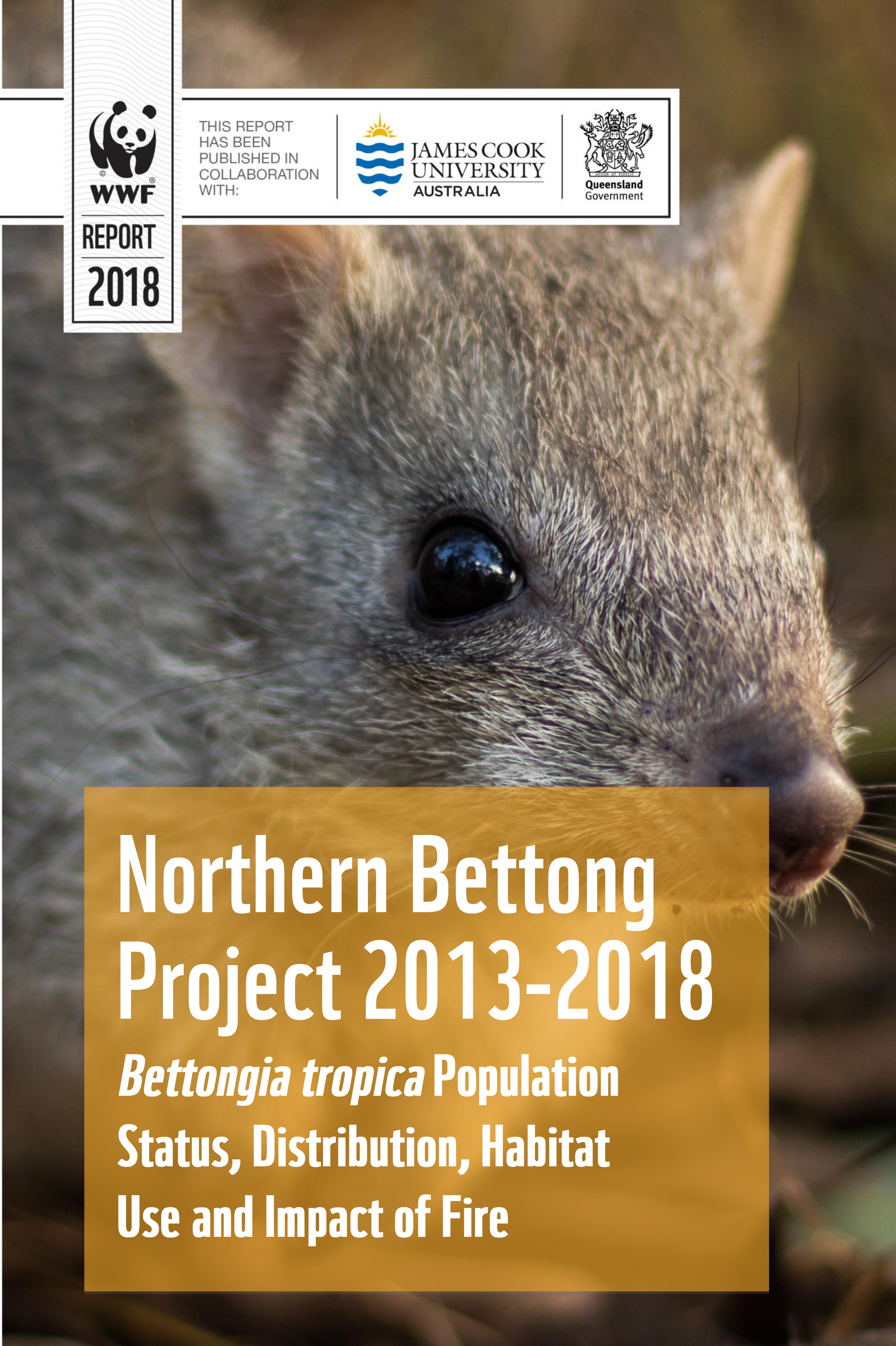

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Northern Bettong Project 2013-2018

Bettongia tropica Population Status, Distribution, Habitat Use and Impact of Fire

