet (F-statistic = 0.09, p-value = 0.77). Additionally bill surface area was not correlated with the prevalence of seed consumption, explaining only 2% of variation, with species with similar bill surface areas varying considerably in the prevalence of seeds in their diets (Fig. 4).

I found correlations between body mass and bill width and the prevalence of seed consumption. In general species with a larger body mass had a higher prevalence of seed consumption (Fig. 5). Upper bill width was also correlated to the prevalence of seed consumption (Fig. 6).

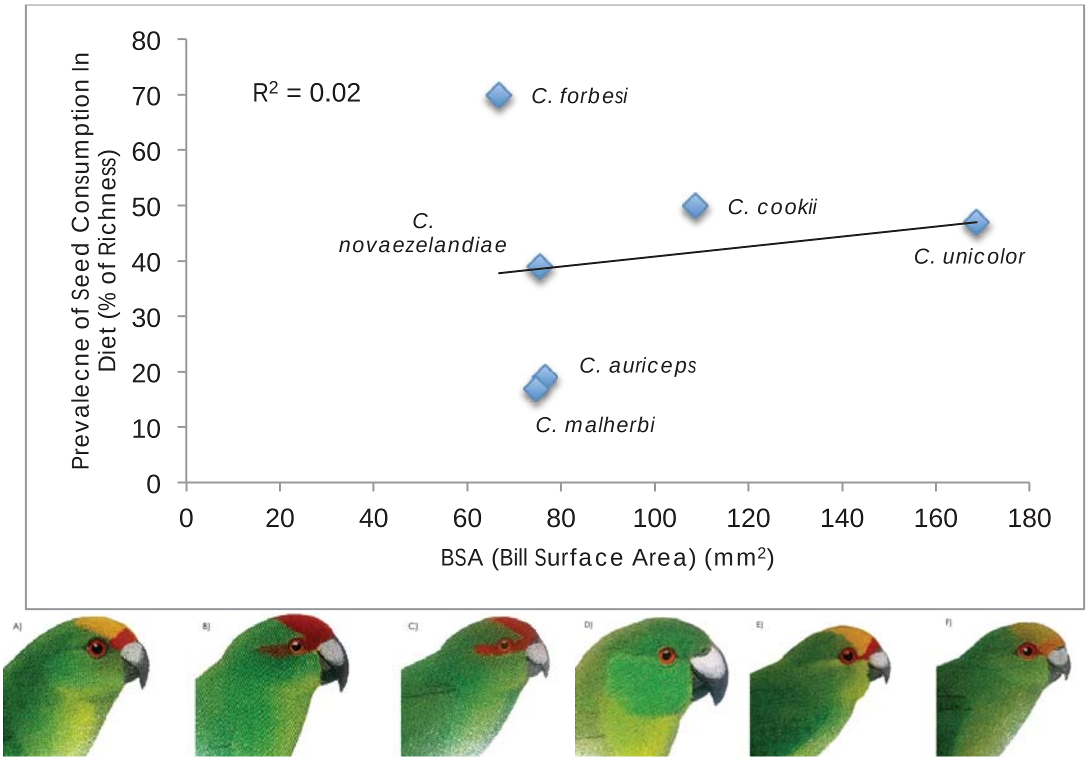

Figure 4. Relationship between BSA and prevalence of seeds in diet with reference of bill shapes for *Cyanoramphus* species. A) Forbes' parakeet, B) Tasman parakeet, C) red-fronted parakeet, D) Antipodes Island parakeet, E) yellow-fronted parakeet and F) orange-fronted parakeet (see Table 1 for scientific names). Modified from Forshaw (2006). Linear regression conducted in R© version 2.15.3. Sample size for BSA measure: *C. auriceps* = 17, *C. cookii* = 3, *C. novaezelandiae* = 38, *C. unicolor* = 5, *C. forbesi* = 65, *C. malherbi = 1.*

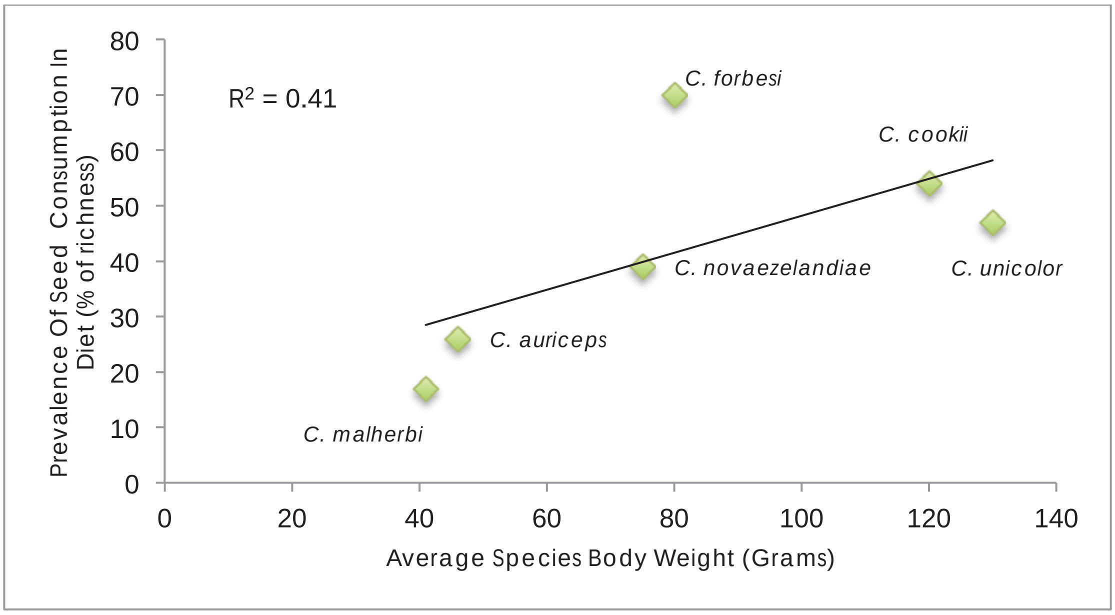

Figure 5. Linear regression (conducted in R© version 2.15.3) of the prevalence of seed consumption in a parakeets diet (measured as % of richness) against average body weights (grams). (Body weight data from: nzbirdsonline.org.nz, and field data for the Tasman parakeet (Ortiz-Catedral, unpublished)).

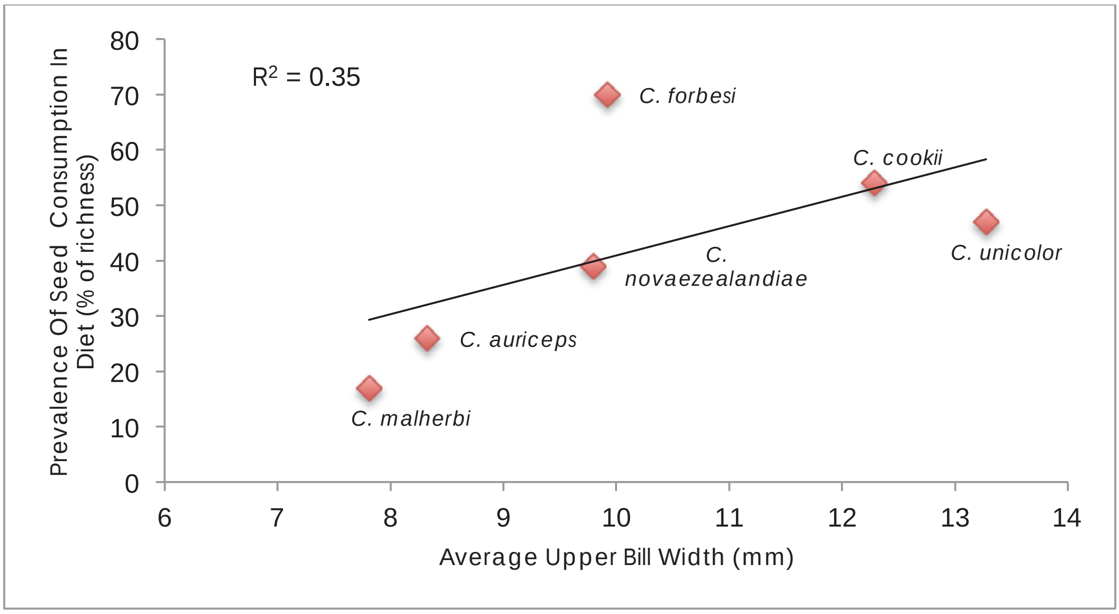

Figure 6. Linear regression (conducted in R© version 2.15.3) the prevalence of seed consumption in a parakeets diet (measured as % of richness) against average upper bill width (mm). Sample size for bill width measure: *C. auriceps* = 17, *C. cookii* = 3, *C. novaezelandiae* = 38, *C. unicolor* = 5, *C. forbesi* = 65, *C. malherbi* = *1*.

Table 5. Dietary items consumed by different *Cyanoramphus* species. (abbreviations: a = *auriceps*, c = *cookii*, f = *forbesi*, m = *malherbi*, n = *novazelandiae*, u = *unicolor*). Data from: (Dawe, 1979; Elliott et al., 1996; Greene, 1998; Higgins, 1999; Kearvell et al., 2002; Nixon, 1982, 1994; Ortiz-Catedral & Brunton, 2009) (Additional data for Tasman parakeet from Chapter Three).

Family	Genus	Species	*Cyanoramphus* Diet	*Seed Consumption*
Aizoaceae	*Aptenia*	*cordifolia*	*n*	*n*
	Disphyma	*australe*	*n*	*n*
		papillatum	*n*	
	Mesembryanthemum	*cordifolium*	*n*	*n*
Alseuosmiaceae	*Alseuosmia*	*macrophylla*	*a*	
Amaranthaceae	*Chenopodium*	*album*	*n*	
		allanii	*n*	
		urbicum	*n*	*n*
	Einadia	*trigonos*	*n*	
Apiaceae	*Anisotome*	*antipoda*	*u*	*u*
	Chaerophyllum	*colensoi*	*a, m*	
Apocynaceae	*Melodinus*	*baueri*	*c*	
	Parsonsia	*heterophylla*	*n*	*n*
Araliaceae	*Meryta*	*sinclairii*	*n*	
		angustifolia	*c*	
		latifolia	*c*	*c*
	Pseudopanax	*arboreus*	*a, m*	
		crassifolius	*n*	*n*
		edgerleyi	*n*	

Araliaceae	*Pseudopanax*	*lessonii*	*n*	
		edgerleyi	*n*	
	Schefflera	*digitata*	*n*	
	Stilbocarpa	*lyallii*	*n*	
		polaris	*u*	
Araucariaceae	*Agathis*	*australis*	*n*	*n*
	Araucaria	*heterophylla*	*c*	*c*
	Cupressus	*funebris*	*n*	
		macrocarpa	*n*	
Arecaceae	*Rhopalostylis*	*baueri*	*c*	*c*
Asparagaceae	*Cordyline*	*australis*	*n*	
		obtecta	*c*	
Asteliaceae	*Astelia*	*banksii*	*n*	
Asteraceae	*Brachyglottis*	*huntii*	*n*	*n*
		repanda	*n*	*n*
	Embergeria	*grandifolia*	*n*	*n*
	Erigeron	*sumatrensis*	*n*	*n*
	Helichrysum	*luteoalbum*	*n*	*n*
	Hypochaeris	*radicata*	*n*	*n*
	Leptinella	*maniototo*	*a, m*	
	Olearia	*angustifolia*	*n*	
		arborescens	*n*	
		chathamica	*n*	
		furfuracea	*n*	*n*
		traversii	*f, n*	*f, n*

Asteraceae	*Ozothamnus*	*leptophyllus*	*n*	*n*
	Senecio	*bipinnatisectus*	*n*	*n*
		huntii	*n*	
		radiolatus	*f, u*	
		reinoldii	*n*	
	Sonchus	*grandifolius*	*f, n*	*f*
		oleraceus	*n*	*n*
	Taraxacum	*officinale*	*n*	*n*
Blechnaceae	*Blechnum*	*durum*	*u*	
		penna-marina	*a, m*	
Brassicaceae	*Lepidium*	*didymum*	*n*	
Campanulaceae	*Lobelia*	*angulata*	*a, m*	
		arenaria	*n*	
		perpusilla	*a, m*	
Capparaceae	*Capparis*	*nobilis*	*c*	
Caryophyllaceae	*Colobanthus*	*apetalus*	*n*	
	Polycarpon	*tetraphyllum*	*n*	
	Stellaria	*decipiens*	*u*	
		media	*n*	*n*
Celastraceae	*Elaeodendron*	*curtipendulum*	*c*	
Convolvulaceae	*Dichondra*	*repens*	*n*	
Coriariaceae	*Coriaria*	*arborea*	*n*	
Crassulaceae	*Crassula*	*moschata*	*n*	
Cyatheaceae	Cyathea	brownii	*c*	
Cyperaceae	*Carex*	*appressa*	*n, u*	*n, u*

Cyperaceae	*Carex*	*virgata*	*n*	*n*
		sectoides	*u*	*u*
		ternaria	*u*	*u*
		trifida	*f, n, u*	*f, u*
	Cyperus	*ustulatus*	*n*	*n*
	Ficinia	*nodosa*	*n*	*n*
	Uncinia	*hookeri*	*u*	
		uncinata	*n*	*n*
Dryopteridaceae	*Polystichum*	*vestitum*	*u*	
Elaeocarpaceae	*Aristotelia*	*serrata*	*m*	
	Elaeocarpus	*dentatus*	*n*	
Ericaceae	*Cyathodes*	*fasciculata*	*n*	
	Dracophyllum	*latifolium*	*n*	*n*
	Leptecophylla	*juniperina*	*n*	
	Leucopogon	*fasciculatus*	*n*	
Euphorbiaceae	*Baloghia*	*inophylla*	*c*	*c*
	Euphorbia	*peplus*	*n*	*n*
Fabaceae	*Cytisus*	*proliferus var palmensis*	*m*	
	Pisum	*sativum*	*n*	
Gentianaceae	*Gentiana*	*antipoda*	*u*	
Geraniaceae	*Geranium*	*molle*	*n*	
		traversii	*n*	
Griseliniaceae	*Griselinia*	*littoralis*	*a*	
Juglandaceae	*Juglans*	*regia*	*n*	
Juncaceae	*Juncus*	*australis*	*n*	*n*

Lamiaceae	*Mentha*	*pulegium*	*n*	
	Vitex	*lucens*	*n*	
Lauraceae	*Beilschmiedia*	*tarairi*	*n*	
	Laurelia	*novae-zelandiae*	*n*	
Loganiaceae	*Geniostoma*	*rupestre var. ligustrifolium*	*n*	
Loranthaceae	*Peraxilla*	*tetrapetala*	*a*	
Malvaceae	*Lagunaria*	*patersonia*	*c*	
	Plagianthus	*regius ssp. chathamicus*	*n*	
		betulinus	*f, n*	*f*
Meliaceae	*Dysoxylum*	*spectabile*	*a, m, n*	
	Melia	*azedarach*	*c*	*c*
Moraceae	*Streblus*	*banksii*	*n*	
Myrtaceae	*Kunzea*	*ericoides*	*a, n*	*a, n*
	Leptospermum	*scoparium*	*m, n*	*n*
	Metrosideros	*fulgens*	*a, n*	*n*
		perforata	*n*	
		excelsa	*a, n*	*n*
		umbellatum	*n*	
	Psidium	*cattleianum*	*c*	*c*
		guajava	*c*	
Nothofagaceae	*Nothofagus*	*cliffortioides*	*a, m*	*m*
		fusca	*a, m*	*m*
		menziesii	*a, m*	*a, m*
		solandri	*m, n*	*m*
		truncata	*a, n*	*n*

Oleaceae	*Nestegis*	*apetala*	*c*	*c*
		lanceolata	*n*	
	Olea	*europaea ssp cuspidata*	*c*	*c*
Onagraceae	*Fuchsia*	*excorticata*	*n*	
Papaveraceae	*Fumaria*	*muralis*	*n*	*n*
Passifloraceae	*Passiflora*	*tetrandra*	*n*	
Pennantiaceae	*Pennantia*	*baylisiana*	*n*	
		corymbosa	*n*	
		endlicheri	*c*	*c*
Phyllocladaceae	*Phyllocladus*	*trichomanoides var alpinus*	*a, m*	*a*
Phytolaccaceae	*Phytolacca*	*octandra*	*n*	
Pinaceae	*Pinus*	*radiata*	*m, n*	*n*
		pinca	*n*	
Piperaceae	*Macropiper*	*excelsum*	*n*	*n*
		excelsum ssp psittacorum	*c*	
Pittosporaceae	*Pittosporum*	*crassifolium*	*n*	
		umbellatum	*a, n*	*a, n*
		bracteolatum	*c*	
Poaceae	*Agrostis*	*capillaris*	*a*	
		magellanica	*n*	
	Anthoxanthum	*odoratum*	*n*	*n*
	Austroderia	*toetoe*	*n*	
		richardii	*n*	*n*
	Bromus	*hordeaceus*	*n*	*n*
	Chionochloa	*conspicua*	*n*	

Poaceae	*Chionochloa*	*bromoides*	*n*	*n*
	Dactylis	*glomerata*	*n*	*n*
	Holcus	*lanatus*	*n*	*n*
		mollis	*n*	
	Lachnagrostis	*filiformis*	*n*	*n*
	Microlaena	*stipoides*	*n*	
	Oplismenus	*hirtellus*	*c*	
	Poa	*anceps*	*n*	*n*
		annua	*n*	*n*
		breviglumis	*n*	
		foliosa	*u*	*u*
		litorosa	*u*	*u*
	Puccinellia	*antipoda*	*u*	
	Rytidosperma	*racemosum*	*n*	*n*
	Sporobolus	*africanus*	*n*	*n*
	Stenotaphrum	*secundatum*	*n*	*n*
Podocarpaceae	*Dacrycarpus*	*dacrydioides*	*n*	
	Dacrydium	*cupressinum*	*n*	
	Podocarpus	*cunninghamii*	*a*	
		totara	*n*	
Polygonaceae	*Muehlenbeckia*	*australis*	*f, n*	*f, n*
		complexa	*n*	*n*
	Rumex	*obtusifolius*	*n*	
Polypodiaceae	*Pyrrosia*	*serpens*	*f, n*	
Primulaceae	*Myrsine*	*ralstoniae*	*c*	*c*

Primulaceae	*Myrsine*	*australis*	*a, n*	
		chathamica	*f, n*	
		divaricata	*a*	
Proteaceae	*Hakea*	*salicifolia*	*c*	*c*
	Knightia	*excelsa*	*n*	*n*
Ramalinaceae	*Ramalina*	*celastri*	*n*	
Rosaceae	*Acaena*	*minor*	*u*	*u*
	Fragaria	*vesca*	*n*	
	Malus	*sylvestris*	*n*	
	Prunus	*domestica*	*n*	
		persica	*n, c*	*c*
Rousseaceae	*Carpodetus*	*serratus*	*a, m*	
Rubiaceae	*Coprosma*	*arborea*	*a, n*	*a*
		macrocarpa	*n*	
		repens	*n*	
		rhamnoides	*n*	
		robusta	*m*	
		rugosa	*u*	
Rutaceae	*Leionema*	*nudum*	*n*	
	Melicope	*ternata*	*n*	
	Zanthoxylum	*pinnatum*	*c*	
Santalaceae	*Korthalsella*	*disticha*	*c*	*c*
	Mida	*salicifolia*	*n*	
Sapindaceae	*Acer*	*pseudoplatanus*	*m*	
	Alectryon	*excelsus*	*m*	

Sapindaceae	*Dodonaea*	*viscosa*	*m, c*	*c*
Sapotaceae	*Pouteria*	*costata*	*n*	*n*
Scrophulariaceae	*Veronica*	*chathamica*	*n*	
		stricta	*m*	
	Myoporum	*laetum*	*n*	
	Parahebe	*lyallii*	*a, m*	
Solanaceae	*Solanum*	*aviculare*	*n*	
		mauritianum	*c*	
		americanum	*n*	
		nodiflorum	*n*	*n*
Strasburgeriaceae	*Ixerba*	*brexioides*	*a*	
Urticaceae	*Parietaria*	*debilis*	*f, n*	
	Urtica	*australis*	*f, n*	*f*
Verbenaceae	*Lantana*	*camara*	*c*	*c*
Violaceae	*Melicytus*	*ramiflorus*	*a, m, n*	
		nova-zealandiae	*n*	
Winteraceae	*Pseudowintera*	*axillaris*	*a*	*a*
Xanthorrhoeaceae	*Dianella*	*intermedia*	*a*	
	Phormium	*tenax*	*f, n*	*f, n*

2.5 DISCUSSION

2.5.1 Dietary Diversity And Overlap

For many parrot species dietary niche breadth has been studied with respect to the relative proportions of food species utilised and often in relation to the phenological abundance (see (Contreras-González et al., 2009; Renton, 2001)). The inter-species differences I observed likely reflect geographical patterns and research effort as dietary niche breadth is a significant positive correlate of geographical range (Slatyer et al., 2013). For instance, the red-fronted parakeet is well studied relative to other *Cyanoramphus* species (Bellingham, 1987; Dawe, 1979; Greene, 1988, 1998; Higgins, 1999) and the species occurs across a large geographical range, but only on island refuges, rather than it's historic range of the New Zealand mainland (Miskelly & Powlesland, 2013). In contrast, Forbes' parakeet has a restricted range; occurring only on Mangere and Little Mangere Islands in the Chatham Island group (20 hectares) (Higgins, 1999), and limited data were available; only one detailed study (conducted over a four year period) identified foods to the species level (Nixon, 1982, 1994). Another two species I investigated are also have restricted ranges, which may explain the limited richness of their diets. The Antipodes Island parakeet inhabits the isolated subantarctic Antipodes Island group (totalling over 2000 hectares) and the Tasman parakeet, inhabits 300 ha of remnant forest on Norfolk Island in the South Pacific (Director of National Parks, 2010). Hence, for the Tasman parakeet dietary knowledge prior to this study was limited ((Higgins, 1999), see also Chapter Three).

The yellow-fronted parakeet, like the red-fronted parakeet, has a broad geographical range, but is still present on the New Zealand mainland (Kearvell et al., 2002). The number of studies available was limited, sampling only three locations: Fiordland (Elliott et al., 1996) and Little Barrier Island/Hauturu (Greene, 1998) and Lake Sumner Forest Park in the South Island of New Zealand (Kearvell et al., 2002). Additionally many studies (such as (Greene, 1998)) only report items which constituted 5% or more of diet, so my analysis may exclude some rarely consumed species, or infrequent cases of seed consumption. The orange-fronted parakeet is a critically endangered species (see Table 1, Chapter One), with three mainland remnant and three translocated island populations (Ortiz-Catedral et al., 2012). The studies which provided the most information on the diet of this species were from Lake Sumner Forest Park in New Zealand (Kearvell et al., 2002) and Maud Island (Ortiz-Catedral & Brunton, 2009) report a diverse diet consisting of 14 species combined. This species serves as an example on the effect of research effort. Up until the 2000's the diet of orange-fronted parakeets was considered narrow with seeds of three beech species (*Nothofagus* spp.) as the main dietary component (Harrison, 1970; Kearvell et al., 2002). The only available study on an offshore island (Ortiz-Catedral & Brunton, 2009) revealed a broader diet, adding items from 11 species, and highlighted the importance of ongoing research on the diet of parakeet species in different locations.

Among sympatric species the dietary overlap is in general low, for example, the yellow-fronted and red-fronted parakeet overlap 6.02% in species consumed (Table 2). While Greene (1998) found significant differences between red-fronted and yellow-fronted parakeet in a sympatric population on Little Barrier Island/Hauturu, the percentage in overlap for dietary plant richness is much higher than my result. Greene (1998) observed red-fronted parakeets feeding on 57 species, and yellow-fronted parakeets items from 17 species, of which 13 species were shared; giving a Jaccard's coefficient of 21%, which may be a more realistic figure when looking closely at sympatric populations. These findings show that differences between populations are also important, and might reflect the vegetation composition at the locations studied. If the species consumes a wide variety of food species across its geographic range the species dietary diversity is likely to be higher than that of a single population. The focus of my data was on overall dietary diversity of each species, and we might expect there to be less overlap when considering foods consumed by across the species range, as infrequent food species are given the same weight as those that might be consumed by multiple populations.

There was no overlap in diet between the Tasman parakeet and Forbes' parakeet (Table 2) or between the Tasman parakeet and Antipodes Island parakeets, both allopatric combinations. The Tasman parakeet does not share an overlapping distribution with any other species examined. However, they have dietary overlap with orange-fronted, red-fronted parakeets. These are plant species that occur both on Norfolk Island and New Zealand. Shared species are peach (*Prunus persica)*, and ake ake (*Dodonaea viscosa*), (see Table 5) but only contribute minor similarity to the diet. Only one of these species is an important seasonal component to the Tasman parakeets diet (ake ake (*D. viscosa*), see Chapter Three).

2.5.2 Bill Morphology

The bill morphology of the Tasman parakeet is significantly different to the red-fronted parakeet (of which it has previously been considered a subspecies (see Chapter One)). While overlap was present in three characteristics, upper depth, lower basal width, and lower depth it is occurs between the upper ranges of the red-fronted parakeet and the lower ranges of the Tasman parakeet, so the smallest of the Tasman parakeets overlap with the largest of the red-fronted parakeets. While I did not distinguish between sexes in my analysis I suspect, given the sexual size dimorphism found across the *Cyanoramphus* group (Young & Kearvell, 2001), that the overlap is between large red-fronted males and smaller female Tasman parakeets. In the four characteristics that differ the red-fronted parakeets bill is significantly smaller (Tables 3 and 4). The bill of the Tasman parakeet is of a similar size to that of the Antipodes Island parakeet (overlapping in five characteristics, see Tables 3 and 4). Differences between the two reveal that the Tasman parakeet has significantly a longer lower bill, but a shallower upper bill (Table 4). In fact, the Tasman parakeet has an unusually shallow upper bill for a *Cyanoramphus* parakeet, even overlapping with the upper bill depth of the much smaller yellow-fronted parakeet (see Tables 3 and 4, and Fig. 3, Appendix 2).

2.5.3 Bill Morphology And Seed Consumption

In general granivorous birds with over-all larger bills have the ability to crack harder seeds. There is a significant positive correlation between bill dimensions (especially width) and bite force (Koves Hrabar & Perrin, 2002). Darwin's finches differ in their ability to handle the seeds of *Tribulus cistoides* as a direct result of bill size (Grant, 1981). As mentioned previously, *Cyanoramphus* parakeets differ significantly in many aspects of bill morphology, I have identified trends between size characteristics (body weight, and upper bill width) and the prevalence of seed consumption in their diets, versus other plant material (Figs. 5 and 6).

The prevalence of seed consumption varied considerably among *Cyanoramphus* species. Species with the smaller body weight and bill width had a low prevalence of seed consumption in their diet. Tasman parakeets have a large bill width and body mass and a have a high prevalence of seed consumption (50% of plant species). Specifically the Tasman parakeet relies heavily on Norfolk pine seed (*Araucaria heterophylla*) during winter (see Chapter Three). At the opposite end of the scale yellow fronted and orange-fronted parakeets, which have a small bill widths and small body mass, have a low prevalence of seed consumption in their diet. One possible explanation is the energetic requirements of these species, with species with a larger basal metabolic rate having a higher prevalence of seed consumption. In finches larger body size relative to bill size reduced the range of possible bill sizes, and the increased metabolic demands of a larger body lessened the ability to specialise (Benkman, 1991). Of the species I investigated basal metabolic rate data is available for three: Antipodes Island parakeet, 194.1 cm^3 O_2/h; red-fronted parakeet, 94.8 cm^3 O_2/h; and the yellow-fronted parakeet, 88.3 cm^3 O_2/h (McNab & Salisbury, 1995). Basal metabolic rate is associated with body mass

(McNab, 1988), and I found *Cyanoramphus* species larger body mass have a higher prevalence of seed consumption in their diet. That the Antipodes Island parakeet does not consume a significantly greater seed variety in it's diet compared with the red-fronted parakeet despite having a larger upper bill width and body mass might be explained by the species predominantly herbivorous habit, feeding on the seeds of grasses and sedges (Greene, 1999). The Forbes parakeets has a much greater prevalence of seed in its diet than might be expected for its body size and mass, but this is likely due to its habit of feeding on the ground (Higgins, 1999; Nixon, 1982).

Specific populations of a species may utilise a greater proportion of seeds than is present in the species overall diet, for example, the yellow-fronted parakeet population in the beech (*Nothofagus* spp) forests of Fiordland (Elliott et al., 1996). The two species with the highest prevalence of seed consumption in their diet are isolated populations that spend a large proportion of time feeding on the ground; Forbes' parakeet (Higgins, 1999; Nixon, 1994), and the Tasman parakeet (see Chapter Three).Forbes' parakeets have also previously been described a forest specialists, where as red-fronted parakeets (*C. novaezelandiae*), and the Chatham Island red-fronted parakeet (*C. n. chathamensis*) often forage in more open areas (Greene, 1998; Nixon, 1994). In contrast the yellow-fronted parakeet and orange-fronted parakeet have the lowest prevalence of seed consumption in their diet, and have small upper bill widths and small body masses. However, dietary information for these two species comes from two very different kinds of habitat. Both species are found in remnant *Nothofagus* forest, where they both exhibit low dietary diversity, and a high proportion of seed consumption (both orange-fronted and yellow-fronted parakeets consume seeds of five species as their main plant resources (Kearvell et al., 2002)). In contrast, when these species are found on islands they exhibit greater dietary diversity, and a lower prevalence of seed consumption (orange-fronted parakeets on Maud Island consume fruits, leaves and flowers (Ortiz-Catedral & Brunton, 2009), yellow-fronted parakeet on Little Barrier Island/Hauturu consumed seed from 18% of major plant resources (Greene, 1998)). As not all foods are available in all locations when the data is combined in a presence absence index, these species have a low prevalence of seed consumption overall.

My results show that similarities in bill morphology and body size might obscure non-overlapping dietary diversity. For example, the yellow-fronted, and orange-fronted parakeet are very similar in terms of bill morphology and body size (Fig. 3), yet have limited overlap in diet (Table 2) and prevalence of seed consumption (Figs. 5 and 6). Likewise Forbes' parakeets and red-fronted parakeets are also similar in these traits (Fig. 3), however these pairs of species show a considerable non-overlapping dietary diversity (Table 2) and also show a vastly different prevalence of seed consumption with respect to these traits (Figs. 5 and 6). This highlights the idea that unresolved taxonomic affinities resulting from morphological similarities could mask considerably differences in dietary diversity.

While I examined the prevalence of seed consumption, investigating the proportions of woody seeds in a *Cyanoramphus* parakeets diet may reveal a greater degree of specialisation. For example, for red-fronted parakeets a large number of the species consumed as seeds are from the family Poaceae, as such the size of the bill will not be a limiting factor for consumption of this type of seed. Tasman parakeets feed on the seeds of the Norfolk Pine (*Araucaria heterophylla*) whilst there is no record of red-fronted parakeets consuming this species, likely due to its limited presence in their geographical range. Red-fronted parakeets do however consume seeds of another member of the family Araucariaceae, the kauri (*Agathis australis*) (Higgins, 1999). This is particularly important because Tasman parakeets rely heavily on the seeds of the Norfolk pine during the winter months (see Chapter Three), it is possible that if their bills were smaller they might be unable to take advantage of this abundant food source.

Overall the dietary diversity and prevalence of seed consumption in the diet of the Tasman parakeet fits the generalist trend of other *Cyanoramphus* species.

2.6 LIMITATIONS AND FUTURE DIRECTIONS

The type of published data available constrained the type of analysis that I was able to conduct. Due to variation in reporting I was only able to determine the presence of plant species in the diets of different *Cyanoramphus* species. Furthermore due to variation in number of studies on *Cyanoramphus* species, as well as variation in study length, I was not able to estimate the importance of plant food species or items in the diets of a given *Cyanoramphus* species. Therefore, this analysis takes into account only the proportion of dietary plant species that are consumed as seed rather than their relative importance. For example, in this analysis Norfolk pine represents 6% of the species that are consumed as seed, where as it constitutes 24.6% of the total diet for the Tasman parakeet (see Chapter Three). Ideally a more detailed analysis would take into account relative importance of food species and types.

My conclusions regarding bill morphological trends are limited by the sample size I was able to obtain and while I was able to identify trends in the relationships between bill size and seed consumption a greater sample size, which also accounts for sexual dimorphism, is required to prove these statistically. Future research into bill morphological trends within this genus could take several directions. Investigating bill size correlation with latitude (Allens rule) as has been observed in salt marsh sparrow taxa (Family Emberizidae) (Greenberg et al., 2012)). This would require more detailed sampling, as some species (*C. novazelandiae* and *C. auriceps* in particular) occur over a large latitudinal range. Bill morphology could be compared to measures of seed size, such as raw dimensions or measures of hardness. Potential seeds could even be presented to captive populations to examine morphologically driven differences in utilisation or handling.

Future research into dietary overlap amongst this genus might take into account geographic variation in plant species, and the effect of geographic range size on dietary breadth.

2.7 CONCLUSIONS

Cyanoramphus parakeets exhibit measurable differences in bill morphology between species (Tables 3 and 4), high dietary diversity (Table 5) and a low degree of overlap in the plant species consumed (Table 2). Further, the estimated prevalence of seeds in the diet of *Cyanoramphus* parakeets is significantly different, ranging from a predominant seed diet (i.e. Forbes parakeet, 70%) to a low seed diet (i.e. orange-fronted parakeets (17%)) (Fig. 2). The Tasman parakeet has very little dietary overlap with other *Cyanoramphus* parakeets (Table 2), with a high prevalence of seed consumption (50%) (Fig. 2). The bill morphology of *Cyanoramphus* species is correlated with the prevalence of seed in their diets (Fig. 6).

2.8 REFERENCES

Barbosa, A. (1996). Relationship between bill morphology and preening behaviour in waders. *Ethology Ecology and Evolution, 8*(3), 291-296.

Beggs, J. R., & Wardle, D. A. (2006). Keystone Species: Competition for Honeydew Among Exotic and Indigenous Species. In R. B. Allen & W. G. Lee (Eds.), *Biological Invasions in New Zealand* (pp. 281-294). Berlin, Heidelberg: Springer Berlin Heidelberg.

Bellingham, M. (1987). Red-crowned Parakeet on Burgess Island. *Notornis, 34*(3).

Benkman, C. W. (1987). Crossbill foraging behavior, bill structure, and patterns of food profitability. *Wilson Bulletin, 99*(3), 351-368.

Benkman, C. W. (1991). Predation, seed size partitioning and the evolution of body size in seed-eating finches. *Evolutionary Ecology, 5*(2), 118-127. doi: 10.1007/BF02270828

Boon, W. M., Kearvell, J. C., Daugherty, C. H., & Chambers, G. K. (2000). Molecular systematics of New Zealand *Cyanoramphus* parakeets: Conservation of Orange-fronted and Forbes' Parakeets. *Bird Conservation International, 10*(3), 211-239.

Boyes, Rutledge S., & Perrin, Michael R. (2009). Generalists, specialists and opportunists: niche metrics of *Poicephalus* parrots in southern Africa. *Ostrich, 80*(2), 93-97. doi: 10.2989/OSTRICH.2009.80.2.5.832

Burton, P. J. K. (1974). Anatomy of head and neck in the Huia (*Heteralocha acutirostris*) with comparative notes on other Callaeidae (Vol. 27, pp. 1-48): Trustees of the British Museum (Natural History).

Campbell-Tennant, D. J. E., Gardner, J. L., Kearney, M. R., & Symonds, M. R. (2015). Climate-related spatial and temporal variation in bill morphology over the past century in Australian parrots. *Journal of Biogeography*. doi: 10.1111/jbi.12499

Cannon, C. E. (1981). The diet of Eastern and Pale-headed Rosellas. *Emu, 81*(2), 101-110.

Contreras-González, A. M., Rivera-Ortíz, F. A., Soberanes-González, C., Valeiente-Banuet, A., & Arizmendi, M. C. (2009). Feeding ecology of military macaws (*Ara militaris*) in a semi-arid region of Central Mexico. *The Wilson Journal of Ornithology, 121*(2), 384-391.

Dawe, M. R. (1979). Behaviour and ecology of the red-crowned parakeet (*Cyanoramphus novaezelandiae*) in relation to management. *Unpublished M. Sc. thesis, University of Auckland, Auckland, New Zealand*.

De León, L. F., Podos, J., Gardezi, T., Herrel, A., & Hendry, A. P. (2014). Darwin's finches and their diet niches: The sympatric coexistence of imperfect generalists. *Journal of Evolutionary Biology, 27*(6), 1093-1104. doi: 10.1111/jeb.12383

Diamond, J. M., & Marshall, A. G. (1977). Niche shifts in New Hebridean birds. *Emu, 77*(2), 61-72.

Diaz, M. (1990). Interspecific patterns of seed selection among granivorous passerines: effects of seed size, seed nutritive value and bird morphology. *Ibis, 132*(3), 467-476. doi: 10.1111/j.1474-919X.1990.tb01064.x

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

Dyke, G. J., & Leonard, L. M. (2001). Palaeognathae *eLS*: John Wiley & Sons, Ltd.

Elliott, G. P., Dilks, P. J., & O'Donnell, C. F. J. (1996). The ecology of yellow-crowned parakeets (*Cyanoramphus auriceps*) in *Nothofagus* forest in Fiordland, New Zealand. *New Zealand Journal of Zoology, 23*(3), 249-265.

Forshaw, J. M. (2006). *Parrots of the world: an identification guide*: Princeton University Press.

Galetti, M. (2013). Seasonal abundance and feeding ecology of parrots and parakeets in a lowland Atlantic forest of Brazil. *Revista Brasileira de Ornitologia-Brazilian Journal of Ornithology, 5*(7), 12.

Grant, P. R. (1981). The feeding of Darwin's finches on *Tribulus cistoides* (L.) seeds. *Animal Behaviour, 29*(3), 785-793. doi: http://dx.doi.org/10.1016/S0003-3472(81)80012-7

Greenberg, R., Danner, R., Olsen, B., & Luther, D. (2012). High summer temperature explains bill size variation in salt marsh sparrows. *Ecography, 35*(2), 146-152. doi: 10.1111/j.1600-0587.2011.07002.x

Greene, T. C. (1988). *Behavioural Ecology of the Red-crowned Parakeet (Cyanoramphus Novaezelandiae Sparrman, 1787) and the Yellow-crowned Parakeet (Cyanoramphus Auriceps Kuhl, 1820) on Little Barrier Island.* (Unpublished Msc thesis), University of Auckland.

Greene, T. C. (1998). Foraging ecology of the red-crowned parakeet (*Cyanoramphus novaezelandiae novaezelandiae*) and yellow-crowned parakeet (*C. auriceps auriceps*) on Little Barrier Island, Hauraki Gulf, New Zealand. *New Zealand Journal of Ecology, 22*(2), 161-171.

Greene, T. C. (1999). Aspects of the ecology of Antipodes Island Parakeet (*Cyanoramphus unicolor*) and Reischek's Parakeet (*C. novaezelandiae* *hochstetteri*) on Antipodes Island, October - November 1995. *Notornis, 46*(2), 301-310.

Hansell, M. (2000). *Bird nests and construction behaviour*. United Kingdom: Cambridge University Press.

Hardin, G. (1960). The Competitive Exclusion Principle. *Science, 131*(3409), 1292-1297.

Harrison, M. (1970). The Orange-fronted Parakeet *Cyanoramphus malherbi*. *Notornis, 17*(2).

Herrel, A., Podos, J., Huber, S. K., & Hendry, A. P. (2005). Bite performance and morphology in a population of Darwin's finches: Implications for the evolution of beak shape. *Functional Ecology, 19*(1), 43-48. doi: 10.1111/j.0269-8463.2005.00923.x

Herrel, A., Podos, J., Vanhooydonck, B., & Hendry, A. P. (2009). Force–velocity trade‐off in Darwin's finch jaw function: a biomechanical basis for ecological speciation? *Functional Ecology, 23*(1), 119-125.

Herrel, A., Soons, J., Aerts, P., Dirckx, J., Boone, M., Jacobs, P., Adriaens, D., & Podos, J. (2010). Adaptation and function of the bills of Darwins finches: Divergence by feeding type and sex. *Emu, 110*(1), 39-47.

Higgins, P.J. (Ed.). (1999). *Handbook of Australian, New Zealand and Antarctic Birds.* (Vol. Volume 4: Parrots to Dollarbird.). Melbourne: Oxford University Press.

Hsu, Y. C., Shaner, P. J., Chang, C. I., Ke, L., & Kao, S. J. (2014). Trophic niche width increases with bill-size variation in a generalist passerine: A test of niche variation hypothesis. *Journal of Animal Ecology, 83*(2), 450-459.

Jaccard, P. (1912). The distribution of the flora in the alpine zone. *New phytologist, 11*(2), 37-50.

Jamieson, I. G., & Spencer, H. G. (1996). The bill and foraging behaviour of the Huia (*Heteralocha acutirostris*): Were they unique? *Notornis, 43*, 14-48.

Juniper, T., & Parr, M. (1998). A Guide to the Parrots of the World. *A&C Black. Londres-Inglaterra*, 45-322.

Kearvell, J. C., Young, J. R., & Grant, A. D. (2002). Comparative ecology of sympatric orange-fronted parakeets (*Cyanoramphus malherbi*) and yellow-crowned parakeets (*C. auriceps*), South Island, New Zealand. *New Zealand Journal of Ecology, 26*(2), 139-148.

Koves Hrabar, H. D. N., & Perrin, M. (2002). The effect of bill structure on seed selection by granivorous birds. *African Zoology, 37*(1), 67-80.

Lindberg, B. A., & Olesen, M. J. (2001). The fragility of extreme specialization: *Passiflora mixta* and its pollinating hummingbird *Ensifera ensifera*. *Journal of Tropical Ecology, 17*(2), 323-329. doi: 10.1017/S0266467401001213

Mack, A. L., & Wright, D. D. (1998). The vulturine parrot, *Psittrichas fulgidus*, a threatened New Guinea endemic: Notes on its biology and conservation. *Bird Conservation International, 8*(2), 185-194.

Marquiss, M., & Rae, R. (2002). Ecological differentiation in relation to bill size amongst sympatric, genetically undifferentiated crossbills *Loxia* spp. *Ibis, 144*(3), 494-508.

Mauck, W. M., III, & Burns, K. J. (2009). Phylogeny, biogeography, and recurrent evolution of divergent bill types in the nectar-stealing flowerpiercers (Thraupini: *Diglossa* and *Diglossopis*). *Biological Journal of the Linnean Society, 98*(1), 14-28.

McNab, B. K. (1988). Food habits and the basal rate of metabolism in birds. *Oecologia, 77*(3), 343-349. doi: 10.1007/BF00378040

McNab, B. K., & Salisbury, C. A. (1995). Energetics of New Zealand's temperate parrots. *New Zealand Journal of Zoology, 22*(3), 339-349. doi: 10.1080/03014223.1995.9518050

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

Moorhouse, R. J. (1996). The extraordinary bill dimorphism of the Huia (*Heteralocha acutirostris*): sexual selection or intersexual competition? *Notornis, 43*, 19-34.

Nixon, A. J. (1982). *Aspects of the ecology and morphology of Cyanoramphus parakeets and hybrids from Mangere Island, Chatham Islands.* (MSc), Victoria University of Wellington.

Nixon, A. J. (1994). Feeding ecology of hybridising parakeets on Mangere Island, Chatham Islands. *Notornis, 41*(4), 18.

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

Ortiz-Catedral, L., Kearvell, J. C., & Brunton, D. H. (2012). Population increase of critically endangered Malherbe's parakeet (*Cyanoramphus malherbi*) introduced to Maud Island, New Zealand. *Conservation Evidence, 9*, 54-57.

Podos, J., & Nowicki, S. (2004). Beaks, adaptation, and vocal evolution in Darwin's finches. *BioScience, 54*(6), 501-510.

Pulliam, H. R., & Enders, F. (1971). The feeding ecology of five sympatric finch species. *Ecology*, 557-566.

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

Schoener, Thomas W. (1965). The Evolution of Bill Size Differences Among Sympatric Congeneric Species of Birds. *Evolution, 19*(2), 189-213. doi: 10.2307/2406374

Slatyer, R. A., Hirst, M., & Sexton, J. P. (2013). Niche breadth predicts geographical range size: A general ecological pattern. *Ecology Letters, 16*(8), 1104-1114. doi: 10.1111/ele.12140

Smith, T. B. (1987). Bill size polymorphism and intraspecific niche utilization in an African finch. *Nature, 329*, 717-719.

Smith, T. B. (1990). Resource Use by Bill Morphs of An African Finch: Evidence for Intraspecific Competition. *Ecology, 71*(4), 1246-1257. doi: 10.2307/1938261

Soobramoney, S., & Perrin, M. R. (2007). The effect of bill structure on seed selection and handling ability of five species of granivorous birds. *Emu, 107*(3), 169-176. doi: 10.1071/MU05018

Sosa-Asanza, A. C. (2000). *Food choice, seasonal, movements, and population trends of parrots in the Ecuadorian Amazon.* University of Georgia, Athens, USA.

Tattersall, G. J., Andrade, D. V., & Abe, A. S. (2009). Heat exchange from the toucan bill reveals a controllable vascular thermal radiator. *Science, 325*(5939), 468-470. doi: 10.1126/science.1175553

Van der Meij, M. A. A., & Bout, R. G. (2006). Seed husking time and maximal bite force in finches. *Journal of Experimental Biology, 209*(17), 3329-3335.

Young, J. R., & Kearvell, J. C. (2001). Distinguishing between sexes and species: Bill size in Orange-fronted and Yellow-crowned Parakeets, *Cyanoramphus auriceps*. *Emu, 101*(2), 137-143. doi: 10.1071/MU00010

CHAPTER THREE: SEASONAL CHANGES IN THE DIET OF THE TASMAN PARAKEET

3.1 INTRODUCTION

Understanding the temporal and spatial variability in the diet of species threatened with extinction is an important component of their conservation management. Identifying key resources during the breeding season, for instance, can help managers devise interventions to boost productivity, thus increasing the size of target populations. For example, the New Zealand endemic kakapo (*Strigops habroptilus*) only reproduces during masting events of key food resources like rimu (*Dacrydium cupressinum*) (Powlesland & Lloyd, 1994). This observation has led to a supplementary feeding program since the mid 1990's that promotes successful reproduction and has almost doubled the population size of kakapo (Powlesland & Lloyd, 1994).

Intensive, science based management has resulted in an increase in the kakapo population to 86 individuals, of which 41 were female, as of 2006 (Clout, 2006; Ralph et al., 2006). Research played an important role in the construction of the supplementary feeding program as the initial diet was found to skew the sex ratio towards male chicks (Clout et al., 2002). Demographic models suggests that thanks to this management the population may reach 150 females within 31 years, at which point a much lower intensity of management will be required (Elliott, 2006).

For highly mobile threatened species, the mapping of feeding resources along migration paths can assist planning for creating key protected areas for re-fuelling (Ford, 2013). Also, this information can be used to prioritize areas for ecological restoration to ensure feeding resources are available across a wide area. The swift parrot (*Lathamus discolour*), which maximise areas of high *Eucalyptus* nectar availability in their annual migrations across Australia and Tasmania (Stojanovic et al., 2015), provides a good example of this landscape level approach to understanding spatial and temporal variability of feeding resources and the dietary requirements of threatened species.

Dietary resource availability affects productivity. Often abundance of key resources limits the number of breeding attempts made (For example; productivity of black-throated blue warblers (*Setophaga caerulescens*), is highly linked to caterpillar abundance (Rodenhouse & Holmes, 1992); and kakapo productivity linked to mast fruiting of the rimu (*D. cupressinum*) (Elliott et al., 2006; Whitehead et al., 2012)). Growth rates of lilac-crowned parrot (*Amazona finschi*) nestlings vary significantly with food availability, increasing in size and growth rate is years of abundant food production (Renton, 2002). Supplementary feeding is a common management strategy to counter food limitation, and has been effective in increasing the productivity of many species in different ways (as discussed in (Heath et al., 2008)). Currently most conservation interventions involving supplementary feeding occur by providing a artificial supplement (For example, provision of a complete honey eater food, as well as jam and sugar solutions to hihi (*Notiomystis cincta*) (Castro et al., 2003)), rather than increasing the abundance of limiting resources. For more integrated management, conservation of key habitats and resources is needed to boost productivity and effectively conserve at risk species (Renton, 2001).

Despite the clear link between information on the feeding requirements of species of interest and successful conservation interventions (Reuleaux et al., 2014), there is a dearth of studies describing even the most basic aspects of diet of some of the world's most endangered species. For instance, the order Psittaciformes (Parrots and Cockatoos), contains one of the largest proportions of species threatened with extinction (26% of 352 species; (Collar, 2000), see Chapter One). Nevertheless, studies on the diet of Psittaciformes are limited (see Chapter One). In general, parrots and cockatoos are renowned for the high diversity of their diets, exploiting various resources such as flowers (Galetti, 1993; Ragusa-Netto & Fecchio, 2006); leaves

(Kristosch & Marcondes-Machado, 2001); invertebrates (Kearvell et al., 2002); fruits (Pryor et al., 2001) and seeds (Boyes & Perrin, 2010; Higgins, 1979) (see also Chapter One). A few species are highly specialized in their diets, for instance Pesquet's parrots (*Psittrichas fulgidus*) in Papua-New Guinea and Indonesia, feed exclusively on soft fig (*Ficus* spp) fruits (Igag, 2002; Juniper & Parr, 1998). On mainland Australia, red-capped parrots (*Purpureicephalus spurius*) feed exclusively on seeds of various *Eucalyptus* species (Higgins, 1999). For many parrot species seeds constitute the predominant food type, for instance 70.4% of the diet of the scaly-headed parrot (*Pionus maximiliani*) (Galetti, 1993), and 81.8% of the diet of the lilac-crowned parrot (*Amazona finschi*) (Renton, 2001) consist of seeds.