CONTENTS

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Project Team

Lead Organisation: WWF-Australia

Project Manager: Darren Grover & Tim Cronin

Project Officer/ Principal Ecologist: Caitlin Weatherstone & Jess Koleck

Project & Research Partner: James Cook University

Project Partner: QLD Department of Environment and Science, Conservation and Sustainability Services (formerly QLD Department of Environment and Heritage Protection)

Project Partner: QLD Department of Environment and Science, Queensland Parks and Wildlife Service (formerly Department of National Parks, Sport and Racing)

Report Editor-in-Chief: Caitlin Weatherstone

Co-Authors: Tim Cronin, Dr. Sandra Abell, Dr. Susan Nuske, Dr Tegan Whitehead, Stephanie Todd

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EXECUTIVE SUMMARY

Context

The northern bettong (*Bettongia tropica*) is an endangered, tropical marsupial limited in distribution to the Wet Tropics bioregion of far north Queensland. Its populations have declined significantly since the arrival of Europeans to Australia. As their populations continue to decline, drastic measures may need to be considered to save the species from extinction in the coming decades.

The Northern Bettong Project was led by WWF-Australia in collaboration with partners James Cook University (JCU), QLD Department of Environment and Science (DES) Conservation and Sustainability Services and DES Queensland Parks and Wildlife Service (QPWS). The Project was funded under the Australian Government's National Landcare Program.

Left: Historical northern bettong records in the Wet Tropics, from 1922-2015 (n=294), clustered at five population centres (red): Mt. Windsor, Carbine Tableland, Lamb Range, Greater Ravenshoe and Coane Range (from north to south). Right: Recent sightings have only recorded northern bettongs in two distinct populations: Carbine Tableland (top) and Lamb Range. Area of occupancy highlighted in orange.

Objectives

This report outlines the results of the Project, which spanned five years between 2013 and 2018. The Project set out to achieve three primary objectives:

1. Estimate the current population status, distribution and habitat use of the northern bettong;
2. Assess the significance of the northern bettong's role in ecosystem function;
3. Develop appropriate fire management regimes for the northern bettong.

Methods

Personnel

This Project combined the skills and expertise of partners, as well as local Traditional Owners, private conservation organisations, natural resource management bodies, research institutions, government departments, independent scientists, community groups and volunteers. The Project involved over 100 people across Queensland.

Study sites

The study was carried out within and adjacent to the World Heritage listed Wet Tropics area of far north Queensland on National Park, State Forest Reserve and private land tenure. Survey sites were selected using historical records from Wildnet's database and habitat modelling developed by the Queensland Herbarium in 2012. Key areas within the 5,000km² known extent of occurrence (EoO) were searched, as well as other areas deemed suitable by Recovery Team members. Areas were searched both within the mapped area and outside it in suitable habitat. Majority of the finer scale habitat and population survey work was carried out at three subpopulations of Lamb Range – Tinaroo Creek, Davies Creek and Emu Creek.

Data collection and analysis

Due to the large size and scale of this Project, several different methods were used to achieve the Project's objectives. This included cage trapping, camera trapping, collaring of animals, collection of scats, oorts (bettong spit-balls of regurgitated grass), habitat data and fungi, desktop analysis of data and DNA analysis. To assess their current distribution and likelihood of additional northern bettong populations remaining throughout the Wet Tropics, the largest ever search for this species commenced in 2014.

Results

1. Population status, distribution and habitat use

Analysis of historical northern bettong records confirmed their persistence in the Wet Tropics region since the 1920's, and the collection of nine (now museum) specimens - from the late 1880's to the early 1900's - confirmed their population pre-1922 spanned from Rockhampton in central Queensland to the Wet Tropics. Analysis since has shown a decline in the distribution of northern bettong populations by over 90% since the arrival of Europeans to Australia. Prior to this Project's commencement in 2013, most of the research into the northern bettong's ecology, habitat requirements, life history and population trends had been concentrated from the early 1990's until 2009. During this time, it was found that this species was now restricted to the western edge of the Wet Tropics in a narrow band of wet sclerophyll forest and open woodland from Mount Windsor to Coane Range, with 90% of the records confined within the Mareeba Shire Council area. The species was thought to persist in at least four distinct population areas – Mt. Windsor, Carbine Tableland, Lamb Range, Coane Range - and possibly in a fifth area in the greater Ravenshoe region. Since there had been no recent recorded sightings in three of the four areas in the last three decades (1986-2015), the only ongoing population was known to be in the Lamb Range in three to five subpopulations - Tinaroo Creek, Emu Creek, Davies Creek, Brindle Creek and Clohesy Creek.