The lack of detailed studies on the diet of threatened parrot species is due in part to the challenges associated with studying these birds. As Collar (2000) states "(parrots) represent everything that is anathema to the fast-track academic research study". Parrots can be cryptic in the field (Murphy et al., 2011), occur at low densities (Ortiz-Catedral et al., 2009) or spend a significant amount of time high in the forest canopy (e.g. Meyers Parrot (*Poicephalus meyeri*)(Boyes & Perrin, 2010), 70% of observations were in top canopy level) making observations from the ground in a field situation difficult.

In general parrots on islands are better studied, possibly due to a bias towards studying at risk species. One group that has many at risk species on islands is the genus *Cyanoramphus* (Miskelly et al., 2008). This highly diverse genus is spread across islands of varying sizes and climates across the pacific (see Fig. 2, Chapter One).

While the genus is spread around the pacific, it has a centre of diversity in New Zealand territories, with eight taxa across New Zealand, the Chatham Islands, the Antipodes Islands, and the Kermadec islands (see Fig. 2, Chapter One). Across these locations there is variation in morphology and diet between taxa (see Chapter Two). Since many of these species are well studied (e.g. red-fronted parakeets (*Cyanoramphus novaezelandiae*) (Dawe, 1979; Greene, 1988, 1998), See also

Chapter Two), the rarity and lack of information available for the endangered Tasman parakeet (*Cyanoramphus cookii*) makes it an ideal candidate for a dietary study.

3.1.1 Generalities Of The Diet of *Cyanoramphus* Parakeets

The diet of *Cyanoramphus* is relatively well known in contrast to other parrot genera (Dawe, 1979; Elliott et al., 1996; Greene, 1988, 1998, 1999; Nixon, 1982; Ortiz-Catedral & Brunton, 2009) thanks to their occurrence of large populations at some locations (i.e. Macauley Island (Greene et al., 2014)) which enable multiple observations in low vegetation; their habit of foraging on the ground (i.e. Antipodes Island parakeets (*Cyanoramphus unicolor*) (Greene, 1999)) and also the high proportion of threatened species, which has promoted field studies since the 1970's (Dawe, 1979; Greene, 1988; Harrison, 1970; Nixon, 1982). *Cyanoramphus* species have a generalist diet (Higgins, 1999) (see also Table 3, Chapter Two), but some species are known to exploit unique resources, for example, the Antipodes Island parakeet (*C. unicolor*) is the only parakeet in the world known to actively depredate, feeding on grey-backed storm petrels (*Oceanites nereis*) and their chicks (Greene, 1999). On mainland New Zealand the yellow-fronted parakeet (*Cyanoramphus auriceps*) utilises beech scales for their energy rich honeydew contents (Taylor, 1985). Additionally the yellow-fronted parakeet and red-fronted parakeet (*C. novazelandiae*) include insects as seasonally important components of their diet (Kearvell et al., 2002). Red-fronted parakeets (*C. novazelandiae*) on Macauley Island have been observed feeding on limpets when exposed by the tides (Taylor, 1985). Feeding height has been noted to change seasonally in *Cyanoramphus* species (Greene, 1998).

Among *Cyanoramphus* one of the least studied and most threatened species is the Tasman parakeet (*Cyanoramphus cookii*). Traditionally considered a subspecies of the widespread red-fronted parakeet (*Cyanoramphus novaezelandiae*), Tasman parakeets are now considered a separate species under the phylogenetic species concept (Boon et al., 2001) (see also Chapter One). Despite nearly 30 years of intense captive and *in situ* management (Hicks & Greenwood, 1989; Hill, 2002), the diet of the Tasman parakeet on Norfolk Island remains poorly known. Previous conservation efforts have successfully prevented the extinction of this species (Butchart et al., 2006). However, a new phase in Tasman parakeet conservation involves a translocation to Phillip Island. In the light of this, and given the extent of habitat modification from introduced species within the Norfolk Island National Park, it is important to obtain data on which resources the parakeets rely on in each season. Detailed information of the species diet in the wild is needed to increase the likelihood of a successful translocation.

Previous knowledge of the diet of the Tasman parakeet is limited, and very little of it has been published. Due to its previous status the Tasman parakeet is often incorporated in dietary publications as a subspecies of the red-fronted parakeet (*C. novazelandiae*), and information on the diet is treated as such (e.g. (Higgins, 1999)), though species are identifiable (see Table 1).

Table 1. Species consumed by the Tasman parakeet as per accounts published prior to this study. (N = native, I = introduced) (Forshaw & Cooper, 1981; Hibbard, 2004; Higgins, 1999).

Higgins, 1999	Part Consumed	Origin	Forshaw & Cooper, 1981	Part Consumed	Origin	Hibbard, 2004	Part Consumed	Origin
Baloghia inophylla	Seeds, Flowers	N	*Baloghia inophylla*	Flowers, Fruits	N	*Baloghia inophylla*	Flowers, Fruits	N
Lagunaria patersonia	Flowers	N	*Lagunaria patersonia*	Flowers	N	*Elaeodendron curtipendulum*	Flowers, Fruits	N
Araucaria heterophylla	Cones	N	*Araucaria heterophylla*	Seeds	N	*Lagunaria patersonia*	Flowers	N
Prunus persica	Fruits	I	*Lantana camara*	Berries	I	*Nestegis apetala*	Flowers	N
Solanum mauritianum	Fruits	I	*Psidium guajava*	Flowers, Fruits	I	*Rhopalostylis baueri*	Flowers	N
Psidium guajava	Fruits	I	*Psidium cattleianum*	Flowers, Fruits	I	*Cordyline obtecta*	Flowers	N
Psidium cattleianum	Fruits	I	*Solanum mauritianum*	Fruits	I	*Araucaria heterophylla*	Seeds	N
			Olea europea cuspidata	Seeds	I	*Lantana camara*	Unripe Berries	I
						Psidium guajava	Flowers, Fruits	I
						Psidium cattleianum	Flowers, Fruits	I
						Solanum mauritianum	Fruits	I
						Olea europea cuspidata	Seeds	I
						Prunus persica	Fruits	I

Notes taken during 1977, 1982 and 1983 by Norfolk Island resident Beryl Evans are from voluntary reporting by community members. They provide some record of numbers and location, but information on diet is limited. I identified the following species consumed:

Table 2. Dietary items from voluntary reporting during 1977, 1982, and 1983.

Species	Part	Percent Observations	Native/Introduced
Baloghia inophylla	Not Identified	6.0%	N
Lagunaria patersonia	Flowers	12.5%	N
Lantana camara	Berries	12.5%	I
Olea europaea cuspidata	Fruits	19.0%	I
Prunus persica	Fruits	6.0%	I
Psidium cattleianum	Fruits	44.0%	I

Together these sources of data suggest the Tasman parakeet feeds on a minimum of 13 species, of which 6 are introduced and 7 are natives. However, other *Cyanoramphus* parakeets show a greater diversity of diet (see Chapter Two) and there is a lack of understanding regarding temporal variation of the Tasman parakeets diet.

In this chapter, I present an analysis of the differences in food type consumption and diversity of food items of the Tasman parakeet in the Mount Pitt section of the Norfolk Island National Park. Specifically, my study sought to identify changes in the diversity and food types between seasons. This chapter represents the first multi-year study on the seasonal diet of the Tasman parakeet and provides detailed information about key seasonal resources and the different forest strata in which these are foraged on.

3.2 OBJECTIVES

The general objective of this chapter is to analyse the diversity of food species consumed by Tasman parakeets between seasons; the changes in food types ingested (i.e. seeds, flowers etc.); and the variability on foraging heights at which these resources are foraged by free-living Tasman parakeets. The specific objectives developed in this chapter are:

1. Determine the minimum number of plant species consumed by Tasman parakeets per season (Spring, Summer, Autumn, Winter).
2. Estimate the feeding niche breadth of Tasman parakeets and quantify differences in the seasonal diversity of food species and food types.
3. Determine seasonal variability in the size of foraging groups and foraging heights.

3.3 METHODS

3.3.1 Data Collection

For a detailed description of the study species and location refer to Chapter One. Observations were collected in all seasons. At the beginning of this study the Tasman parakeet had a very low population level (between 46-92 individuals (Ortiz-Catedral, 2014)). For this reason a methodology was chosen that would maximise the amount of data that could be collected from infrequent sightings (Reuleaux et al., 2014). Therefore the methodology used is less systematic, instead favouring intensive search effort. While this imposes some limitations on the conclusions I could draw (see section 3.6 Limitation and Improvements), this data presents a large advance in the state of knowledge of the foraging ecology of the Tasman parakeet.

Four to five days a week, from 7:00 to 12:00 hours and from 14:00 up to 18:00 hours, up to four observers walked along all accessible tracks and roads within the Mount Pitt section of the Norfolk Island National Park. These tracks and roads add up to 9 km, and range in width from 1 m to 3 m. This was done to maximise the area covered in a single day. Observations were not conducted during inclement weather. The two-hour break from midday corresponds to a period of lesser Tasman parakeet activity (L. Ortiz-Catedral, pers. comm., 2014) which is also common in other related parrot species (Legault et al., 2012).

Visibility on either side of the road during sampling periods varied, from about 5 m in dense guava patches, to approximately 20 m in niau palm (*Rhopalostylis baueri*) stands and up to 100 m from vantage points. Observations were made either by the naked eye (in cases where parakeets were located within a metre of observers, or for greater distances by binoculars or 300 mm and 400 mm fixed length Canon lenses. Observers recorded; time, location (GPS coordinates), flock size, foraging height of parakeets in the forest strata (estimated visually to the nearest 0.5 m, as has been used in other Pacific parrot species (Legault et al., 2012)), and the type and species of food consumed. Only items an observer could confirm as ingested were registered as dietary items. In cases where parakeets were observed billing but not ingesting leaves or fruits, these observations were excluded from the dietary analysis.

Approximately, each observer walked 18 km $^{\text{day}}$ over an 8-hour sampling period, walking at approximately 2-5 km $^{\text{hour}}$. Whenever a parakeet was detected, a feeding-bout was recorded. Bouts consisted of parakeets either feeding singly, or in groups on the same plant species, observation of a bout ended if the same item was fed on for 5 minutes A separate bout was recorded if the same bird, a member of the foraging group or the entire group moved to a different feeding plant. This sampling methodology falls under the general *Ad Libitum* sampling discussed by Altmann (1974). Observers used this methodology because it is particularly suitable for rare species such as the Tasman parakeet, which occur at low densities and often in complex environments. This methodology has been successfully used for other species of parrot feeding high in the forest canopy (Galetti, 1993; Renton, 2001). *Ad Lib.* sampling is less restrictive than “First-food eaten” (Taylor, 1975), where focal individuals are observed only until their first feeding record. While *Ad Lib*. Sampling increases the chances of pseudoreplication, it has yielded substantial information for other rare parakeets closely related to Tasman parakeets, such as Malherbe's parakeet, occurring at low densities on Maud Island, New Zealand (Ortiz-Catedral & Brunton, 2009). Specifically for the Tasman parakeet study, the advantage of *Ad Lib*. sampling is that allowed the rapid assessment of dietary diversity when a parakeet or group of parakeets are located, allowing us to gather a greater amount of information from this small population.

3.3.2 Statistical Analyses

For my analysis, I include observations on the diet of Tasman parakeets collected by colleagues and volunteers using the same methodology from June 2013 to November 2013.

Statistical analysis was conducted using only observations of dietary intake; observations of feeding on bark and grit were excluded from the analysis.

To determine seasonal variability in the diversity of feeding species consumed by Tasman parakeets I estimated Shannon Index of diversity for each season on a reduced data set comprising only seasonally important species (Shannon & Weaver, 1949). Important species are defined as species that contribute to more than 5% of feeding observations in a given season. This index was chosen because it takes into account not only the number of species registered per sampling event, but also their relative importance in the overall dataset. Also the Shannon index allows comparisons between heterogeneous datasets, accounting for variation in number of observations per season.

To compare the variability in seasonal food types and changes in size of foraging groups across the seasons I conducted Fishers exact test, using SAS© Version 9.4.

To determine variation in seasonal foraging height I estimated coefficients of variation across the seasons. I used the formula:

$$\hat{c}_v = \frac{s}{\bar{x}}$$

Where s = sample standard deviation and $\bar{x}$ = sample mean.

I also conducted an anova on seasonal change in foraging heights.

Statistical test were carried out using SAS© Version 9.4, and confidence level was set a-priori to a = 0.05. Any averages are presented as mean ± SE.

3.4 RESULTS

The Tasman parakeet was observed in a total of 512 bouts on 30 plant species (21 native, 9 introduced) (Table 3). Records were made during all seasons. These feeding bouts were obtained after over 2328 hours in the field. Of these observations, 29 represent non-dietary intake (bark n = 27, and grit n = 2) and no observations of Tasman parakeets feeding on insects have been made to date. Of dietary items, I registered a total of 483 feeding bouts on 25 plant species from 24 genera in 22 families. These 483 observations were used for all statistical analyses.

When weighted for sample size the five species most commonly consumed by the Tasman parakeet were: Norfolk pine (*Araucaria heterophylla*) (24.6%), African olive (*Olea europea cuspidata*) (22.7%), niau/Norfolk Island palm (*Rhopalostylis baueri*) (20.4%), cherry guava (*Psidium cattleianum*) (12%), and ake ake (*Dodonaea viscosa*) (8.9%). These five species comprise 88.6% of all feeding observations. Additionally Tasman parakeets were observed feeding on the following species, comprising between 1-5% of diet: *Nestegis apetala* (2.3%), *Myrsine ralstoniae* (1.8%), *Prunus persica* (1.4%), and *Melia azedarach* (1.3%) The remaining species; *Solanum mauritianum, Pennantia endlicheri, Baloghia inophylla, Korthalsella disticha, Pyrrosia confluens, Zanthoxylum pinnatum, Meryta angustifolia, Hakea salicifolia salicifolia,* *Hibiscus sp*, *Elaeodendron curtipendulum*, *Meryta latifolia*, *Oplismenus hirtellus*, *Capparis nobilis*, *Lagunaria patersonia patersonia*, *Macropiper excelsum psittacorum*, *and Melodinus baueri* comprised less than 1% of the diet of the Tasman parakeet (for raw observations see Table 1, Appendix 3).

Table 3. List of the 30 plant species consumed by the Tasman parakeet (*Cyanoramphus cookii*) in different seasons within the Norfolk Island National Park, including food type eaten. * Indicates introduced plant species.

Common Name	Family	Species	Season	Food types	Obs
Norfolk Pine	Araucariaceae	*Araucaria heterophylla*	Winter, Spring, Autumn	Dry Seed, Pollen, Bark	114
Bloodwood	Euphorbiaceae	*Baloghia inophylla*	Winter, Spring	Dry Fruit, Bark	4
Devils Guts	Capparaceae	*Capparis nobilis*	Spring	Dry Fruit, Bark	3
Rough Lemon	Rutaceae	*Citrus taitensis**	Spring	Bark	1
Norfolk tree fern	Cyatheaceae	*Cyathea brownii*	Spring	Bark	1
Ake ake	Sapindaceae	*Dodonaea viscosa*	Spring, Autumn	Dry Fruit, Dry Seed, Bark	79
Maple	Celastraceae	*Elaeodendron curtipendulum*	Autumn	Flowers	1
-	Proteaceae	*Hakea salicifolia salicifolia**	Spring	Dry Seed	2
Hibiscus	Malvaceae	*Hibiscus sp**	Spring	Bark, Flowers, Leaves	3
Mistletoe	Santalaceae	*Korthalsella disticha*	Autumn	Fleshy Fruit, Dry Seed	2
White Oak	Malvaceae	*Lagunaria patersonia patersonia*	Spring	Flowers	1
Pepper tree	Piperaceae	*Macropiper excelsum psittacorum*	Spring	Bark, Leaves	2
Lilac	Meliaceae	*Melia azedarach**	Winter, Autumn	Fleshy Fruit	6
Whiteywood	Violaceae	*Melicytus ramiflorus oblongifolius*	Spring	Bark	1
Big creeper	Apocynaceae	*Melodinus baueri*	Spring	Dry Fruit	1
-	Araliaceae	*Meryta angustifolia*	Winter	Fleshy Fruit	1

-	Araliaceae	*Meryta latifolia*	Autumn	Dry Seed	1
Pohutukawa	Myrtaceae	*Metrosideros sp**	Autumn	Bark	1
Beech	Primulaceae	*Myrsine ralstoniae*	Winter, Spring, Summer	Fleshy Fruit, Leaves, Bark	9
Ironwood	Oleaceae	*Nestegis apetala*	Winter, Spring	Dry Fruit, Fleshy Fruit, Leaves, Bark	21
African Olive	Oleaceae	*Olea europaea cuspidata**	Winter, Spring, Summer, Autumn	Dry Seed, Fleshy Fruit, Flowers	69
Basket grass	Poaceae	*Oplismenus hirtellus*	Autumn	Sprout	1
-	Pennantiaceae	*Pennantia endlicheri*	Autumn	Dry Seed, Bark	5
Oleander	Pittosporaceae	*Pittosporum bracteolatum*	Spring, Autumn	Bark	3
Peach	Rosaceae	*Prunus persica**	Spring	Fleshy Fruit, Dry Seed, Leaves	12
Red Guava	Myrtaceae	*Psidium cattleianum**	Summer, Autumn	Dry Seed, Fleshy Fruit	33
Robber Fern	Polypodiaceae	*Pyrrosia confluens*	Spring	Sori, Leaves, Rhyzome	3
Niau/Norfolk palm	Arecaceae	*Rhopalostylis baueri*	Winter, Spring, Summer, Autumn	Dry Seed, Fleshy Fruit, Flowers, Pedicel	123
Tobacco	Solonaceae	*Solanum mauritianum**	Spring, Autumn	Fleshy Fruit	4
Little Yellowwood	Rutaceae	*Zanthoxylum pinnatum*	Spring	Fleshy Fruit	3
Grit	-	-	Winter, Autumn	-	2
				Total	512

Figure 1. Tasman parakeets feeding on fleshy fruits (f) or dry seeds (s) of the following species (from to left to right, then bottom left to right): peach^{f} (*Prunus persica*), peach^{s}, shade tree^{f} (*Meryta angustifolia*), African olive^{f} (*Olea europea cuspidata*), Norfolk Island pine^{s} (*Araucaria heterophylla*) and lilac^{f} (*Melia azedarach*). Photos by L. Ortiz-Catedral©

3.4.1 Seasonal Variation in Dietary Diversity

Total dietary richness between seasons ranges from 18 species in spring to 4 in summer (Table 4). The Tasman parakeet also exhibits changes in diversity of important food species (i.e. those comprising over 5%of the seasons total) across the seasons. The highest index of diversity (Shannon-Weiner) of important species was registered in autumn and spring, both with 4 important species, while the lowest were registered in winter and summer, both with only 3 important species (Table 4). These differences are driven by the different proportions of important species consumed (Fig. 2) rather than by richness of significant species, which remained relatively constant across the year.

The relative importance of feeding species varied between seasons (see Fig. 2): the Norfolk pine (*A. heterophylla*) was the most important species in winter (65.3%), and autumn (28.3%). African olive (*O. e. cuspidata*) was a key species in summer

(54.7%), and important in autumn (22%). In spring niau (*R. baueri*) and ake ake (*D. viscosa*) were equally important (34.3% and 35.7% respectively). Niau also contributed significantly to autumn (25.2%).

Table 4. Shannon-Weiner indices of diversity for important food sources each season (species constituting more the 5% of seasonal observations).

Season	Winter	Spring	Summer	Autumn
Shannon Index	0.79	1.12	0.88	1.36
Richness - Important Species	3	4	3	4
Sample Size - Important Species	92	172	40	114
Total Dietary Richness	7	18	4	11
Total Sample Size (n)	101	213	42	127

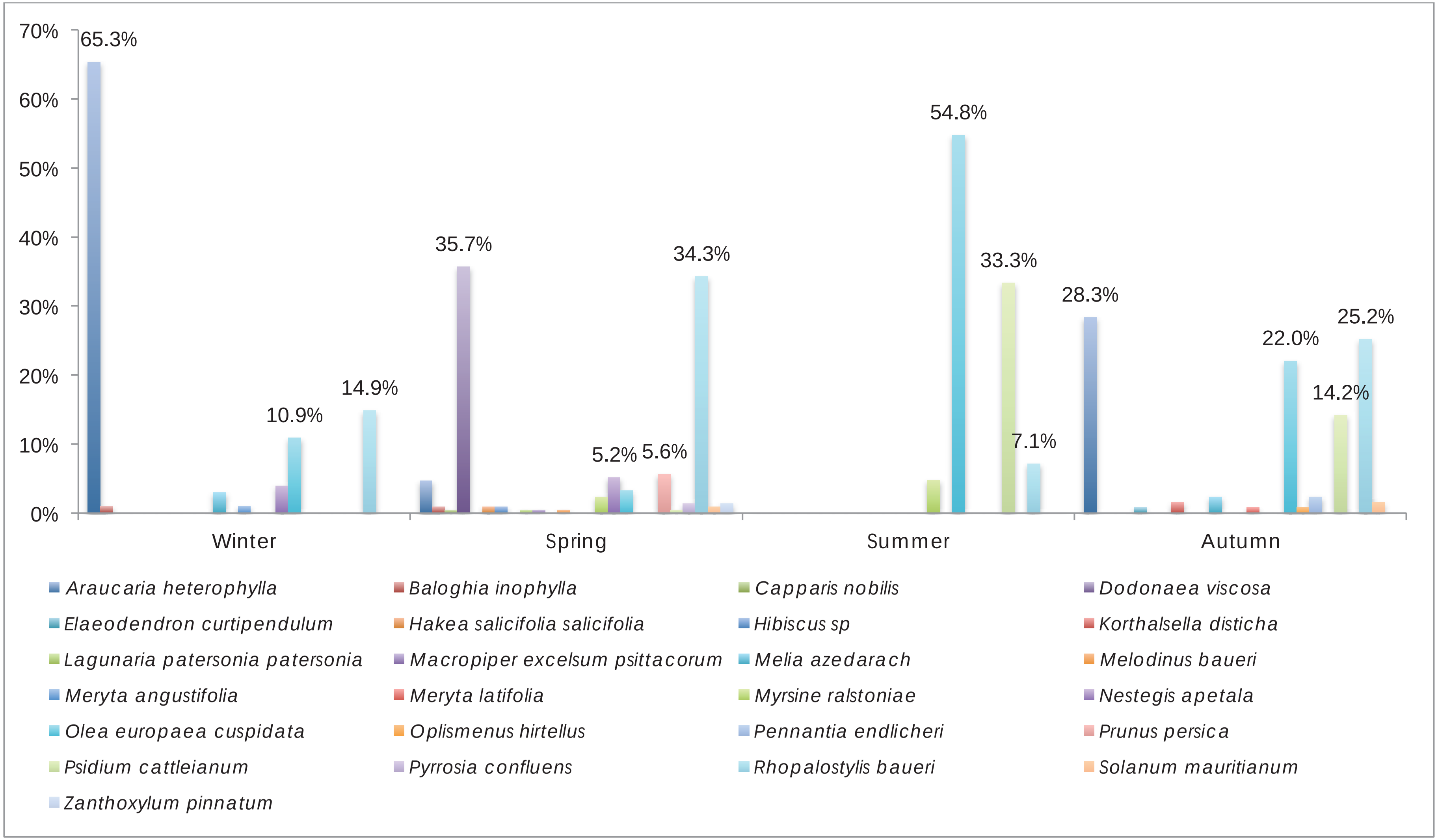

Figure 2. Food species as a percentage of diet per season. Showing percentages for seasonally important species (>5%), Sample size for each season (Winter = 101, Spring = 214, Summer = 42, Autumn = 127).

3.4.2 Seasonal Variation In Food Types

Tasman parakeets consume a variety of food types that includes dry seeds, dry and fleshy fruits, flowers, leaves, pedicels, sprouts, pollen and sori. In addition, they ingest two non-dietary items: bark and grit (Table 3). Weighting for the varying sample sizes per season (see Table 4) food types (n = 483) varied in their relative importance: dry seeds comprised 63.1% of overall diet, followed by fleshy fruits (30.9%), dry fruit (2.4%), and flowers (1.1%) with the remaining food types; pedicels, pollen, leaves, rhyzomes, sori and sprouts, which were contributed to diet only in one season, making up 2.5% (for raw data see Table 2, Appendix 3).

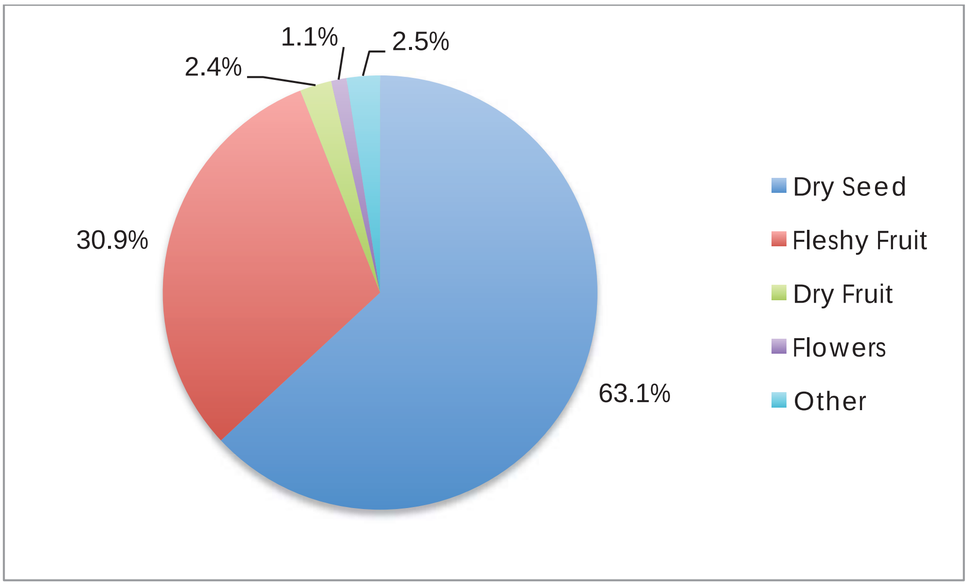

Figure 3. Percentage of food types from all observations weighted for seasonal sampling effort (Winter = 101, Spring = 214, Summer = 42, Autumn = 127) (Other represents combination of categories which were only consumed in one season (see also Table 1, Appendix 2)).

The relative proportions of food types varied significantly between seasons (Table 5). Seeds were more frequently consumed in autumn than in other seasons (autumn: 35.64%, n = 289, $\chi^2 = 51.36$, $p < 0.0001$). Fleshy and dry fruits were more frequently consumed in spring than in other seasons (Fleshy fruit: 54.55% n = 154; $\chi^2 = 76.96$, p = <0.0001), Dry fruit: 94.74% n = 19; $\chi^2 = 49.42$, p = <0.0001. Other food types were most frequently consumed in spring (spring: 68.75%, n = 16, $\chi^2 = 18.5$, p = 0.0003). Proportions of flowers consumed did not differ significantly between seasons (n = 5, $\chi^2 = 3.8$, p = 0.28).

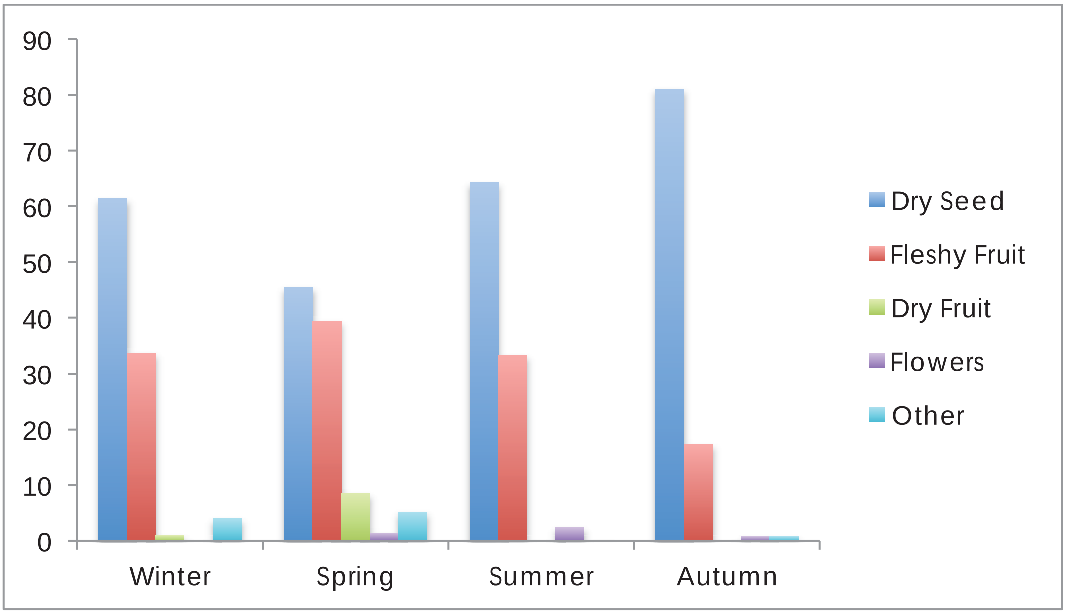

Figure 4. Food types as a percentage of seasonal diet, sample sizes (Winter = 101, Spring = 214, Summer = 42, Autumn = 127). Other represents combination of food types that were only consumed in one season (for raw data see Table 2, Appendix 3).

3.4.3 Foraging Height

Tasman parakeets showed significant differences in mean foraging height across the seasons (anova: F-value = 16.65, n = 483, p = < 0.0001, see also Fig. 5); specifically they forage at lower heights during winter than in any other season (winter 2.55 ± 0.25 m, p = <0.005). Foraging height in autumn was significantly higher than in winter and summer (6.94 ± 0.61, p = <0.0001). Winter had the greatest variation in foraging height, followed by autumn. Conversely, summer and spring showed low variability as measured by their coefficients of variation (Table 6). In winter the most common observation was ground feeding with 55.4% (n=56) of observations (i.e. mode = 0 m, Table 6) resulting in high variability from a skewed distribution with many low height values (min and median = 0 m) and fewer larger values (max = 20) (Table

6). No other season showed such a marked bias toward ground feeding. The total number of observations of ground feeding was 87, representing 18% of all feeding observations. Of the 56 ground feeding events recorded in winter, the greatest proportion of these was of *A. heterophylla* seeds (89.2%, n = 50).

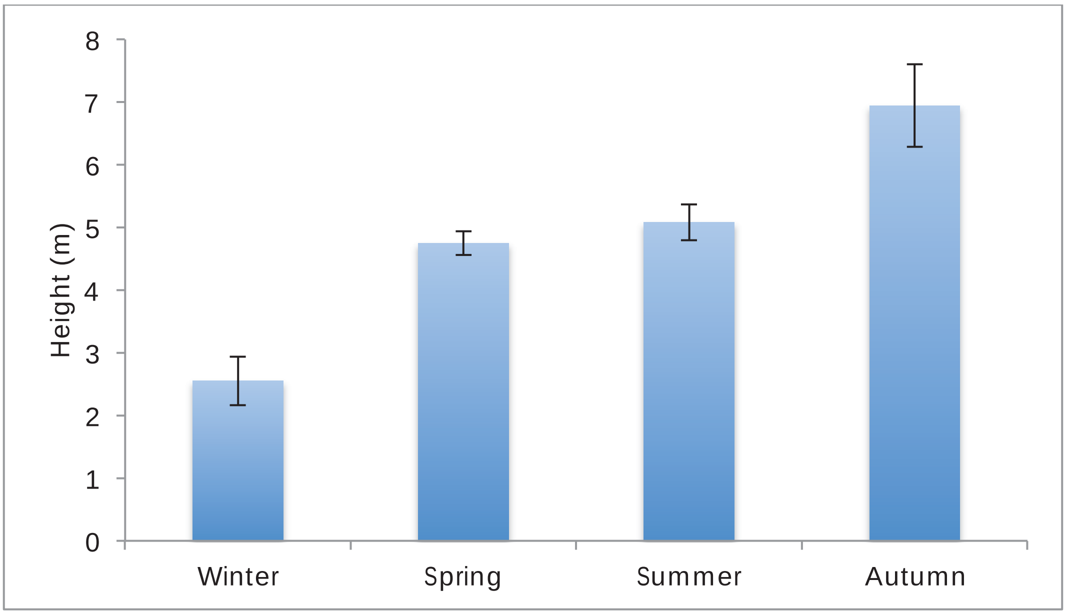

Figure 5. Average foraging heights (m) per season, sample sizes (Winter = 101, Spring = 214, Summer = 42, Autumn = 127).

Table 5. Breakdown of foraging height (m) for each season

Season	Winter	Spring	Summer	Autumn
Average	2.55	4.75	5.08	6.94
Sample Size	101	213	42	127
Standard Error	0.25	0.32	0.78	0.61
Coefficient Of Variation	156%	59%	37%	108%
Mode	0	6	6	4
Min	0	0	2	0
Median	0	4.5	5	5
Max	20	20	9	35

3.4.4 Foraging Group Size

I found significant inter-seasonal differences in flock size (F-value = 9.62, n = 483, p = < 0.0001). Flock size in autumn was significantly larger than in other seasons (mean flock size: autumn 1.7 ± 0.08 individuals, p = <0.001), other seasons did not differ significantly. The smallest mean flock size was registered in summer (mean flock size: summer 1.2 ± 0.064 individuals). No larger flock sizes were observed in winter (mean flock size: winter 1.27 ± 0.052 individuals) or summer, while larger groups were observed in both autumn and spring (mean flock size: spring 1.36 ± 0.043) (Fig. 6). The largest group size registered was a group of 9 in autumn. A group of 8 was also registered in spring.

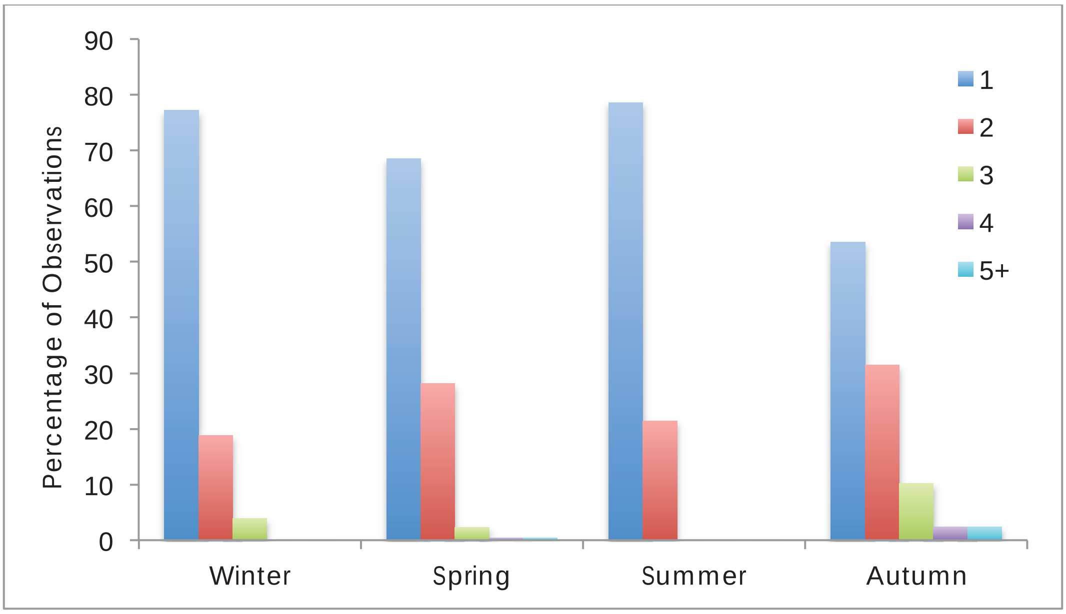

Figure 6. Percentage of observations for each group size per season (observations of groups of 5 and above are combined), sample sizes (Winter = 101, Spring = 214, Summer = 42, Autumn = 127).

3.5 DISCUSSION

I found seasonal variation in the diet of the Tasman parakeet, both in richness and diversity of species from which both food items consumed and the proportions of different food types. I also found significant variation in feeding height and group size between the seasons.

This study has added to the dietary knowledge of the Tasman parakeet. Where previously food items from 13 species were known, there are now 25 species with food items confirmed as dietary intake, and another five species have been observed with the Tasman parakeet feeding only on the bark (see Table 3).

3.5.1 Seasonal Variation In Food Species

The Tasman parakeet shows contraction and expansion of its feeding niche, and incorporates dietary switching (switching between important food species (Renton, 2001)) across the seasons.

There is low richness in the number of important food species consumed (Table 4). Despite this, richness in the total number of food species varies between seasons, minor dietary components contributed to the greater total dietary richness in spring and autumn (total richness = 18 and 11 species respectively), than for winter and summer (total richness = 7 and 4 species respectively). This difference between richness and diversity of important species might suggest the Tasman parakeet is more specialised in diet than the red-fronted parakeet (*C. novaezelandiae*). In the Little Barrier Island population red-fronted parakeets fed on 17 important species, with a richness of 57 different food species (Greene, 1998), indicating a much broader diet. The yellow-fronted parakeet (*C. auriceps*) on Little Barrier Island displayed less total richness (17 species) of diet, but greater richness of important species (14) (Greene, 1998) than the Tasman parakeet. Opportunistic observations on the much smaller (see Chapter Two) orange-fronted parakeet (*C. malherbi*) show they consumes at least 14 plant species (Ortiz-Catedral & Brunton, 2009). In contrast orange-fronted parakeets in *Nothofagus* forest had diets with a richness of three important species; red beech (*N. fusca*), silver beech (*N. menzeisii*) and black beech (*N. solandri*) (Kearvell et al., 2002), whilst the sympatric yellow-fronted parakeet additionally having mountain toatoa (*Phyllocladus alpinus*) as an important species.

The native niau palm (*R. baueri*) is an important component of the Tasman parakeets diet in all seasons. In contrast there are no published accounts of *Cyanoramphus* parakeets feeding on items from this species or genus (see Chapter Two). Anecdotal observation has been made of the Kermadec red-fronted parakeet (*Cyanoramphus novaezelandiae cyanurus*) feeding on niau palms on Raoul Island in March 2008 (L. Ortiz-Catedral, pers. comm., 2016). This species is available on Norfolk Island in all seasons (Pers. Obs.) as sprays in different stages of ripeness are constantly available and able to be utilised by the Tasman parakeet.

The Norfolk pine (*A. heterophylla*) is a critical component of Tasman parakeet diet in winter, and an important component in autumn (Fig. 2). The majority of this species occurs within the existing Tasman parakeet habitat within the NINP (Director of National Parks, 2010). Historically there has been some concern about dieback of this critical resource (Benson, 1980).

Ake ake (*Dodonaea viscosa*) is utilised in correlation with its availability. The species produces ‘bracts’ (flower like capsules containing seed) during spring, the seeds from these made up 35.7% of the spring diet observations (Fig. 2). This shows a strong resource use shift in accordance with seasonal availability.

The weed African olive (Olea europea cuspidata) provides another significant food resource for parakeets in 3 seasons (summer, autumn, and winter). Olive fruits prolifically, with initial estimates suggesting a seed bank in the order of millions (Mills, 2015), and the species is found in a significant proportion of the Tasman parakeets current range within the NINP (Director of National Parks, 2010).

Cherry guava (*Psidium cattleianum*) made up a third of observation in summer, and was also an important resource in autumn. This species is an abundant weed within the NINP, and is the subject of a control program as it forms monocultures preventing the regeneration of native vegetation (Director of National Parks, 2010).

Together these five species constitute over 85% of the Tasman parakeets diet. Two of these important species are introduced weeds, with active control programs.

3.5.2 Non-Dietary Observation

The majority of non-dietary observations were parakeets chewing bark from 14 different species (n = 27). The Tasman parakeet has previously been observed using macerated bark and leaves of *Olea europea cuspidata* to rub into plumage, possibly for it’s anti-parasitic properties (Forshaw & Cooper, 1981). Other *Cyanoramphus* parakeets have also been observed rubbing macerated manuka (*Leptospermum scoparium*) and kanuka (*Kunzia ericoides*) bark into their plumage for its anti-parasitic properties (Greene, 1989).

The Tasman parakeet has also been observed chewing but not ingesting leaves in between bites of the fruit of *Prunus persica* (L. Ortiz-Catedral, pers. comm.). Similar behaviours have also been observed in other species. For example, the scaly-headed parrot (*Pionus maximiliani*) largely ignored foliage, though some field observers noted they appeared to take leaves in between bites of fruit which they may not have ingested (Galetti, 1993).

Girt ingestion has been recorded in other parrot species (Gilardi et al., 1999), including the orange fronted parakeet (*Cyanoramphus malherbi*) (Ortiz-Catedral & Brunton, 2009).

3.5.3 Seasonal Variation In Food Types

The significant changes in food type utilisation in each season of the Tasman parakeet are common among other generalist parrot species. For example, the scaly-headed parrot (*Pionus maximiliani*) consumes a larger percentage of seeds in the wet season (83% of bouts), and a larger percentage of fruits in the dry season (ca. 39% of bouts) (Galetti, 1993). The New Zealand parrot the North Island kaka (*Nestor meridionalis septentrionalis*) shows considerable seasonal variation in the diet, with seed being the most commonly observed food type and almost complete reliance on hinau (*Elaeocarpus dentatus*) seed in late summer/autumn (March), and tawa (*Beilschmiedia tawa*) seed during summer (January) (Moorhouse, 1997). The red-fronted parakeet also shows shifts in important food types across seasons (Dawe, 1979).

The Tasman parakeet relies mainly on dry seeds, but the relative importance changes across the seasons. Fleshy and dry fruits made up a significant proportion of spring diet compared with other seasons. Dry seeds were more frequently consumed in autumn than in any other season (Fig. 4).

Pine seeds are of most importance in winter, with 61.4% (n = 62) of the seasons diet, and are additionally important in autumn (28%, n = 36). In spring parakeets feeding on ake ake (*D. viscosa*) seeds make up 45.8% of the seasons diet. Niau (*R. baueri*) represents a significant proportion of the diet in both spring (34.3%, n = 73) and autumn (25.2%, n = 32) but the food type differs with fleshy fruit being of more importance in spring (n = 60) and summer (n = 15), and dry seed being of greatest importance in autumn (n = 30).

3.5.4 Seasonal Variation In Foraging Height

I found Tasman parakeets spend a large proportion of time spent foraging on the ground, especially during winter. This represents a considerable risk to the Tasman parakeet, as Norfolk Island is not free of predators, feral cats and rats are present within the park. The large amount of time spent foraging on the ground presents as risk as the birds are sedentary whilst they manipulate pine seeds, which can take up to ten minutes (L. Ortiz-Catedral, pers. comm., 2015). Foraging height may be impacted by season due to changes in food species. For example, feeding on

Norfolk pine seed mostly occurs at ground level in winter, as the seeds have fallen to the ground. Where as food from species like guava and niau are often obtained while still attached to the tree, and so have a higher average height.

The coefficients of variation (Table 6) show that there is more variability in winter and autumn than spring and summer. The large variation in autumn is due, in part, to outlying observations of Tasman parakeets feeding on Norfolk pine seeds of high in the canopy.

3.5.5 Foraging Group Size

I found significant inter-seasonal differences in foraging group size, which contrasts with other *Cyanoramphus* species. The absence of larger groups as has been reported in other *Cyanoramphus* species. For example, flock size of another island dwelling *Cyanoramphus* parakeet, the New Caledonian parakeet (*C. saisseti*) is consistent throughout the year (Legault et al., 2012). Though the Tasman parakeet showed variation in the proportions of foraging group size across the season they are still most likely to occur either singly or in pairs, like the New Caledonian parakeet (solo ≈ 50% obs, pairs ≈ 40% obs, n = 417) (Legault et al., 2012). Flocking behaviour is also not reported in either the Antipodes Island parakeet or Reischek's parakeet (Forshaw & Cooper, 1989).

This pattern likely reflects the low population level of the Tasman parakeet. In contrast, larger groups and flocking has been reported in the red-fronted parakeet on islands where larger populations are present (Greene, 1988). Flocking behaviour has been reported in other *Cyanoramphus* parakeets when population levels were higher in the past, for example, the orange-fronted parakeet has previously found in both single and mixed species flocks (with red-fronted or yellow-fronted parakeets) (Harrison, 1970; Taylor, 1998). Anecdotal accounts speak of Tasman parakeets flocking and destroying crops such that they were considered pests, and were shot or trapped in order to protect crops (Hicks & Greenwood, 1989; Hill, 2002).

3.6 LIMITATIONS AND IMPROVEMENTS

Due to the nature of field research sampling effort is not the same for each season. There were several factors that influenced the number of observations made each season; number and length of trips, amount of time spent on foraging observations. Further the number of individuals in the population fluctuates in a yearly cycle (L. Ortiz-Caterdral, pers. comm.) and overall increased over the duration of the study as an effect of ongoing management. Additionally there may be some effect of changes in detectability per season. For example, larger groups were observed in autumn, which may have been easier to detect. However, there is no data available on fluctuations in detectability for the Tasman parakeet, and it is likely changes reflect seasonal population trends, i.e. population decrease over winter (see Chapter Four). Therefore, it is not expected that proportions of food types eaten will be significantly affected by these factors, rather that relative importance of food types and species consumed that would influence and changes in these proportions (Dawe, 1979).

Ideally dietary surveys would be carried out using a method that controls search effort, for example, transects (Reuleaux et al., 2014). However since this work was limited by the requirement to keep to the accessible areas of the NINP (see methods section) and the small population size of the Tasman parakeet, this method was not employed. Instead collection of incidental observations allowed us to better asses the diet of the Tasman parakeet as it was likely to provide a greater number of observations and more information on rare dietary items (Reuleaux et al., 2014). In the future, when the population of the Tasman parakeet is larger this work could be improved upon by using a more systematic approach to better represent the diet of the Tasman parakeet.

Other improvements to this body of work would include the introduction of habitat type data into the analysis. For example, some *Cyanoramphus* parakeets show preferences for forest interior (such as yellow-fronted parakeets on Little Barrier

Island/Hauturu (Greene, 1988)) and edge habitats, while others venture into open areas (red-fronted parakeets (Greene, 1999)). Additional information on which types of habitat are important to the Tasman parakeet can also inform restoration of the forest within NINP, the wider Norfolk Island and also Phillip Island. Quantification of variation in food availability and abundance of the most important seasonal food species would also be beneficial, as additional data would allow managers to predict gaps and short falls in plant food production. Additionally measures of time budgets of the Tasman parakeet could elucidate how much food pressure the species is under to meet its caloric requirements.

3.7 CONCLUSION

The richness of the Tasman parakeets diet is greater than previously realised (30 species (Table 3) compared to 15 previously known). They show significant seasonal change in dietary diversity (Table 4), and a significant difference in the relative abundance of food types consumed between seasons (Fig. 4). Additionally I found differences in the variability of foraging heights (Table 6) and foraging group sizes (Figs. 6 and 7) across the seasons.

3.7 REFERENCES

Altmann, J. (1974). Observational study of behavior: sampling methods. *BEHAVIOUR, 49*(3-4), 227-267.

Benson, M. L. (1980). Dieback of Norfolk Island pine in its natural environment. *Australian Forestry, 43*(4), 245-252. doi: 10.1080/00049158.1980.10674278

Boon, W. M., Daugherty, C. H., & Chambers, G. K. (2001). The Norfolk Island Green Parrot and New Caledonian Red-crowned Parakeet are distinct species. *Emu, 101*(2), 113-121.

Boyes, R. S., & Perrin, M. R. (2010). Aerial surveillance by a generalist seed predator: Food resource tracking by Meyer's parrot *Poicephalus meyeri* in the

Okavango Delta, Botswana. *Journal of Tropical Ecology, 26*(4), 381-392. doi: 10.1017/S0266467410000210

Butchart, S. H. M., Stattersfield, A. J., & Collar, N. J. (2006). How many bird extinctions have we prevented? *ORYX, 40*(3), 266-278. doi: 10.1017/S0030605306000950

Castro, I., Brunton, D. H., Mason, K. M., Ebert, B., & Griffiths, R. (2003). Life history traits and food supplementation affect productivity in a translocated population of the endangered Hihi (Stitchbird, *Notiomystis cincta*). *Biological Conservation, 114*(2), 271-280. doi: 10.1016/S0006-3207(03)00046-6

Clout, M. N. (2006). A Celebration of kakapo: progress in the conservation of an enigmatic parrot. *Notornis, 53*(1).

Clout, M. N., Elliott, G. P., & Robertson, B. C. (2002). Effects of supplementary feeding on the offspring sex ratio of kakapo: A dilemma for the conservation of a polygynous parrot. *Biological Conservation, 107*(1), 13-18. doi: 10.1016/S0006-3207(01)00267-1

Collar, N. J. (2000). Globally threatened parrots: criteria, characteristics and cures. *International Zoo Yearbook, 37*(1), 21-35. doi: 10.1111/j.1748-1090.2000.tb00704.x

Dawe, M. R. (1979). Behaviour and ecology of the red-crowned parakeet (*Cyanoramphus novaezelandiae*) in relation to management. *Unpublished M. Sc. thesis, University of Auckland, Auckland, New Zealand*.

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

Elliott, G. P. (2006). A simulation of the future of kakapo. *Notornis, 53*(1).

Elliott, G. P., Dilks, P. J., & O'Donnell, C. F. J. (1996). The ecology of yellow-crowned parakeets (*Cyanoramphus auriceps*) in *Nothofagus* forest in Fiordland, New Zealand. *New Zealand Journal of Zoology, 23*(3), 249-265.

Elliott, G. P., Eason, D. K., Jansen, P. W., Merton, D. V., Harper, G. A., & Moorhouse, R. J. (2006). Productivity of kakapo (*Strigops habroptilus*) on offshore island refuges. *Notornis, 53*(1), 138-142.

Ford, H. A. (2013). Are we underestimating the threat to Australia's migratory land birds? *Pacific Conservation Biology, 19*(4), 303-311.

Forshaw, J. M., & Cooper, W. T. (1981). *Australian parrots* (2nd ed.). Melbourne: Lansdowne Editions.

Forshaw, J. M., & Cooper, W. T. (1989). Parrots of the World. *Willoughby, Landsdowe, Australia*.

Galetti, M. (1993). Diet of the scaly-headed parrot (*Pionus maximiliani*) in a semideciduous forest in southeastern Brazil. *BIOTROPICA, 25*(4), 419-425.

Gilardi, J. D., Duffey, S. S., Munn, C. A., & Tell, L. A. (1999). Biochemical functions of geophagy in parrots: Detoxification of dietary toxins and cytoprotective effects. *Journal of Chemical Ecology, 25*(4), 897-922.

Greene, T. C. (1988). *Behavioural Ecology of the Red-crowned Parakeet (Cyanoramphus Novaezelandiae Sparrman, 1787) and the Yellow-crowned Parakeet (Cyanoramphus Auriceps Kuhl, 1820) on Little Barrier Island.* (Unpublished Msc thesis), University of Auckland.

Greene, T. C. (1989). Antiparasitic behaviour in New Zealand parakeets (*Cyanoramphus* species). *Notornis, 36*(4).

Greene, T. C. (1998). Foraging ecology of the red-crowned parakeet (*Cyanoramphus novaezelandiae novaezelandiae*) and yellow-crowned parakeet (*C. auriceps auriceps*) on Little Barrier Island, Hauraki Gulf, New Zealand. *New Zealand Journal of Ecology, 22*(2), 161-171.

Greene, T. C. (1999). Aspects of the ecology of Antipodes Island Parakeet (*Cyanoramphus unicolor*) and Reischek's Parakeet (*C. novaezelandiae hochstetteri*) on Antipodes Island, October - November 1995. *Notornis, 46*(2), 301-310.

Greene, T. C., Westbrooke, I. M., Brown, D., Dilks, P. J., Barkla, J. W., & Griffiths, R. (2014). Assessing minimum population size of Kermadec parakeets (*Cyanoramphus novaezelandiae cyanurus*) on Macauley Island, Kermadec Islands. *Notornis, 61*(3), 154-161.

Harrison, M. (1970). The Orange-fronted Parakeet *Cyanoramphus malherbi*. *Notornis, 17*(2).

Heath, S. R., Kershner, E. L., Cooper, D. M., Lynn, S., Turner, J. M., Warnock, N., Farabaugh, S., Brock, K., & Garcelon, D. K. (2008). Rodent control and food supplementation increase productivity of endangered San Clemente Loggerhead Shrikes (*Lanius ludovicianus mearnsi*). *Biological Conservation, 141*(10), 2506-2515. doi: 10.1016/j.biocon.2008.07.011

Hibbard, C. (2004): Zoological Parks Board of New South Wales.

Hicks, J., & Greenwood, D. (1989). Rescuing Norfolk Island's parrot. *Birds international, 1*(4), 34-47.

Higgins, M. L. (1979). Intensity of seed predation on *Brosimum utile* by Mealy Parrots (*Amazona farinos*). *BIOTROPICA, 11*(1), 80. doi: 10.2307/2388177

Higgins, P.J. (Ed.). (1999). *Handbook of Australian, New Zealand and Antarctic Birds.* (Vol. Volume 4: Parrots to Dollarbird.). Melbourne: Oxford University Press.

Hill, R. (2002). Recovery plan for the Norfolk Island Green Parrot (*Cyanoramphus novaezelandiae cookii*): Natural Resource Management, Environment Australia.

Igag, P. (2002). *The conservation of large rainforest parrots: A study of the breeding biology of palm cockatoos, eclectus parrots and vulturine parrots.* The Australian National University.

Juniper, T., & Parr, M. (1998). A Guide to the Parrots of the World. *A&C Black. Londres-Inglaterra*, 45-322.

Kearvell, J. C., Young, J. R., & Grant, A. D. (2002). Comparative ecology of sympatric orange-fronted parakeets (*Cyanoramphus malherbi*) and yellow-crowned parakeets (*C. auriceps*), South Island, New Zealand. *New Zealand Journal of Ecology, 26*(2), 139-148.

Kristosch, G. C., & Marcondes-Machado, L. O. (2001). Diet and feeding behavior of the Reddish-bellied Parakeet (*Pyrrhura frontalis*) in an *Araucaria* forest in southeastern Brazil. *Ornitologia Neotropical, 12*, 215-223.

Legault, A., Theuerkauf, J., Rouys, S., Chartendrault, V., & Barré, N. (2012). Temporal variation in flock size and habitat use of parrots in New Caledonia. *Condor, 114*(3), 552-563. doi: 10.1525/cond.2012.110154

Mills, K. (2015). Food plants for the green parrot on Phillip Island - Preliminary notes.: Parks Australia, Norfolk Island.

Miskelly, C. M., Dowding, J. E., Elliott, G. P., Hitchmough, R. A., Powlesland, R. G., Robertson, H. A., Sagar, P. M., Scofield, R. P., & Taylor, G. A. (2008). Conservation status of New Zealand birds, 2008. *Notornis, 55*(3), 117-135.

Moorhouse, R. J. (1997). The diet of the North Island kaka (*Nestor meridionalis septentrionalis*) on Kapiti Island. *New Zealand Journal of Ecology, 21*(2), 141-152.

Murphy, S. A., Joseph, L., Burbidge, A. H., & Austin, J. (2011). A cryptic and critically endangered species revealed by mitochondrial DNA analyses: The Western Ground Parrot. *Conservation Genetics, 12*(2), 595-600. doi: 10.1007/s10592-010-0161-1

Nixon, A. J. (1982). *Aspects of the ecology and morphology of Cyanoramphus parakeets and hybrids from Mangere Island, Chatham Islands.* (MSc), Victoria University of Wellington.

Ortiz-Catedral, L. (2014). Hope is the thing with green feathers. *PsittaScene, Spring, 2014,* 12-18.

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

Ortiz-Catedral, L., Kearvell, J. C., Hauber, M. E., & Brunton, D. H. (2009). Breeding biology of the critically endangered Malherbes parakeet on Maud Island, New Zealand, following the release of captive-bred individuals. *Australian Journal of Zoology, 57*(6), 433-439.

Powlesland, R. G., & Lloyd, B. D. (1994). Use of supplementary feeding to induce breeding in free-living kakapo *Strigops habroptilus* in New Zealand. *Biological Conservation, 69*(1), 97-106.

Pryor, G. S., Levey, D. J., & Dierenfeld, E. S. (2001). Protein requirements of a specialized frugivore, Pesquet's Parrot (*Psittrichas fulgidus*). *Auk, 118*(4), 1080-1088.

Ragusa-Netto, J., & Fecchio, A. (2006). Plant food resources and the diet of a parrot community in a gallery forest of the Southern Pantanal (Brazil). *Brazilian Journal of Biology, 66*(4), 1021-1032.

Ralph, G. Powlesland, Don, V. Merton, & John, F. Cockrem. (2006). A parrot apart: the natural history of the kakapo (*Strigops habroptilus*), and the context of its conservation management. *Notornis, 53*(1).

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

Renton, K. (2002). Influence of environmental variability on the growth of Lilac-crowned parrot nestlings. *Ibis, 144*(2), 331-339. doi: 10.1046/j.1474-919X.2002.00015.x

Reuleaux, A., Richards, H., Payet, T., Villard, P., Waltert, M., & Bunbury, N. (2014). Insights into the feeding ecology of the Seychelles Black Parrot *Coracopsis barklyi* using two monitoring approaches. *Ostrich*.

Rodenhouse, N. L., & Holmes, R. T. (1992). Results of experimental and natural food reductions for breeding black-throated blue warblers. *Ecology, 73*(1), 357-372.

Shannon, C. E., & Weaver, W. (1949). *The mathematical theory of communication*: Urbana, University of Illinois Press, 1949.

Stojanovic, D., Terauds, A., Westgate, M. J., Webb, M. H., Roshier, D. A., & Heinsohn, R. (2015). Exploiting the richest patch has a fitness pay-off for the migratory swift parrot. *Journal of Animal Ecology*. doi: 10.1111/1365-2656.12375

Taylor, R. H. (1975). Some ideas on speciation in New Zealand parakeets. *Notornis, 22*(11), 0-121.

Taylor, R. H. (1985). Status, habits and conservation of *Cyanoramphus* parakeets in the New Zealand region *In 'Conservation of Island Birds'* (pp. 195-211): (Ed. P.J. Moors).

Taylor, R. H. (1998). A reappraisal of the Orange-fronted Parakeet (*Cyanoramphus* sp.) species or colour morph? *Notornis, 45*, 49-63.

Whitehead, J., Case, B., Wilson, K. J., & Molles, L. (2012). Breeding variation in female kakapo (*Strigops habroptilus*) on Codfish Island in a year of low food supply. *New Zealand Journal of Ecology, 36*(1), 64-74.

CHAPTER FOUR: SPATIO-TEMPORAL VARIATION IN FORAGING AREAS OF THE TASMAN PARAKEET: A PILOT STUDY

4.1 INTRODUCTION

Parrots make use of resources on a seasonal basis in different eco-regions (Renton, 2001) and often rely on temporally variable resources such as fruits, seeds, flowers (Renton, 2001). This variation can create preferred areas of seasonal foraging, in response to the patchy nature of food resources and their inter-seasonal abundance. Understanding resource variability and the spatial responses of species of conservation concern is crucial for effective management. Species such as Meyers parrot (*Poicephalus meyeri*) (Boyes & Perrin, 2010) and the lilac crowned parrot (*Amazona finschi*)(Renton, 2001) track resources between seasons. Similarly, the Swift parrot (*Lathamus discolour*) undergoes large migrations tracking productive *Eucalyptus* patches (Stojanovic et al., 2015).

While this study focused on the dietary ecology of the Tasman parakeet within NINP, several sightings of Tasman parakeets were made outside the park, for example, at our accommodation along Selwyn Pine Road. Other residents also shared sightings they had made of Tasman parakeets visiting or feeding in their own gardens. While introduced predator control of rats and cats is ongoing within the park (Director of National Parks, 2010). Tasman parakeets, like all wild species, do not understand boarders, and therefore may be at risk of depredation when they leave the park. Because of this I wanted to investigate if the area over which the Tasman parakeet forages changes seasonally, and if it would be worth conducting further studies to ensure predator control operations and the areas Tasman parakeets occupy align.

Managing species of conservation concern in the presence of introduced predators requires control operations. Traditionally predator control operations have focussed on removing predators totally (for example the restoration of Tiritiri Matangi Island (Galbraith & Cooper, 2013)), or limiting their abundance. For example, in areas with predator control kaka (*Nestor meridionalis*) populations benefit from increased female survival and decreased predation rates (Moorhouse et al., 2003). More recently predator control is being conducted in conjunction with time periods that present high risk, such as breeding season and masting events. For example, predator control operations benefit kokako (*Callaeas wilsoni*) when made in late spring before the breeding season, over subsequent years, to take advantage of delays in mammalian predator population recovery (Innes & Barker, 1999). In New Zealand, mast fruiting of beech (*Nothofagus* spp.), and the subsequent increase in mouse (*Mus musculus*) abundance can be used to reliably predict an increase abundance of higher order predators such as stoats (*Mustela erminea*) (O'Donnell & Phillipson, 1996). This has lead to control operations targeting mast years (O'Donnell & Hoare, 2012).

The Tasman parakeet occurs within a small area of Norfolk Island, representing approximately 10% of its pre-human distribution, within which introduced mammalian predators are still present (Hill, 2002). Since the 1970's the core of management of this species consists of assisted breeding by providing rat (*Rattus rattus* and *R. exulans*) and cat (*Felis catus*) proof nests for the Tasman parakeet across the Norfolk Island National Park.

In chapter three I have shown that the relative importance of food species and food types in the diet of the Tasman parakeet vary significantly between seasons (see Table 2 and Figs. 2 and 4, Chapter Three). Rather than consistently feeding on a single food type or species, Tasman parakeets exhibit a broad diet that includes a variety of food types from 30 native and introduced species (Fig. 1 and Table 2). I conducted a pilot study to investigate the potential for a correlation between inter-seasonal variation in foraging location and the feeding resources used by the

Tasman parakeet. In this chapter I present a qualitative analysis of the differences in foraging locations, based on resource use and area utilised within the Norfolk Island National Park.

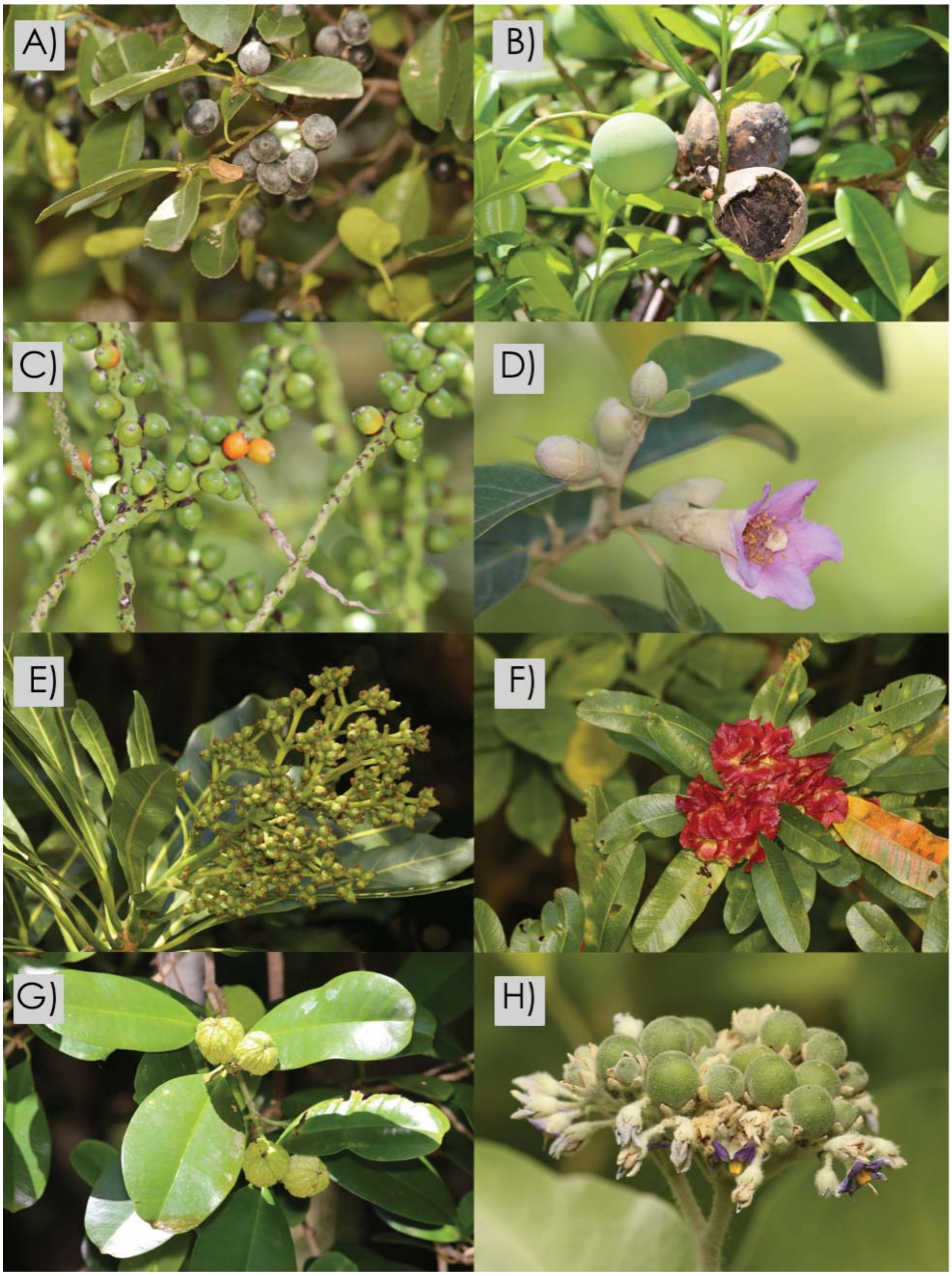

Figure 1. Some examples of food species for the Tasman parakeet. A) Elaeodendron curtipendulum; B) Capparis nobilis; C) Rhopalostylis baueri; D) Lagunaria patersonia; E) Meryta angustifolia; F) Dodonaea viscosa; G) Baloghia inophylla; H) Solanum mauritianum. All species in this figure are native to Norfolk Island except S. mauritianum introduced to Norfolk Island in the late 1800's (Coyne, 2011).

4.2 OBJECTIVES

The general objective of this chapter is to provide a visual exploration of spatial data collected on the foraging locations of Tasman parakeets between seasons to determine if a systematic survey would be appropriate. The specific objectives developed in this chapter are:

1. Map seasonal location of foraging Tasman parakeets.
2. Provide a preliminary analysis of spatio-temporal variability in the foraging patterns of the Tasman parakeet as an aspect of their feeding ecology.

4.3 METHODS

4.3.1 Data Collection And Analysis

The data discussed in this chapter was collected using the sampling methodology discussed in chapter three; specifically the GPS coordinates of each foraging observation were imported to Base Camp™ (Garmin, Kansas, USA) and then to Google Earth™. Due to the low density, and changes in abundance of Tasman parakeets during my study I obtained an uneven number of observations between seasons. Due to the unavailability of GPS units during some study periods the data presented in this chapter is a subset of the data presented in chapter three. Data includes one sampling period from summer (2014, n = 42) and autumn (2013, n = 30), and two sampling periods over winter (2013, n = 29; and 2014, n = 72) and spring (2013, n = 47; 2014, n = 108) (see also Tables 1 and 2).

Due to restrictions on my research permit my access to areas away from visitor roads and tracks was limited, thus the majority of observations occurred along the main tracks of the NINP (see Fig. 2). To explore patterns in foraging area of the Tasman parakeet I created polygons manually, encompassing the core 90% of each seasons observations using the polygon tool of Google Earth™, and then used the extreme coordinates of these to estimate the convex polygon surface area using the EarthPoint online tool (earthpoint.us.).

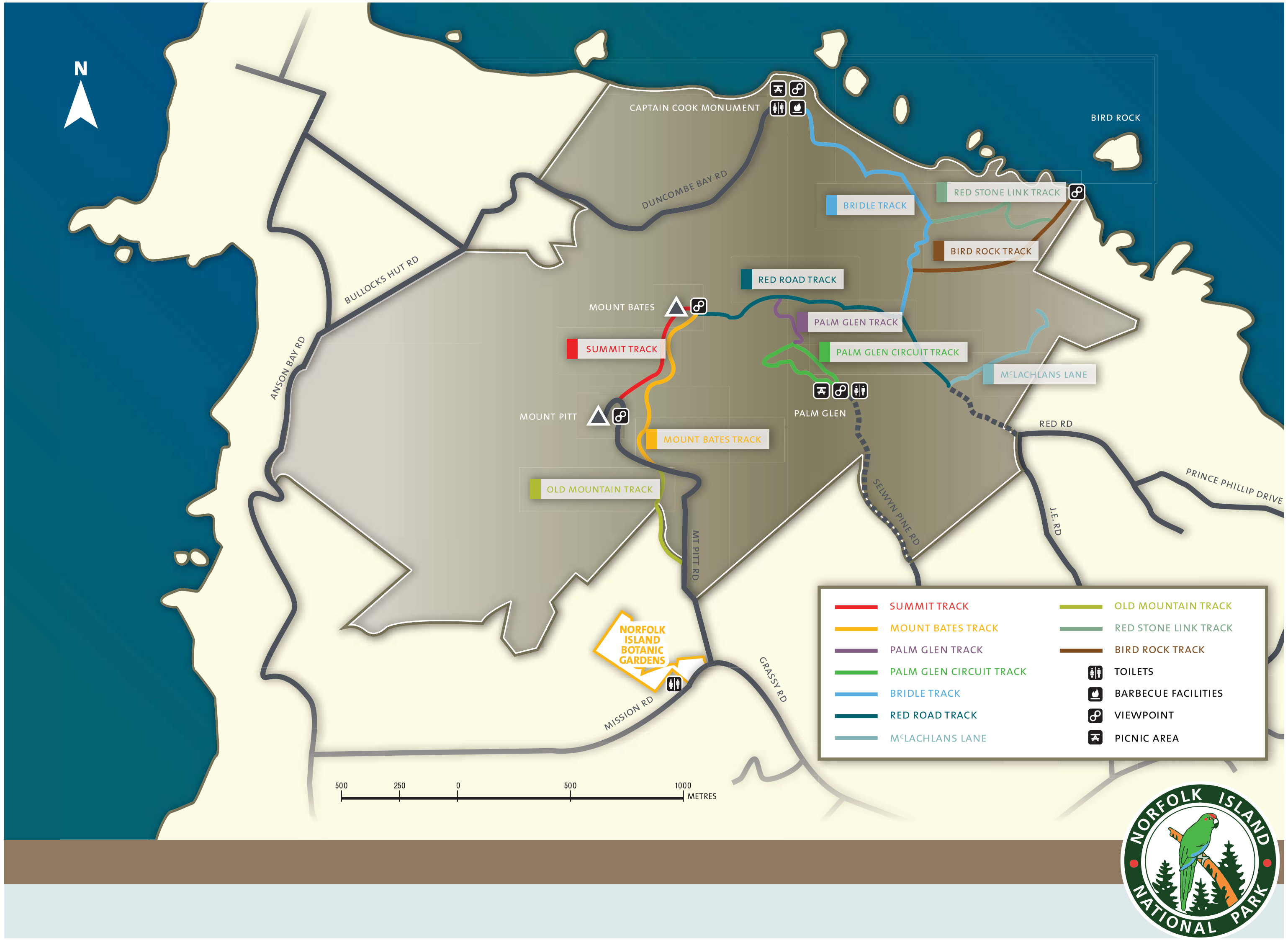

Figure 2. Map of NINP walking tracks. (Map from www.parksaustralia.gov.au/norfolk/plan/maps.html, retrieved April, 2016)

4.4 RESULTS

4.4.1 Inter-Seasonal Variation In Foraging Areas

The Tasman parakeet shows fluctuation in the locations in which it feeds seasonally. In winter the majority of sightings were along the Mount Bates Track, Summit Track, Red Road and also the Bridle Track (Fig. 3). The Summit Track and Red Road have high densities of mature pines (Director of National Parks, 2010). During this season consumption of Norfolk pine (*A. heterophylla*) represented 65.3% of observations (n = 66). Fruits and seeds of the naiu palm (*Rhopalostylis baueri*, 14.9%, n = 15), and African olive (*Olea europea cuspidata,* 10.9%, n = 11) also contributed significantly and niau palm stands are found along the Summit Track, and there is a significant quantity of African olive along the northern coast (Bridle Track) where the Tasman parakeets were also sighted. Finally in winter the Tasman parakeets utilised the smallest area with 46 hectares containing 90% of all observations.

In spring there was a large amount of observations along the Summit and Mount Bates Tracks (Fig. 4) These correspond to the most common item consumed in spring; seeds of ake ake (*Dodonaea viscosa,* 49%, n = 76). Fruits and seeds of the native niau palm (*Rhopalostylis baueri*) were the second most commonly ingested item (18.7%; n = 29), which correspond to the large amount of observations along the Palm Glen Tracks (Fig. 4). In this season Tasman parakeets utilised a larger area of 74 hectares. Additionally this season had the highest total dietary richness with items consumed from 16 different species, ten of which were consumed exclusively in spring (see Table 1).

In summer Tasman parakeets were often found foraging along the Palm Glen Tracks in olive and guava bush as well as along the Bridle Track on olive (Fig. 5). Only four species were consumed in summer, of these seeds and fruits of African olive (*O. europea ssp. Cuspidata*) were the most common (54.8%; n = 23). The seeds and fruits of cherry guava (*P. cattleianum*) were another common food item (33.3%, n = 14).

Despite the much lower total species richness of the Tasman parakeets summer diet, they were found foraging over a similar area to spring, 74 hectares.

In autumn (n = 30) sightings of the Tasman parakeet were the most diffused, occurring over the largest foraging area, 93 hectares. Autumn also has the greatest overall dietary diversity (Table 4, Chapter Three). Tasman parakeets were often observed in the lower Palm Glen Road area feeding on fruit and seeds of cherry guava (*Psidium cattleianum,* 46.7%, n = 14) (Fig. 6). Observations made in other areas were seeds of the Norfolk pine (*A. heterophylla*, 33.3%, n = 10).

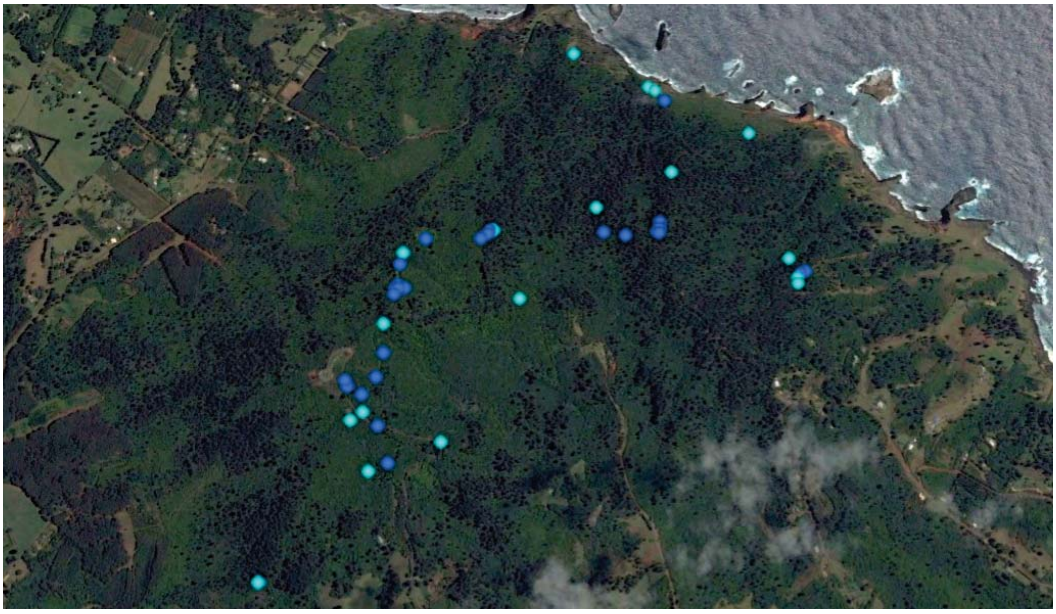

Figure 3. Locations of foraging Tasman parakeets in winter (2013 pale blue, n = 29; 2014 dark blue, n = 72). Area utilised = 46 hectares. Image generated using Google Earth (Map data: © Google, CNES / Astrium).

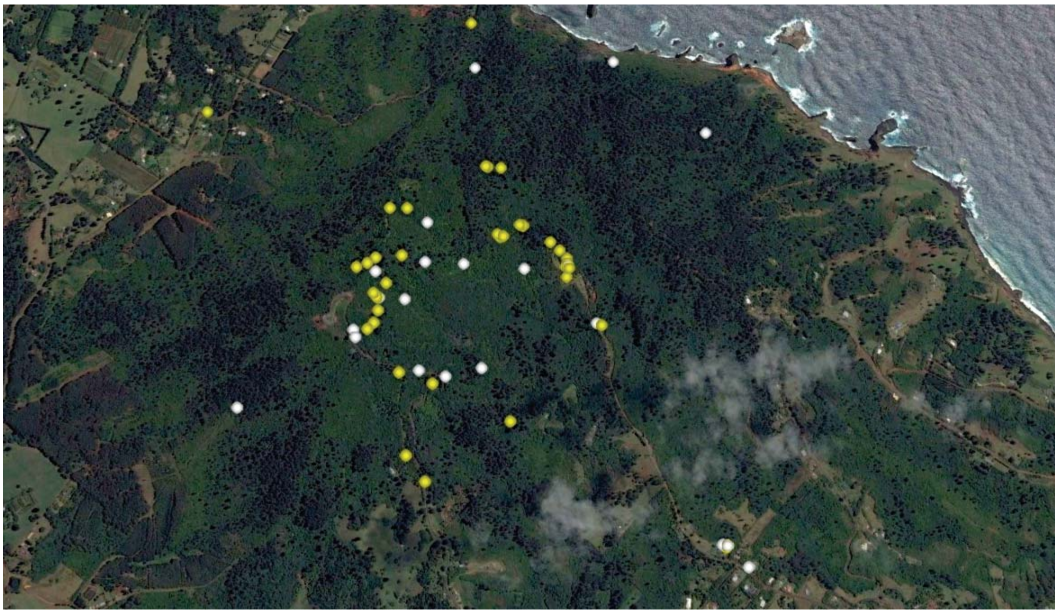

Figure 4. Locations of foraging Tasman parakeets in spring (2013 yellow, n = 47; 2014 white, n = 108). Area utilised = 74 hectares. Image generated using Google Earth (Map data: © Google, CNES / Astrium).

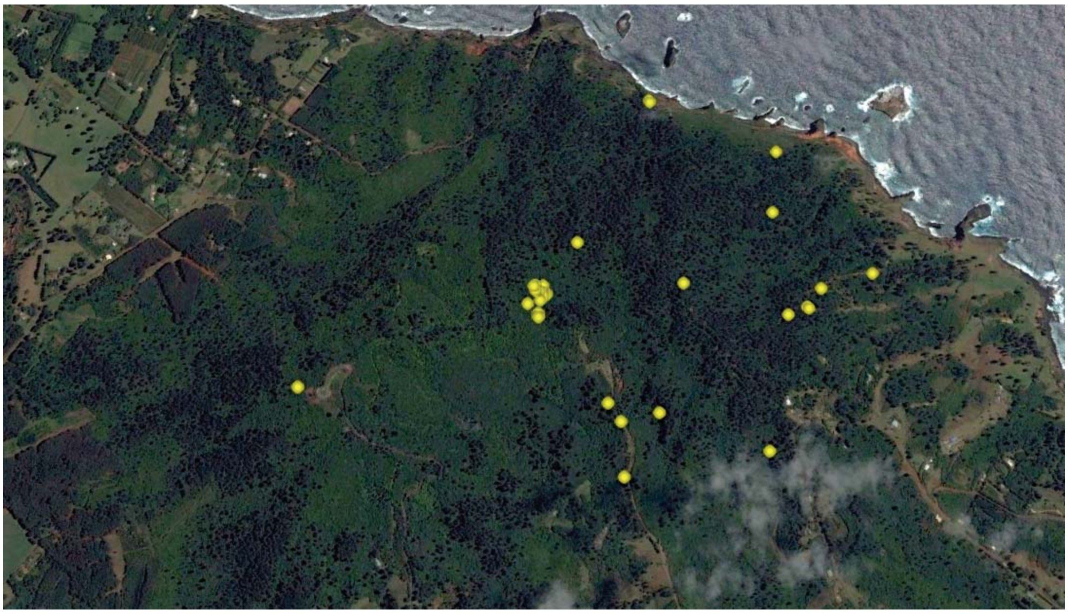

Figure 5. Locations of foraging Tasman parakeets in summer (2014, n = 42). Area utilised = 74 hectares. Image generated using Google Earth (Map data: © Google, CNES / Astrium).

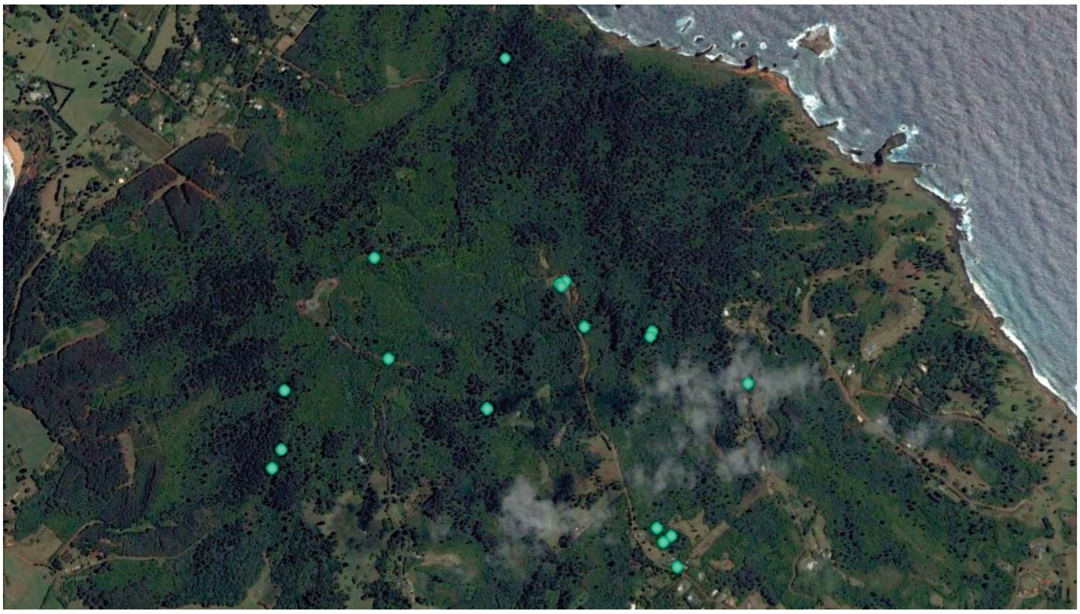

Figure 6. Locations of foraging Tasman parakeets in autumn (2013, n = 30). Area utilised = 93 hectares. Image generated using Google Earth (Map data: © Google, CNES / Astrium).

Table 1. Subset of observations of plant species consumed by the Tasman parakeet represented by GPS data per season (excluding non-dietary items). (For common names see Table 3, Chapter Three). See also Table 1, Appendix 2 for full data set.

Species	Winter	Spring	Summer	Autumn	Total
Araucaria heterophylla	66	5	0	10	81
Baloghia inophylla	1	2	0	0	3
Capparis nobilis	0	1	0	0	1
Dodonaea viscosa	0	76	0	0	76
Elaeodendron curtipendulum	0	0	0	1	1
Hakea salicifolia salicifolia	0	2	0	0	2
Hibiscus sp	0	2	0	0	2
Korthalsella disticha	0	0	0	0	0
Lagunaria patersonia patersonia	0	1	0	0	1
Macropiper excelsum psittacorum	0	1	0	0	1
Melia azedarach	3	0	0	3	6
Melodinus baueri	0	1	0	0	1
Meryta angustifolia	1	0	0	0	1
Meryta latifolia	0	0	0	0	0
Myrsine ralstoniae	0	3	2	0	5
Nestegis apetala	4	9	0	0	13
Olearia europea	11	6	23	0	40
Oplismenus hirtellus	0	0	0	0	0
Pennantia endlicheri	0	0	0	0	0
Prunus persica	0	12	0	0	12
Psidium cattleianum	0	0	14	14	28
Pyrrosia confluens	0	0	0	0	0
Rhopalostylis baueri	15	29	3	2	49
Solanum mauritianum	0	2	0	0	2
Zanthoxylum pinnatum	0	3	0	0	3
Total	101	155	42	30	328

Table 2. Subset of food type observations represented by GPS data per season. Sample size: Winter = 101, Spring = 155, Summer = 42, Autumn = 30. See also Table 2, Appendix 2 for full data set.

Food type	Dry Fruit	Dry Seed	Fleshy Fruit	Flowers	Leaves
Winter	1	62	34	0	0
Spring	18	89	41	3	4
Summer	0	27	14	1	0
Autumn	0	10	19	1	0
Total	19	188	108	5	4

Food type	Pedicel	Pollen	Rhyzome	Sori	Sprout
Winter	0	4	0	0	0
Spring	0	0	0	0	0
Summer	0	0	0	0	0
Autumn	0	0	0	0	0
Total	0	4	0	0	0

4.4.2 Ground Feeding

The total number of observations of ground feeding is 87, representing 18% of all feeding observations. The highest proportion of these observations comes from winter, 55.4% (n=56) of observations. No other season showed such a marked bias toward ground feeding. Of the 56 ground feeding events recorded in winter, the greatest proportion of these was of *A. heterophylla* seeds (89.2%, n = 50).

4.4.3 Incidental Behavioural Observations

One unique observation was of a flock of five Tasman parakeets feeding on a group of hibiscus trees. These birds were sighted at dusk, and remained there for some time giving a volunteer and I a good opportunity to observe their behaviour. The birds deliberately navigated bare bushes, targeting new shoots, pulling off flower buds breaking them open whilst holding them with one foot and chewing on the fleshy base of the style and before discarding. They were also observed breaking branches with their beaks, ripping off bark and chewing it. There was evidence of older damage to the plants. This behaviour has not previously been observed in the Tasman parakeet (Margaret Christian, pers. com.).

The Tasman parakeets were also observed breaking off and chewing the male cones of the Norfolk. Individual scales were mandibulated and the cones were discarded.

4.5 DISCUSSION

4.5.1 Preferred Areas Of Foraging

The Tasman parakeet shows significant changes in dietary diversity and consumption of food types seasonally (see Chapter Three). In addition to these they show spatial variation in foraging areas that likely correlates with fluctuations in food resource use. This suggests the Tasman parakeet exhibits a seasonal pattern of foraging on areas of high density of specific feeding resources. Other parrots show preferential areas of foraging. For example, the lilac crowned parrot (*Amazona finschi*) shows spatial variation in habitat use in correspondence with food availability, switching between semi-deciduous forest during the dry season, and deciduous forest during the rainy season (Renton, 2001).

A large amount of seasonal variation in foraging area can potentially be explained by the distribution of habitat types, particularly weedy forests within the NINP (Director of National Parks, 2010). Weedy forest produces a large amount of seed in summer, in particular olive and guava produce copious amounts of seed (olive; (Cuneo et al., 2010), cherry guava; (Foster Huenneke & Vitousek, 1990), which may explain the presence of parakeets in the Palm Glen area, as well as along the northern coast of the island (which is a more exposed habitat with a large amount of olive). In addition these species made up a large proportion of feeding observations in summer (see Fig. 2, Chapter Three).

The limited distribution of Tasman parakeet foraging areas in winter is a concern. The majority of winter diet is comprised of the seeds of the Norfolk pine

(65.3%). The areas in which they are found in winter are mainly ridges, which is where the densities of pines are the largest. If pines in some areas produce more seed than those in others, particularly if they are different ages (as they do on Phillip Island, see (Mills et al., 2015) it is likely the Tasman parakeet will exhibit resource tracking behaviour and favour area with high food resource abundance. The core area in which the Tasman parakeet was found foraging for pine seed in winter was 46 hectares, representing just 10% of the total are a of the NINP. Furthermore the largest proportion of observations from winter was of Tasman parakeets feeding on pine seed on the ground (see Chapter Three). The combination of this small core feeding area and the Tasman parakeets propensity to feed at ground level presents both a serious risk of predation, and a great opportunity to efficiently protect young and adults by targeting pest control efforts.

4.5.2 Targeted Predator Control

The Norfolk Island group has already been identified as a location where cat control would be beneficial (Dickman et al., 2010), and several predator control programs are currently active (Director of National Parks, 2010). Knowledge of the feeding areas of Tasman parakeets across the seasons, in particular the crucial winter months, may help managers to more effectively use their time in targeted control in areas which Tasman parakeets are likely to be feeding.

The foraging area of the Tasman parakeet is reduced in winter, and this is where predators likely have the largest impact on the population (picking off young unwary birds (see Chapter Five), kaka chicks are also vulnerable to post-fledging predation thought by stoats (Moorhouse et al., 2003). Additionally a significant majority of foraging in winter occurs at ground level on the seed of a single species, the Norfolk pine (*A. heterophylla*). Cats, have been found to depredate birds often between 6am and midday (Barratt, 1995), which corresponds with a high period of Tasman parakeet activity. Knowledge of the areas in which they forage might allow managers to more effectively target predator control to prevent losses from cats in particular. Also given that even moderate seed falls have shown to dramatically increase both ship rat (*Rattus rattus*) densities (ca 7 fold increase) including over winter breeding in New Zealand (King, 1997). Rats also present a risk to the Tasman parakeet, especially if as population density increases birds being to occupy natural non-predator proofed nesting hollows. All of these factors result in additional risk to recently fledged birds and hence to the worlds only population of the Tasman parakeet. Targeted predator control could be used to optimize time and effort while accomplishing management goals. Specifically, the further investigation of a more intense cat trapping program during winter in the small area where Tasman parakeets preferentially forage allow the prevention of loss of fledglings, which is suspected to be the largest current barrier to recruitment within the NINP.

4.5.3 Potential Relationship Between Foraging And Nesting Locations

Tasman parakeets appear to maintain a breeding territory (D. Greenwood pers. comm.). It is possible there may be a relationship between foraging locations and nesting sites. Monk parakeets (*Myiopsitta monachu*) select sites with the highest density of palm trees, providing an abundance of plants for foraging (Sol et al., 1997). Since the Tasman parakeet also nests year round it is possible they are using nests in correlation with seasonal food availability.

4.5.4 Weed Management And Restoration Of NINP

As mentioned previously (Chapter Three) two of the species that form a large proportion of the Tasman parakeets diet are invasive weeds with control programs (olive (14.3%) and guava (6.8%) total). Given the tendency for Tasman parakeets to forage in these areas with high densities of these species during winter, summer and autumn, see Figs. 3, 5, and 6) it will be interesting to see how their continued control will affect the diet of the Tasman parakeet. Especially if the decrease in abundance of these important seasonal resources will increase competition with introduced crimson rosellas (see Chapter Five). During summer Tasman parakeets have been seen suffering from antagonistic interactions with crimson rosellas in a densely fruited olive grove at the intersection of the Palm Glen circuit and track (Pers. Obs.). The Tasman parakeet was attacked by a crimson rosella, and fell from the tree in which it was foraging.

4.5.5 Incidental Behavioural Observations

These descriptions add to our knowledge of the species behaviour, and could be useful for comparison to other species. Consumption of hibiscus is not present in the diet of any of the *Cyanoramphus* parakeets I studied (Chapter Two). One possible reason the hibiscus has not been noted previously, as a dietary resource is that there is little hibiscus is present for us to observe this behaviour on. Hibiscus is however present on Phillip Island with the endemic *Hibiscus insularis*.

4.5.6 Sampling Methodology

Often when quantifying the diet of parrot species standardised transects are used (see (Reuleaux et al., 2014)) Whilst others, often on species with smaller population sizes rely on incidental observation (Galetti, 1993, 2013; Ortiz-Catedral & Brunton, 2009; Renton, 2001). Whilst incidental observations may be less representative, incidental observations yield significantly more observations, and provide information on rarer feeding events (Reuleaux et al., 2014). In this case given the low population size of the Tasman parakeet (Chapter One), and the subsequent unlikelihood of encounters (Ortiz-Catedral & Skirrow, 2015) this method was determined to be the best to obtain a large amount of data on the elusive Tasman parakeet.

4.6 LIMITATIONS AND FUTURE DIRECTIONS

This work was based on incidental observations; therefore the next step will be to conduct a systematic analysis. Quantification of seasonal food availability patterns is also necessary to demonstrate resource-tracking behaviour in the Tasman parakeet. Spatial patterns may also be influenced by environmental conditions, e.g.: temperature, humidity, elevations, habitat type, canopy cover, and exposure. Additionally comparison of abundant seasonal food resources with nesting locations may reveal trends in nest site choice that may help managers locate and protect new nests as the Tasman parakeet population expands.

4.7 REFERENCES

Barratt, D. G. (1995). Predation and movement by house-based domestic cats Felis catus (L.) in suburban and rural habitats - preliminary findings. *People and nature conservation*, 181-187.

Boyes, R. S., & Perrin, M. R. (2010). Aerial surveillance by a generalist seed predator: Food resource tracking by Meyer's parrot *Poicephalus meyeri* in the Okavango Delta, Botswana. *Journal of Tropical Ecology, 26*(4), 381-392. doi: 10.1017/S0266467410000210

Coyne, P. (2011). *Norfolk Island's Fascinating Flora*. Belconnen, ACT: Petaurus Press.

Cuneo, P., Offord, C. A., & Leishman, M. R. (2010). Seed ecology of the invasive woody plant African Olive (*Olea europaea* subsp. *cuspidata*): Implications for management and restoration. *Australian Journal of Botany, 58*(5), 342-348. doi: 10.1071/BT10061

Dickman, C. R., Denny, E., & Buckmaster, T. (2010). *Identification of sites of high conservation priority impacted by feral cats*. Report for Australian Government Department of the Environment, Water, Heritage and the Arts. Canberra, Australia.

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

Foster Huenneke, L., & Vitousek, P. M. (1990). Seedling and clonal recruitment of the invasive tree *Psidium cattleianum*: Implications for management of native Hawaiian forests. *Biological Conservation, 53*(3), 199-211. doi: http://dx.doi.org/10.1016/0006-3207(90)90086-5

Galbraith, M., & Cooper, H. (2013). Tiritiri Matangi-an overview of 25 years of ecological restoration. *New Zealand Journal of Ecology, 37*(3), 258-260.

Galetti, M. (1993). Diet of the scaly-headed parrot (*Pionus maximiliani*) in a semideciduous forest in southeastern Brazil. *BIOTROPICA, 25*(4), 419-425.

Galetti, M. (2013). Seasonal abundance and feeding ecology of parrots and parakeets in a lowland Atlantic forest of Brazil. *Revista Brasileira de Ornitologia-Brazilian Journal of Ornithology, 5*(7), 12.

Innes, J., & Barker, G. (1999). Ecological consequences of toxin use for mammalian pest control in New Zealand: An overview. *New Zealand Journal of Ecology, 23*(2), 111-127.

King, C. M. (1997). Distribution and response of rats Rattus rattus, R. exulans to seedfall in New Zealand beech forests. *Pacific Conservation Biology, 3*(2), 143-155.

Mills, K., Ball, D., Christian, J., & Christian, K. (2015). Report on survey work on Phillip Island as part of the green parrot conservation project: Parks Australia, Norfolk Island.

Moorhouse, R. J., Greene, T., Dilks, P., Powlesland, R., Moran, L., Taylor, G., Jones, A., Knegtmans, J., Wills, D., Pryde, M., Fraser, I., August, A., & August, C. (2003). Control of introduced mammalian predators improves kaka *Nestor meridionalis* breeding success: Reversing the decline of a threatened New Zealand parrot. *Biological Conservation, 110*(1), 33-44. doi: 10.1016/S0006-3207(02)00173-8

O'Donnell, C. F. J., & Hoare, J. M. (2012). Quantifying the benefits of long-term integrated pest control for forest bird populations in a New Zealand temperate rainforest. *New Zealand Journal of Ecology, 36*(2), 131-140.

O'Donnell, C. F. J., & Phillipson, S. M. (1996). Predicting the incidence of mohua predation from the seedfall, mouse, and predator fluctuations in beech forests. *New Zealand Journal of Zoology, 23*(3), 287-293.

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

Ortiz-Catedral, L., & Skirrow, M. (2015). *Observing elusive populations: Finding an efficient method for sampling Tasman parakeets (Cyanoramphus cookii)*. Massey University.

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

Reuleaux, A., Richards, H., Payet, T., Villard, P., Waltert, M., & Bunbury, N. (2014). Insights into the feeding ecology of the Seychelles Black Parrot *Coracopsis barklyi* using two monitoring approaches. *Ostrich*.

Sol, D., Santos, D. M., Feria, E., & Clavell, J. (1997). Habitat selection by the Monk Parakeet during colonization of a new area in Spain. *Condor, 99*(1), 39-46.

Stojanovic, D., Terauds, A., Westgate, M. J., Webb, M. H., Roshier, D. A., & Heinsohn, R. (2015). Exploiting the richest patch has a fitness pay-off for the migratory swift parrot. *Journal of Animal Ecology*. doi: 10.1111/1365-2656.12375

CHAPTER FIVE: THE RELEVANCE OF THIS STUDY FOR THE CONSERVATION OF TASMAN PARAKEETS AND FUTURE RESEARCH NEEDS

5.1 CONSERVATION OF THE TASMAN PARAKEET

The Tasman parakeet is a micro-endemic species, with a single breeding population globally restricted to the Norfolk Island National Park (see Chapter One). The population size of this species has fluctuated historically, from 32 individuals in the 1970-1980’s to approximately 200-250 individuals in 1990-2000. These fluctuations are attributed to changes in the intensity of predation by rats and cats on nests, fledglings and adult birds; habitat deterioration and potentially diseases (Forshaw & Cooper, 1989; Hicks & Greenwood, 1989; Higgins, 1999). However, there is no precise information on the relative effect of these factors on the demography of Tasman parakeets. The on-going control of rats and cats in the Norfolk Island National Park allows the successful breeding of Tasman parakeets, from 2013 to 2015 approximately 150 chicks have successfully fledged (A. Smith, 2015 *in litt.*). However, there is evidence indicating low recruitment of juveniles into the breeding population, most likely as a result of predation of fledglings during winter (Ortiz-Catedral, pers. comm.). Thus, while control of introduced predators allows breeding pairs to fledge young, their survival post-fledging is very low.

Since the 1980’s it has been proposed that a major conservation breakthrough for the species would be the translocation a breeding population to nearby Phillip Island (Coyne, 2009; Forshaw & Cooper, 1981)(see map Fig. 3, Chapter One). Phillip Island has neither introduced rodents or cats, a crucial requirement for any potential islands for reintroduction of *Cyanoramphus* parakeets (Elliott et al., 2006; Moorhouse et al., 2003; White et al., 2012). In 2013, a proposal to translocate

Tasman parakeets to Philip Island in 2017-2018 was launched (A. Smith, *in litt*.) but at the time it was stressed that there was a clear need to better understand the nesting and feeding ecology of Tasman parakeets to assess whether or not Phillip Island would provide enough feeding resources for a breeding population of Tasman parakeets (Ortiz-Catedral, pers. comm.).

Studies on the nesting biology of a translocated population of orange-fronted parakeets suggest that availability of nesting sites on small islands may not be a limiting factor in establishment (Ortiz-Catedral et al., 2009). While part of the management of the Tasman parakeet has been the provision of nest sites, these have been a requirement due to the pests on the main Norfolk Island. Phillip Island is pest free and therefore Tasman parakeets should be able to nest as they desire. One concern is a lack of old growth trees to provide nesting hollows, due to the previous denuded vegetation of Phillip Island. However, other *Cyanoramphus* parakeets have shown willingness to nest on the ground with minimal protection at predator free sites (for example red-fronted parakeets nesting under a flax (*Phormium tenax*) bush on predator free Tiritiri Matangi Island (Ortiz-Catedral & Brunton, 2009)), and the extinct Maquarie Island parakeet (*Cyanoramphus erythrotis*) was a ground nester, as is the Antipodes Island parakeet (Greene, 1999).

Prior to this study, the general assumption has been that Tasman parakeets have a similar diet to their close relative the red-fronted parakeets of New Zealand and both species have been treated as a single taxonomic entity (Higgins, Forshaw etc.). In chapter two I have shown that the diet of the Tasman parakeet is different from the red-fronted parakeet and other members of the *Cyanoramphus* genus. The similarity in diet between the red-fronted parakeet and the Tasman parakeet is very low (0.58%, Table 2, Chapter Two) and most likely reflects the local vegetation diversity and structure as well as a considerable difference in bill morphology. Tasman parakeet bills are significantly larger than the red-fronted parakeet in four bill characteristics: upper length, upper width, lower distal width, and lower length

(Chapter Two). These significant differences in bill dimensions indicate that the Tasman parakeet is likely to access a wider range of dietary resources, such as the hard seeds of the Norfolk Island pine and niau palm (Chapters Two and Three).

As for dietary diversity, the lower diversity of the Tasman parakeet (Fig. 2 Chapter Two) is likely a reflection of both study effort and geographical range size. NINP covers a range of 465 ha, and while it contains different forest types within it cannot match the diversity of habitat types within which red-fronted parakeet is found (for example: old growth forest on Little Barrier Island/Hauturu (Greene, 1998); regenerating coastal forest on Tiritiri Matangi (Ortiz-Catedral & Brunton, 2009); and open grassy habitat such as Burgess Island (56 ha) (McFadden & Greene, 1994). Furthermore the historical distribution of the red-fronted parakeet, across the entire North and South Islands of New Zealand, is likely a correlate of its generalist diet, as range size and niche breadth are positively correlated (Boyes & Perrin, 2009).

The Tasman parakeet has the second highest prevalence of seeds in its diet when compared to other *Cyanoramphus* species (Chapter Two). This is a reflection of both bill morphology and body size. The Tasman parakeet has a high prevalence of seeds in its diet because it is able to capitalise on its large bill size (BSA) in consuming the large woody seeds of the Norfolk pine, as well as a range of other hard (e.g. African olive (*Olea europea cuspidata*) and soft (e.g. hopbush (*Dodonaea viscosa*)) seeds (See Chapter Three). It also may need to consume a large proportion of seeds because of its larger body mass hence the high prevalence of seed consumption in its diet. Conversely species with a smaller mass consume less seeds in their diet (Fig. 5, Chapter Two). For example, the orange and yellow fronted parakeets are small birds with small bills (*C. malherbi*: body weight average 41 g, BSA = 75 mm^3; *C. auriceps*: body weight average 46 g, BSA = 76mm^3), which also consume the lowest proportion of seeds. The Antipodes Island parakeet is an outlier to some extent; this is due to its diet. The Antipodes Island parakeet is frequently described as a folivore (Higgins, 1999), feeding largely on leaves of grass and sedge species (See Table 2, Chapter Two). In one study the leaves of one species, *Poa litorosa* made up over 50% of observations (Greene, 1999). The seeds of species are consumed largely as supplementation of their dietary intake depending on the season. This also reflects the vegetation community of Antipodes Island (Godley, 1989).

I thus suggest that the Tasman parakeet follows the generalist pattern of the other *Cyanoramphus* species, with adaptation to allow for specialisation for feeding on the large seeds of the Norfolk pine. I suggest the large prevalence (54% of diversity, Chapter Two) and proportion (63.1% of intake, Chapter Three) of seeds in the diet of the Tasman parakeet contributes towards fulfilling the energy requirements of the species large body size.

My study has advanced the state of knowledge about the diet of this critically endangered species. As discussed in chapter three, prior to my research only 15 species were classified as part of the diet of Tasman parakeets and little data on their seasonal preferences was available. I have demonstrated that Tasman parakeets feed on at least 25 species and their relative importance follows a seasonal trend. This information is crucial to the conservation of the Tasman parakeet, especially in light of the proposed translocation to Phillip Island; specifically my research shows that a key feeding resource during winter are seeds of Norfolk Island pine (65.3%, Chapter Three), thus this resource must be made available in high supply for parakeets wintering on Phillip Island if the local Norfolk pine population fails to provide enough seeds.

Preliminary assessment shows that pine seed levels on Phillip Island are substantial, despite only 10% of pines bearing cones (Mills et al., 2015). In particular there is a considerable presence of a seed in Long Valley (1.23 ha) (Fig. 1), with at least 2.63 fresh seeds per m^2, and 1.92 dried seeds per m^2 (Mills et al., 2015). African olive is also a major seasonal resource for the Tasman parakeet, especially in summer and autumn. African olive is found in thick groves on Phillip Island, with the total level of olive seed estimated to be in excess of 4 million annually (Mills et al., 2015). Cherry guava (*Psidium cattleianum*) is also a major component of diet in autumn and summer, but the species is not present on Phillip Island (Director of National Parks, 2010; Mills, 2009). White oak also has a high presence on Phillip Island, and the Tasman parakeet consumes its flowers on Norfolk Island. Several species that are not a component of the Tasman parakeets diet, but are eaten by other *Cyanoramphus* parakeets are abundant on Phillip Island, and could present the opportunity for dietary niche expansion. For example, flax (*Phormium tenax*) is found in the diets of both the red-fronted parakeet (*C. novazelandiae*) and Forbes' parakeet (*C. forbesi*) (see Chapter Two). Additionally native sedge Moo-oo (*Cyperus lucidus*) present a potential resource which Tasman parakeets can to expand to (Mills et al., 2015). The Antipodes Island parakeet relies heavily on sedges (Greene, 1999) the overlap in bill morphology (see Chapter Two) suggests they will be able to utilise this resource.

Figure 1. Long Valley on Phillip Island. The Norfolk pines in the photograph are ca. 30 years old (M. Christian pers. comm.). Photo: L. Ortiz-Catedral©

Phillip Island is an ideal location for a *Cyanoramphus* translocation. In addition to its predator free status, preliminary surveys indicate abundant levels of dietary resources (especially Norfolk pine and African olive seed) (Mills et al., 2015) which I have found contributed significantly to the Tasman parakeets diet. Additionally similarities in bill morphology between Tasman parakeet and other *Cyanoramphus* species (Antipodes Island parakeet, Forbes' parakeet and red-fronted parakeet (see Chapter Two)) and knowledge of those species diet suggest that there is potential for the Tasman parakeet to expand its diet upon introduction to a novel environment, just as the orange fronted parakeet has on Maud Island (Ortiz-Catedral et al., 2009).

I have demonstrated that the Tasman parakeet uses a variety of different resources throughout the year. Key seasons with low diversity are winter and summer, where the parakeets rely largely on single resources (Norfolk pine and African olive respectively). While the management and conservation of Norfolk pines will keep this resource safe for the Tasman parakeet it is possible it may have an influence on the breeding success of the species in the same way rimu (*Dacrydium cupressinum*) fruit production influences breeding success in the critically endangered kakapo (*Strigops habroptilus*) (Elliott et al., 2006). Therefore it may be important to be able to predict years that are productive for pine seed, and be able to coordinate additional pest management in those years to mitigate predation impacts as has been successful in New Zealand (O'Donnell & Hoare, 2012; Powlesland et al., 2003). Another issue is the reliance on African olive in summer. As African olive is a weedy species with a control plan within the Norfolk Island National Park (NINP) its removal could impact the Tasman parakeets diet in the long term. In this case further research is required, as it is difficult to know if the Tasman parakeet is feeding on this species because of its high abundance, or because there is a lack of other suitable resources in summer. Knowledge of which species are important in which seasons will also help managers to predict and gaps or shortfalls in resource production on Phillip Island for the potential translocation there.

In the diet of the Tasman parakeet fleshy and dry fruits made up a significant proportion of spring diet compared with other seasons. Dry seeds were more frequently consumed in autumn than in any other season. The reliance of the Tasman parakeet on a small number of food types is common amongst other parrot species (for example the scaly headed parrot (*Pionus maximiliani*) (Galetti, 1993), and the North Island kaka (*Nestor meridionalis septentrionalis*) (Moorhouse, 1997). My study suggests that production of resources may be seasonally significant, for example, poor fruit production in spring may negatively affect the Tasman parakeet, with flow on effects if there is not enough dry seed in autumn when it is a key component.
I found differences in the variability of feeding heights across the seasons. I suggest that feeding height varies seasonally due to the type of resource being consumed (i.e. seeds on the ground, vs flowers or fruit higher in the canopy). One significant resource that the Tasman parakeet spends a significant amount of time feeding on at ground level is Norfolk pine seed (n = 66, 13.6% of total observations). The total number of observations of ground feeding is 87, representing 18% of all feeding observations. The highest proportion of these observations comes from winter, 55.4% (n = 56) of observations. This represents a predation risk, especially for young birds. This may represent a population barrier to recruitment, as juvenile birds are particularly at risk as they lack predator detection skills and have poor flight skills. Rats and cats were seen active during the daytime when parakeets are active (Pers. Obs.).

5.2 FUTURE RESEARCH

While the Tasman parakeet has been under management for many years there are still many scientific avenues of enquiry that could benefit the management of the species. The ability to conduct more systematic research also increases as the population size grows.

5.2.1 Competition With Crimson Rosellas (*Platycercus elegans*)

One important aspect affecting the survival of the Tasman parakeet I did not quantify in this study was the degree of competition for feeding resources between crimson rosellas and Tasman parakeets. Crimson rosellas were introduced to Norfolk Island as cage birds in the late 1800's (Chirstian, 2005) and by the 1960's had become well established and considered common (Smithers & Disney, 1969). Since the 1980's crimson rosellas have been considered competitors for nesting sites and feeding resources of Tasman parakeets (Forshaw & Cooper, 1981; Hicks & Greenwood, 1989).

In their native range in mainland Australia, crimson rosellas inhabit tropical and subtropical lowlands and forests and extend south to temperate mountain and foothill forests as well as *Eucalyptus* woodlands (Forshaw & Cooper, 1981). The diet of crimson rosellas on mainland Australia consists of seeds, nectar, fruits, buds and occasionally insects (Forshaw & Cooper, 1981). On Norfolk Island, crimson rosellas are reported to feed on fruits of bloodwood (*Baloghia inophylla*), guava (*Psidium guajava*), tobacco (*Solanum mauritianum*) and *Lantana camara* (Forshaw & Cooper, 1981). Bloodwood and tobacco are minor elements of the diet of Tasman parakeets (< 10% of overall diet, Chapter Three). However, I have seen crimson rosellas feeding on other species that are significant resources for the Tasman parakeet including niau palm, Norfolk Island pine, African olive and cherry guava within my study area. Outside the Norfolk Island National Park, crimson rosellas have been observed ingesting seeds of Hawaiian holly (*Schinus terebinthifolius*) (L. Ortiz-Catedral, pers. comm.).

Crimson rosellas occur throughout Norfolk Island, including the Norfolk Island National Park (Chirstian, 2005) where they outnumber Tasman parakeets with an estimated population size of 1200 (Skirrow and Ortiz-Catedral, unpublished). That is, crimson rosellas are approximately six times more abundant within my study site than the highest estimated number of Tasman parakeets. Because of their higher abundance crimson rosellas can be expected to have a considerable effect on feeding resources of Tasman parakeets, in particular niau palm and Norfolk Island pine seeds. Clearly this needs to be quantified. I attempted to document the diet of crimson rosellas on Norfolk Island using the methodology described in chapter three, but unlike Tasman parakeets, these birds are very wary of human observers and often fly away before observations can be made. An alternative to study the degree of competition between crimson rosellas and Tasman parakeets is the installation of motion-sensitive cameras on key feeding resources to determine visitation rates and estimate fruit take per species. This approach has been successfully used to document frugivory of canopy birds (Rivas-Romero & Soto-Shoender, 2015).

Figure 2. A crimson rosella feeding on niau palm (*Rhopalostylis baueri*). Photo L. Ortiz-Catedral©

5.2.2 Competition For Food With Introduced Rodents

Two species of invasive rodents have established on Norfolk Island since the late 1800's: kiore or Pacific rat (*Rattus exulans*) and ship or black rat (*Rattus rattus*) (Smith et al., 2001). These rodents depredate eggs and nestlings on a variety of island bird species (Athens et al., 2002; Harper, 2009; Towns et al., 2006) including the Tasman parakeet (Director of National Parks, 2008, 2010; Hill, 2002). One aspect that has not yet been quantified is the level of competition for food imposed by these rodents on the Tasman parakeet. During this study I saw a rat feeding on the ground during the day within 2 m of a feeding Tasman parakeet. Also volunteers for my study have noticed Pacific rats feeding on seeds and fruits of African olive, Norfolk Island pine, niau palm, Maple (*Elaeodendron curtipendulum*) and *Meryta latifolia* (Fig. 2). On the later species, groups of two to five rats were seen on separate occasions feeding on developing fruits up to 2 m above the ground. The fruit set in the photograph was entirely consumed within a few days (L. Ortiz-Catedral, pers. comm.). The density of each rodent species in the Norfolk Island National Park has not been accurately estimated, but warrants investigation within key feeding and nesting areas of the Tasman parakeet.

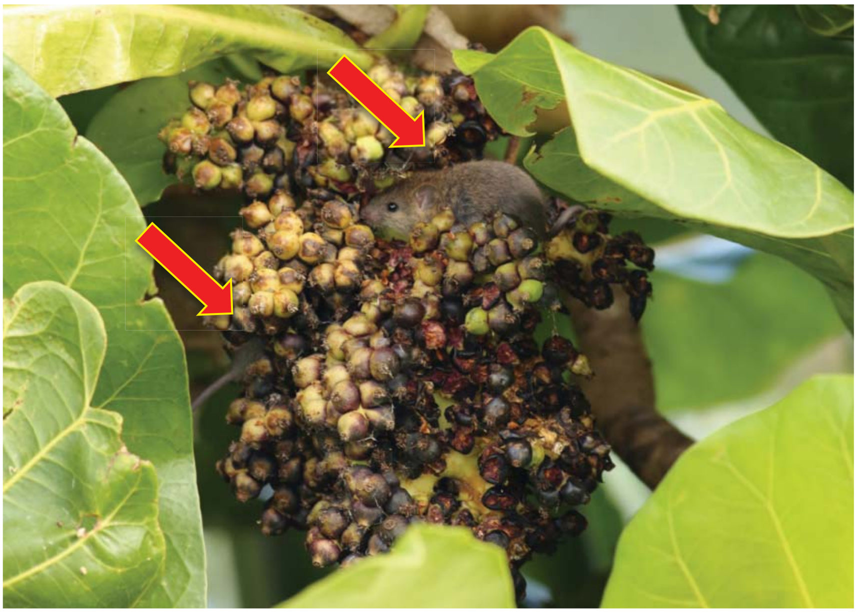

Figure 3. Two Pacific rats (*Rattus exulans*) eating fruits of *Meryta latifolia* in the Norfolk Island National Park. This entire fruit set was consumed by Pacific rats within a few days. Photo L. Ortiz-Catedral©.

As discussed in chapter four, Tasman parakeets move to different foraging areas between seasons (Figs. 3 - 6, Chapter Four) but it is unclear if this is a response to seasonal food shortages in other areas. Thus understating the effects of invasive rodents on spatially variable foraging resources of the Tasman parakeet is crucial to the effective management of this species.

5.2.3 Habitat Use Of Tasman Parakeets And Resource Availability

As discussed in chapter four, I conducted a pilot study on the seasonal spatial variation of foraging grounds for the Tasman parakeet. The information obtained in my study suggests a seasonal pattern of foraging on areas of high density of specific feeding resources. However, because my study was limited to accessible roads and tracks I was unable to test whether this was an artefact of my sampling scheme or an actual pattern followed by Tasman parakeets. Nevertheless, there is evidence to support a pattern of resource abundance tracking by Tasman parakeets. During both winters of my study, Tasman parakeets were observed primarily along areas of high density of Norfolk Island pine (Fig. 3, Chapter Four). In this season, Norfolk Island pine seeds represent 65.3% of the species consumed (Chapter Three). During summer in contrast, most of the feeding observations were on the eastern side of the Norfolk Island National Park, in lower areas with high abundance of African olive (Fig. 5, Chapter Four). Clearly there is a need for a structured sampling aimed at quantifying abundance of key resources and the spatial movements of Tasman parakeets. Radio-telemetry studies can provide insights into the spatial inter-seasonal variation of Tasman parakeets, especially their movements out the NINP. This technology is regularly used to quantify home ranges of endangered birds (Leavelle et al., 2015).

5.3 REFERENCES

Athens, J. S., Tuggle, H. D., Ward, J. V., & Welch, D. J. (2002). Avifaunal extinctions, vegetation change, and Polynesian impacts in prehistoric Hawai'i. *Archaeology in Oceania, 37*(2), 57-78.

Boyes, Rutledge S., & Perrin, Michael R. (2009). Generalists, specialists and opportunists: niche metrics of *Poicephalus* parrots in southern Africa. *Ostrich, 80*(2), 93-97. doi: 10.2989/OSTRICH.2009.80.2.5.832

Chirstian, M. L. (2005). *Norfolk Island... The birds.*: Green Eyes Publications.

Coyne, P. (2009). *Incredible! : the amazing story of the birth and rebirth of a natural treasure Phillip Island, South Pacific*. Belconnen, A.C.T.: Petaurus Press.

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

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

Elliott, G. P., Eason, D. K., Jansen, P. W., Merton, D. V., Harper, G. A., & Moorhouse, R. J. (2006). Productivity of kakapo (*Strigops habroptilus*) on offshore island refuges. *Notornis, 53*(1), 138-142.

Forshaw, J. M., & Cooper, W. T. (1981). *Australian parrots* (2nd ed.). Melbourne: Lansdowne Editions.

Forshaw, J. M., & Cooper, W. T. (1989). Parrots of the World. *Willoughby, Landsdowe, Australia*.

Galetti, M. (1993). Diet of the scaly-headed parrot (*Pionus maximiliani*) in a semideciduous forest in southeastern Brazil. *BIOTROPICA, 25*(4), 419-425.

Godley, E. J. (1989). The flora of Antipodes Island. *New Zealand Journal of Botany, 27*(4), 531-564. doi: 10.1080/0028825X.1989.10414138

Greene, T. C. (1998). Foraging ecology of the red-crowned parakeet (*Cyanoramphus novaezelandiae novaezelandiae*) and yellow-crowned parakeet (*C. auriceps auriceps*) on Little Barrier Island, Hauraki Gulf, New Zealand. *New Zealand Journal of Ecology, 22*(2), 161-171.

Greene, T. C. (1999). Aspects of the ecology of Antipodes Island Parakeet (*Cyanoramphus unicolor*) and Reischek's Parakeet (*C. novaezelandiae hochstetteri*) on Antipodes Island, October - November 1995. *Notornis, 46*(2), 301-310.

Harper, G. A. (2009). The native forest birds of Stewart Island/Rakiura: patterns of recent declines and extinctions. *Notornis, 56*(2).

Hicks, J., & Greenwood, D. (1989). Rescuing Norfolk Island's parrot. *Birds international, 1*(4), 34-47.

Higgins, P.J. (Ed.). (1999). *Handbook of Australian, New Zealand and Antarctic Birds.* (Vol. Volume 4: Parrots to Dollarbird.). Melbourne: Oxford University Press.

Hill, R. (2002). Recovery plan for the Norfolk Island Green Parrot (*Cyanoramphus novaezelandiae cookii*): Natural Resource Management, Environment Australia.

Leavelle, K. M., Powell, L. L., Powell, G. V. N., & Forsyth, A. (2015). A radio-telemetry study of home range and habitat use of the endangered yellow-billed cotinga (Carpodectes antoniae) in Costa Rica. *Wilson Journal of Ornithology, 127*(2), 302-309. doi: 10.1676/wils-127-02-302-309.1

McFadden, I, & Greene, T. C. (1994). *Using brodifacoum to eradicate kiore (Rattus exulans) from Burgess Island and the Knights Group of the Mokohinau Islands*: Department of Conservation Wellington.

Mills, K. (2009). The Vegetation of Phillip Island, Norfolk Island Group.

Mills, K., Ball, D., Christian, J., & Christian, K. (2015). Report on survey work on Phillip Island as part of the green parrot conservation project: Parks Australia, Norfolk Island.

Moorhouse, R. J. (1997). The diet of the North Island kaka (*Nestor meridionalis septentrionalis*) on Kapiti Island. *New Zealand Journal of Ecology, 21*(2), 141-152.

Moorhouse, R. J., Greene, T., Dilks, P., Powlesland, R., Moran, L., Taylor, G., Jones, A., Knegtmans, J., Wills, D., Pryde, M., Fraser, I., August, A., & August, C. (2003). Control of introduced mammalian predators improves kaka *Nestor meridionalis* breeding success: Reversing the decline of a threatened New Zealand parrot. *Biological Conservation, 110*(1), 33-44. doi: 10.1016/S0006-3207(02)00173-8

O'Donnell, C. F. J., & Hoare, J. M. (2012). Quantifying the benefits of long-term integrated pest control for forest bird populations in a New Zealand temperate rainforest. *New Zealand Journal of Ecology, 36*(2), 131-140.

Ortiz-Catedral, L., & Brunton, D. H. (2009). Nesting sites and nesting success of reintroduced red-crowned parakeets (*Cyanoramphus novaezelandiae*) on Tiritiri Matangi Island, New Zealand. *New Zealand Journal of Zoology, 36*(1), 1-10.

Ortiz-Catedral, L., Kearvell, J. C., Hauber, M. E., & Brunton, D. H. (2009). Breeding biology of the critically endangered Malherbes parakeet on Maud Island, New Zealand, following the release of captive-bred individuals. *Australian Journal of Zoology, 57*(6), 433-439.

Powlesland, R. G., Wills, D. E., August, A. C. L., & August, C. K. (2003). Effects of a 1080 operation on kaka and kereru survival and nesting success, Whirinaki Forest Park. *New Zealand Journal of Ecology, 27*(2), 125-137.

Rivas-Romero, J. A., & Soto-Shoender, J. R. (2015). Filling in the gaps: Evaluating the use of camera traps in the canopy to examine frugivore visits to *Oreopanax echinops* in the highlands of Guatemala. *Southwestern Naturalist, 60*(4), 366-397. doi: 10.1894/0038-4909-60.4.366

Smith, I., Clark, G., & White, P. (2001). Mammalian and reptilian fauna from Emily and Cemetery Bays, Norfolk Island. *Records of the Australian Museum, Supplement 27*, 75-79.

Smithers, C. N., & Disney, H. J. S. (1969). The distribution of terrestrial and freshwater birds on Norfolk Island. *Australian Journal of Zoology, 15*, 127-140.

Towns, D. R., Atkinson, I. A. E., & Daugherty, C. H. (2006). Have the harmful effects of introduced rats on islands been exaggerated? *Biological Invasions, 8*(4), 863-891. doi: 10.1007/s10530-005-0421-z

White, T. H., Jr, Collar, N. J., Moorhouse, R. J., Sanz, V., Stolen, E. D., & Brightsmith, D. J. (2012). Psittacine reintroductions: Common denominators of success. *Biological Conservation, 148*(1), 106-115. doi: 10.1016/j.biocon.2012.01.044

APPENDICES

A.1 APPENDIX 1

My research was conducted under full approval by: Norfolk Island National Park and Department of Environment Australia.

Australian Government

Director of National Parks

COLLABORATIVE RESEARCH AGREEMENT

between

DIRECTOR OF NATIONAL PARKS

and

MASSEY UNIVERSITY

in relation to collaborative research on

the Recovery of Norfolk Island Green Parrots

Agreement Reference: 3000027307

24. DISPUTE RESOLUTION 10

25. TERMINATION 10

26. NEGATION OF EMPLOYMENT, PARTNERSHIP AND AGENCY 10

27. WAIVER 10

28. ASSIGNMENT 11

29. NOTICES 11

THE SCHEDULE 12
A. Research Organisation's Representative 12
B. DNP's Representative 12
C. Specified Personnel 12
D. Research 12
E. Environmental Conditions 15
F. Research Period 15
G. DNP's Contribution 15
H. Research Organisation's Contributions 15
I. Material to be provided by DNP 15
J. Use of DNP Material 16
K. Confidential Information 16
L. Attribution 16
M. Acknowledgment 16
N. Reporting 16
O. Insurance 17
P. Intellectual Property 17

ATTACHMENT A 19

ATTACHMENT B 20

ATTACHMENT C 22

DATE

This Agreement is made the 11 day of April 2016.

PARTIES

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

and

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

BACKGROUND

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

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

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

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

OPERATIVE PART

1. Interpretation

1.1 In this Agreement, unless the contrary intention appears:

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

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

1.2 In this Agreement:

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

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

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

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

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

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

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

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

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

2. Commencement and Duration

2.1 Despite the date of signing this Agreement is deemed to have started on 4 June 2013, and unless terminated earlier in accordance with this Agreement, will finish at the end of the period set out in Item F [*Research Period*], and the Research Organisation has complied with clauses 8 and 16.

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

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

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

11. DNP Material

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

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

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

12. Intellectual Property in Research Material

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

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

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

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

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

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

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

13. Moral Rights

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

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

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

14. Confidential Information

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

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

15. Personal Information

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

16. Reporting

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

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

17. Acknowledgment and Publications

17.1 In:

(a) promotional Materials arising from Research; and

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

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

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

18. Media

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

19. Conflict of Interest

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

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

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

as at the signing of this Agreement.

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

(a) notify DNP immediately in writing; and

(b) make full disclosure of all relevant information relating to the conflict; and

(c) take such steps as DNP may reasonably require to resolve or otherwise deal with the conflict.

20. Work Health and Safety

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

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

21. Access to Premises and Records

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

22. Indemnity

22.1 The Research Organisation indemnifies DNP from and against any:

(a) costs or liability incurred by the DNP;

(b) loss of or damage to property of the DNP; or

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

arising from either:

(d) a breach by the Research Organisation of this Agreement; or

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

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

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

22.4 In this clause,

(a) "DNP" includes officers, employees and agents of the DNP; and

(b) "fault" means any negligent or unlawful act or omission or wilful misconduct.

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

23. Insurance

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

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

24. Dispute Resolution

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

- (a) If one party has concerns regarding the performance of the Research, that party will raise concerns with the other party in writing; and
- (b) Both parties will work together to address the concerns raised under this clause;

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

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

25. Termination

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

25.2 Where one party:

- (a) fails to comply with its obligations under the Agreement and the other party considers the failure can not be remedied; or
- (b) repeatedly fails to comply with its obligations under the Agreement; or
- (c) by written notice, withdraws from carrying out the Research; or
- (d) being a corporation, comes under one of the forms of external administration referred to in chapter 5 of the *Corporations Act 2001*, or an order has been made for the purpose of placing the corporation under external administration; or
- (e) being an individual, becomes bankrupt or enters into a scheme of arrangement with creditors;

the other party may, by written notice -

- (f) terminate this Agreement.

26. Negation of Employment, Partnership and Agency

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

27. Waiver

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

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

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

28. Assignment

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

29. Notices

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

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

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

THE SCHEDULE

A. Research Organisation's Representative

Dr. Luis Ortiz-Catedral

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

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

B. DNP's Representative

Craig Doolan

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

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

C. Specified Personnel

C.1 Lead Researcher - Professor Dianne Brunton

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

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

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

D. Research

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

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

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

Research Outcomes

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

Research Activities

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

1. B Research Title

Determining the morphological differences in male and female green parrots

Research Objectives

1) To establish the beak size range of male compared with female parakeets;
2) determine if there is a sex bias in juvenile parakeets

Research Outcomes

This research will verify if current practices of determining the sex of a juvenile parakeet are accurate

Research Activities

1) DNP is responsible for collection of samples
2) Research Organisation is responsible for analysis of samples
3) DNP is responsible for comparing sample analysis with morphological data
4) DNP and Research Organisation will co-author a peer reviewed journal article

2. Research Title

Breeding biology

Research Objectives

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

Research Outcomes

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

Research Activities

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

3. Research Title

Estimating seasonal variability in the food resources of Green parrots on Norfolk Island

Research Objectives

1) Quantify the number of species used as food sources by Green parrots;
2) Determine changes in food availability of food items that represent >10% of total observations;
3) Estimate visitation rates of Green parrots to feeding trees using motion-triggered cameras

Research Outcomes

1. Report to DNP describing the variety of food items consumed by Green parrots
2. Publication of at least one scientific paper describing the results of this component
3. Elaboration of two Master's thesis at the Research Organisation

Research Activities

Objectives 1,2 & 3 are the responsibility of the Research Organisation
Objective 1: Four field trips per year, 2-4 weeks in duration
Objective 2: Four Field trips per year, 2-4 weeks in duration
Objective 3: Estimation of visitation rates of Green parrots to feeding trees using motion-triggered cameras

4. Research Title

Investigating movements and behaviour via radio-tracking

Research objectives

To investigate:

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

Research outcomes

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

Research Activities

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

E. Environmental Conditions

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

ii. The Research must be conducted out of view of the general public where possible.

iii. Before entering or moving around the Reserve, the Research Organisation must take all reasonable steps to clean vehicles and other transport if they have been off sealed or graded roads, to ensure they do not spread weed seeds or pathogens in the Reserve.

iv. All traps, nets and any other devices used for capturing and securing animals, and any devices that are to be attached to animals, must be thoroughly cleaned, and free of any pathogens that may cause disease, before they are brought into the Reserve or moved between areas within the Reserve.

v. The Research Organisation must comply with the conditions specified in Attachment B.

F. Research Period

The Research Period will commence 4th June 2013 and will end on 1st May 2017, unless terminated earlier in accordance with this Agreement.

G. DNP's Contribution

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

i. Lifts in DNP vehicles;

ii. Use of DNP computers in the Reserve;

iii. Staff time and expertise;

H. Research Organisation's Contributions

The Research Organisation agrees to provide the following:

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

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

I. Material to be provided by DNP

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

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

ii. The following biological material:

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

J. Use of DNP Material

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

i. only use DNP's Material for the purposes of Item D [*Research*];
ii. obtain written approval from DNP before disclosing or sharing DNP Materials to a third party; and
iii. upon termination of this Agreement (unless DNP agrees otherwise), return all DNP Materials provided and destroy any copies held in the Research Organisation's possession.

K. Confidential Information

i. Location of Green Parrot nest sites

L. Attribution

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

i. Abigail Smith and Dr. Luis Ortiz-Catedral or
ii. as agreed between the parties (including waiving attribution where appropriate).

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

i. Abigail Smith or
ii. as advised by DNP (including waiving attribution where appropriate).

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

i. Dr. Luis Ortiz-Catedral; or
ii. as advised by the Research Organisation (including waiving attribution where appropriate).

M. Acknowledgment

DNP is to be acknowledged as follows:

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

N. Reporting

N.1 – Meetings

The Research Organisation and DNP agree to meet:

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

N.2 – Reports

Reports to DNP are to be sent to

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

The Research Organisation will provide:

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

O. Insurance

Each party shall maintain:

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

P. Intellectual Property

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

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

EXEUCTION

Signed as an Agreement

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

[signature of witness]

Park Manager

CASSANDRA JONES

[name of witness]

11/04/2016

[date of signature]

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

[signature of witness]

Hon. Steve Maharey

Vice-Chancellor

[name of witness]

[date of signature]

ATTACHMENT A

Attachment A to the Collaborative Research Agreement.

A PCR survey for beak and feather disease virus (BFDV) on Norfolk Island

ATTACHMENT B

A. General Conditions

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

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

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

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

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

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

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

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

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

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

(a) behave contrary to the EPBC Regulations or any warning or regulatory signs;

(b) pick fruits, flowers or branches, or otherwise damage any native plants;

(c) interfere with, feed, handle or disturb any native animal, or damage or disturb a nest or dwelling place of a native animal;

(d) touch or interfere with any rock art, sacred site or cultural artefact;

(e) impede public access to any part of the reserve.

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

(a) the Research Organisation sells any part of the organisation to which the Agreement relates, or for any other reason ceases to conduct the Research;

(b) the Research Organisation is a company and there is a change in the owners of the majority of issued shares in the company.

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

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

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

(a) notify the Research Organisation of the contravention; and,

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

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

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

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

---

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

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

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

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

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

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

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

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

B. Scientific Research Conditions

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

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

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

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

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

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

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

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

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

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

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

C. Norfolk Island Conditions

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

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

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

Note: Maximum size of vehicle permitted in the reserve:

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

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

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

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

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

ATTACHMENT C

Attachment C to the Collaborative Research Agreement.

Parks Australia Research Publishing Policy

A.2 APPENDIX 2

A.2.1 Raw Data For The Tasman Parakeet Diet

Table 1. Total number of observations of plant species consumed by the Tasman parakeet per season (excluding non-dietary items). (For common names see Table 3, Chapter Three).

Species	Winter	Spring	Summer	Autumn	Total
Araucaria heterophylla	66	10	0	36	112
Baloghia inophylla	1	2	0	0	3
Capparis nobilis	0	1	0	0	1
Dodonaea viscosa	0	76	0	0	76
Elaeodendron curtipendulum	0	0	0	1	1
Hakea salicifolia salicifolia	0	2	0	0	2
Hibiscus sp	0	2	0	0	2
Korthalsella disticha	0	0	0	2	2
Lagunaria patersonia patersonia	0	1	0	0	1
Macropiper excelsum psittacorum	0	1	0	0	1
Melia azedarach	3	0	0	3	6
Melodinus baueri	0	1	0	0	1
Meryta angustifolia	1	0	0	0	1
Meryta latifolia	0	0	0	1	1
Myrsine ralstoniae	0	5	2	0	7
Nestegis apetala	4	11	0	0	15
Olea europaea cuspidata	11	7	23	28	69
Oplismenus hirtellus	0	0	0	1	1
Pennantia endlicheri	0	0	0	3	3
Prunus persica	0	12	0	0	12
Psidium cattleianum	0	1	14	18	33
Pyrrosia confluens	0	3	0	0	3
Rhopalostylis baueri	15	73	3	32	123
Solanum mauritianum	0	2	0	2	4
Zanthoxylum pinnatum	0	3	0	0	3
Total	101	213	42	127	483

Table 2. Total number of observations for different food types per season. Sample Size (n) per season: Winter = 101, Spring = 213, Summer = 42, Autumn = 127.

Food type	Dry fruit	Dry seed	Fleshy Fruit	Flowers	Leaves
Winter	1	62	34	0	0
Spring	18	97	84	3	7
Summer	0	27	14	1	0
Autumn	0	103	22	1	0
Total	19	289	154	5	7
Food type	Pedicel	Pollen	Rhyzome	Sori	Sprout
Winter	0	4	0	0	0
Spring	2	0	1	1	0
Summer	0	0	0	0	0
Autumn	0	0	0	0	1
Total	2	4	1	1	1

A.3 APPENDIX 3

A.3.1 Tukey Honest Significant Differences

The following figures show a visual comparison of the 95% confidence intervals for mean differences in measurements of bill morphology between pairs of *Cyanoramphus* species constructed by the Tukey HSD test procedure.

Sample sizes were consistent for all comparions: *C. auriceps* = 17, *C. cookii* = 3, *C. novaezelandiae* = 38, *C. unicolor* = 5.

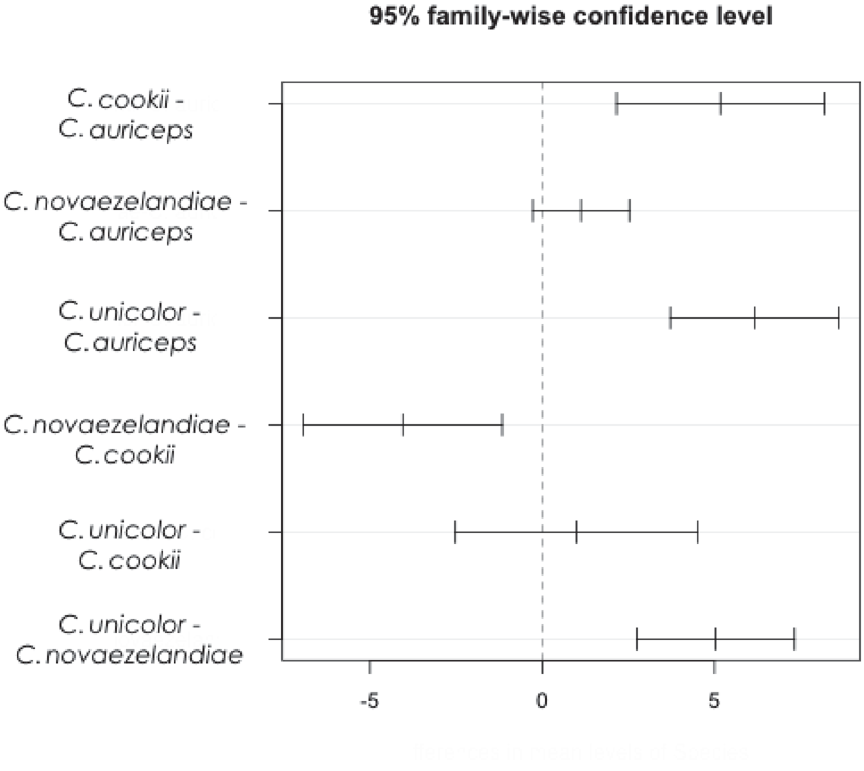

Figure 1. 95% confidence intervals for mean upper bill length (mm).

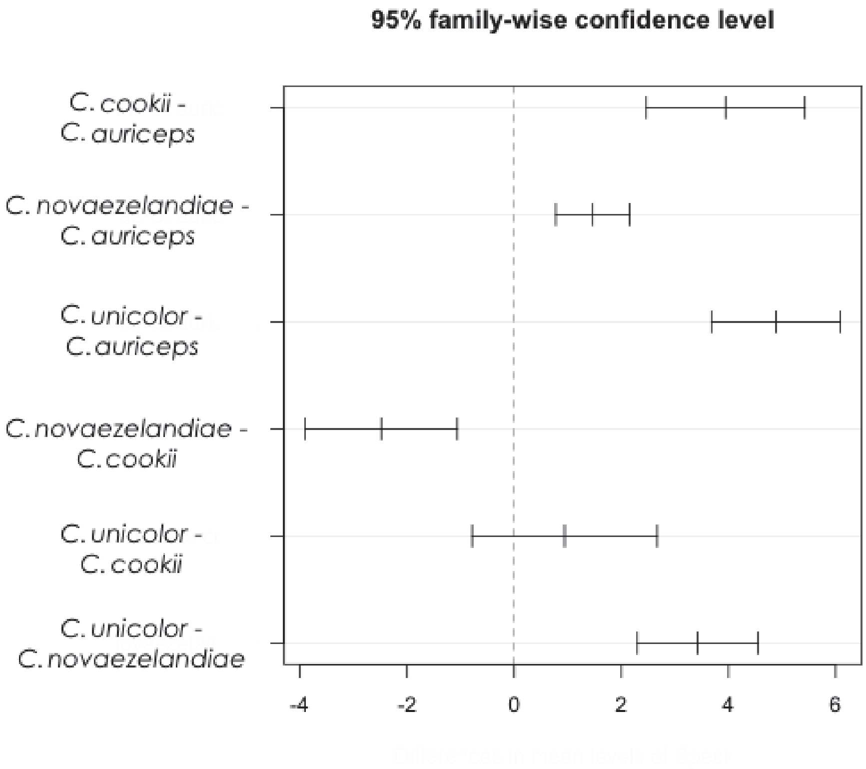

Figure 2. 95% confidence intervals for mean upper bill width (mm).

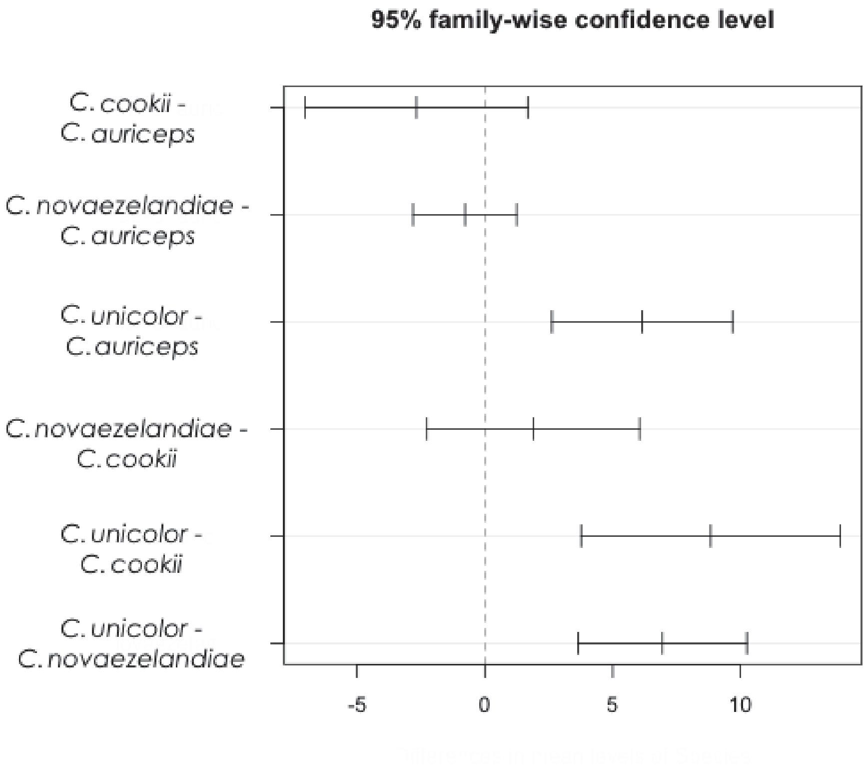

Figure 3. 95% confidence intervals for mean upper bill depth (mm).

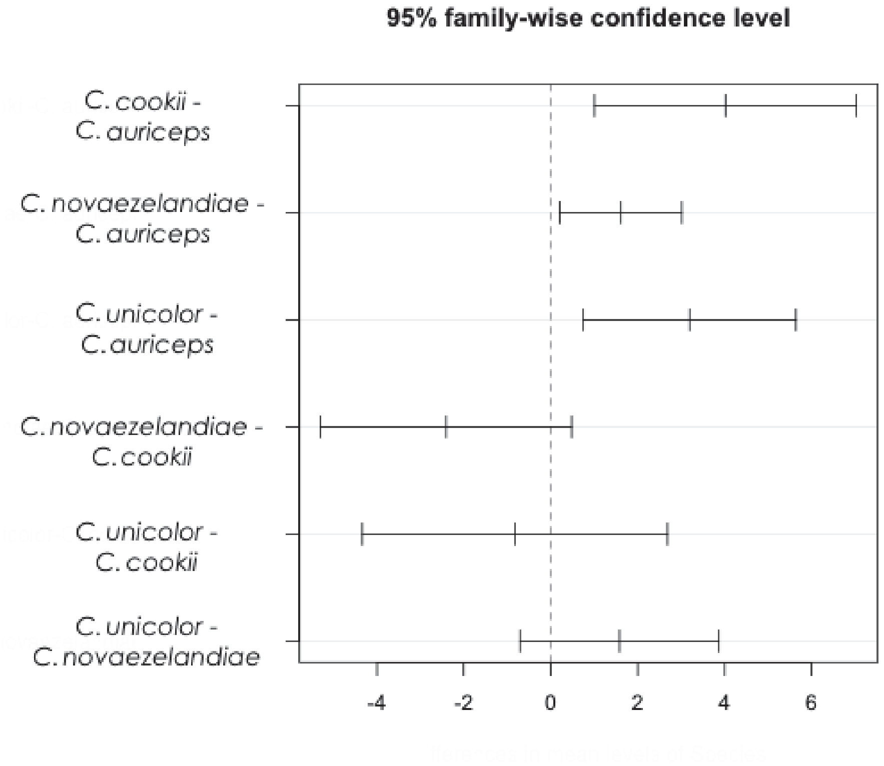

Figure 4. 95% confidence intervals for mean lower bill basal width (mm).

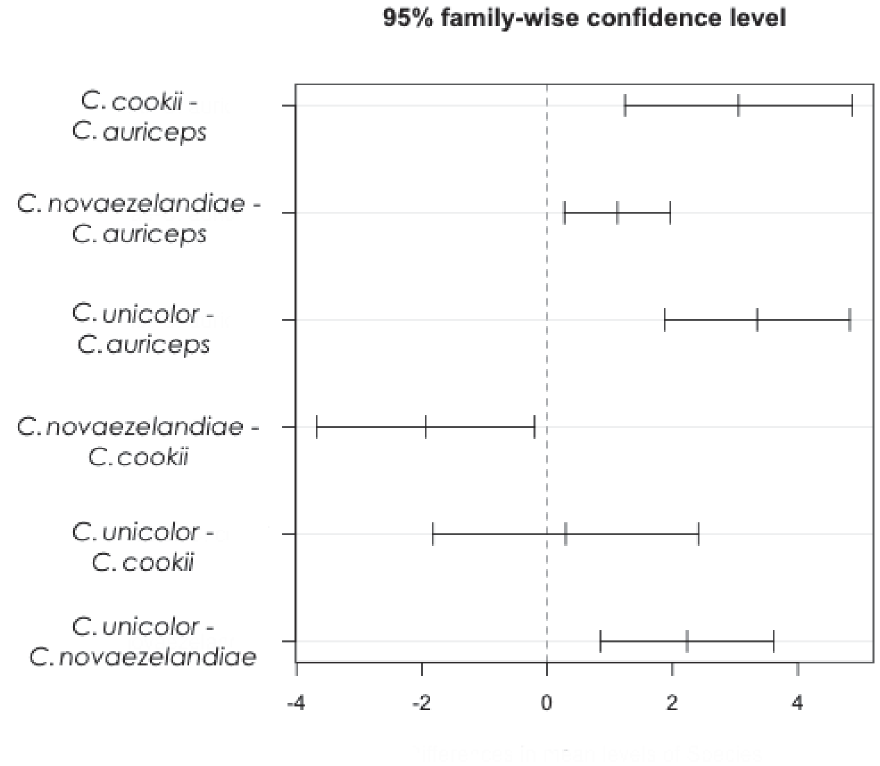

Figure 5. 95% confidence intervals for mean lower bill distal width (mm).

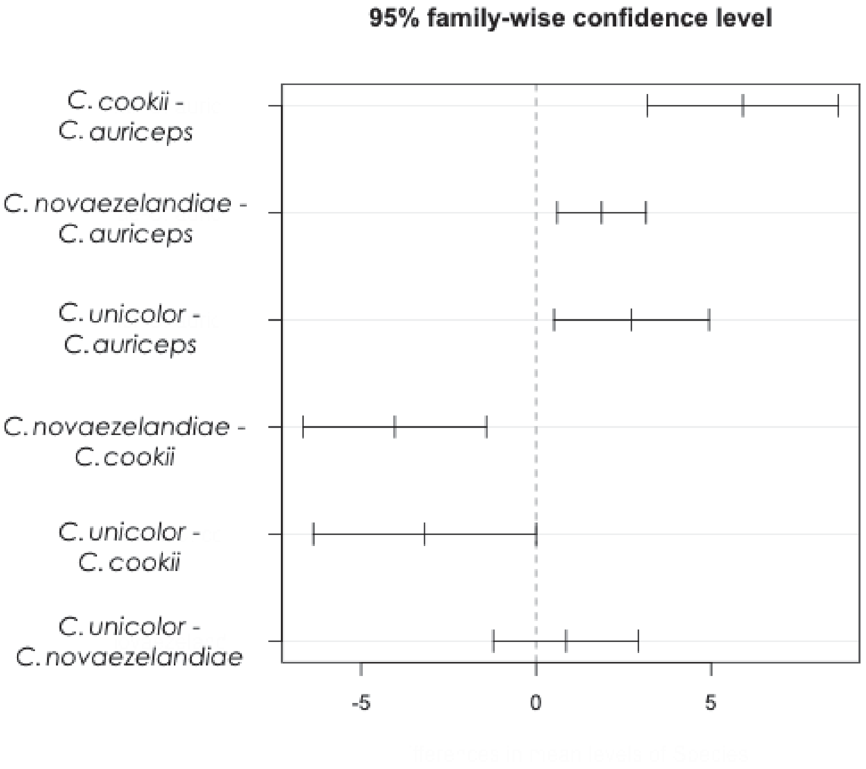

Figure 6. 95% confidence intervals for mean lower bill length (mm).

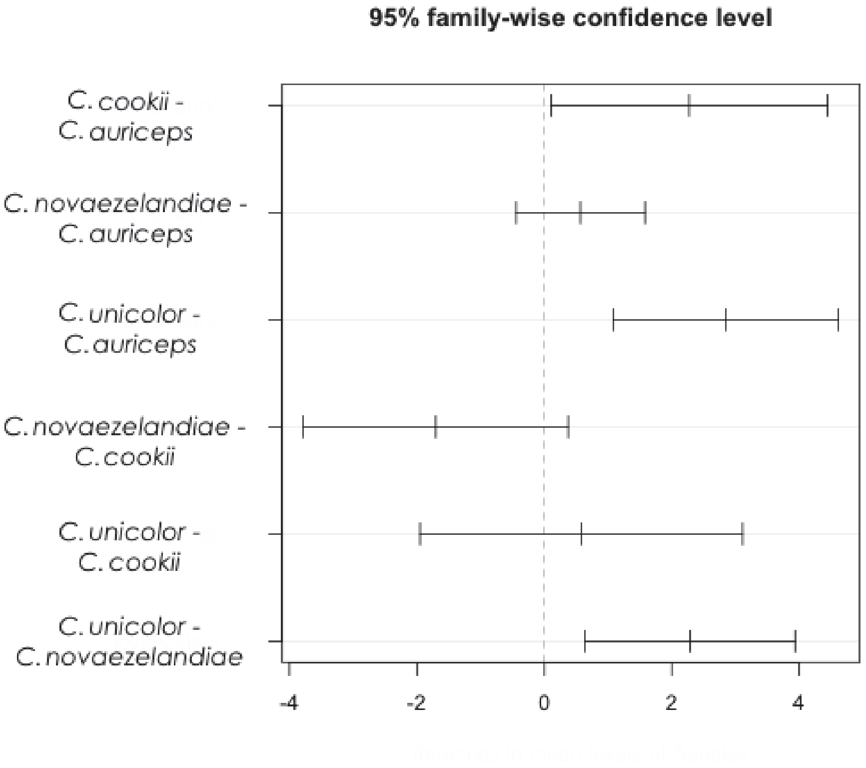

Figure 7. 95% confidence intervals for mean lower bill width (mm).