Population status and trends

Cage trapping in the Lamb Range's three subpopulations resulted in the capture of 1,094 northern bettongs consisting of 188 individuals. Most individuals and captures were recorded at Tinaroo Creek, with the least at Davies Creek. Northern bettong individuals at Davies Creek, Emu Creek and Tinaroo Creek were caught up to 25, 25 and 27 times respectively. Across all sites, >70% of individuals were captured more than once, with individuals on average being caught six times throughout the duration of the study. At Davies Creek, Emu Creek and Tinaroo Creek, population density averaged 7.17 bettongs/km², 8.82 bettongs/km² and 13.00 bettongs/km² respectively. Density estimates at Tinaroo Creek were substantially higher than the other sites.

The Lamb Range population was determined to be stable when compared with a similar population study conducted 20 years prior in the same location.

Fine scale distribution and movement patterns

In the Lamb Range, northern bettongs had home ranges of 20.90 ± 1.55ha (mean ± SE), with home ranges largely overlapping between individuals. Within their home ranges, bettongs had separate core foraging areas and nesting areas. Across all sites, males had larger home ranges than females, with home ranges of both genders increasing during the dry season. Home ranges were similar between sites, indicating that the density of food resources was also similar between sites. The distribution of males appeared influenced by the distribution of females and food resources; whilst females were influenced only by the distribution of food.

Microhabitat requirements

Camera trapping in the Lamb Range resulted in a total of 154,047 camera images with animal detections. Northern bettongs comprised 17% - 31% of all camera captures across the three sites. Predator and competitor species constituted less than 4% of captures at each site. There was a ratio of around one predator image per 60-70 images of northern bettongs and an average of one competitor to 92 images of northern bettongs. Other wildlife species were detected on camera traps, with Emu Creek having a higher diversity of species. Predation risk appeared to influence both nesting and foraging microhabitat selection of northern bettongs. Across all sites, mammalian predators detected on camera traps included wild dogs or dingoes (*Canis lupus*), with one feral cat also detected at Tinaroo Creek. Competitors such as the feral pig (*Sus scrofa*) occurred throughout the landscape, while rufous bettongs (*Aepyprymnus rufescens*) were detected only at Emu Creek.

Different habitat parameters were found to be important for nesting and foraging. Nests were situated in steep areas with high grass cover and an abundance of grass trees. Whilst foraging, northern bettongs selected habitats with a higher density of cockatoo grass (*Alloteropsis semialata*), a lower density of tree basal area, taller (mature) trees and steeper slopes.

Broad distribution

The camera trapping surveys throughout the Wet Tropics bioregion featured primarily on infertile granitic soils across a range of tenures and regional ecosystem (RE) types. The modelled habitat included a narrow 10-kilometre-wide strip located to the west of Wet Tropics rainforest. The habitats searched for northern bettongs included 15 RE types consisting of; open woodland dominated by cabbage gum (*Eucalyptus platyphylla)*, lemon-scented gum (*Corymbia citriodora)*, forest red gum (*Eucalyptus tereticornis*), ironbarks (*Eucalyptus spp*.) and bloodwoods (*Corymbia spp*.); she-oak forest dominated by *Allocasuarina torulosa* and *Allocasuarina littoralis*; open wet sclerophyll forest dominated by turpentine (*Syncarpia glomulifera)*, rose gum (*Eucalpytus grandis)* and red mahogany (*Eucalyptus resinifera);* and closed wet sclerophyll forest/rainforest edges dominated by rose gum.

The large-scale survey to search for extant populations of the northern bettong deployed 587 sensor cameras over a three-year period (2015-2018). A total of 11 key areas were chosen and covered approximately 95,000 hectares of native forest between Mt. Windsor and the Coane Range near Paluma. These surveys were successful in re-discovering the Carbine Tableland population of the northern bettong in 2016 - which had not been recorded since 2003 – validating their ongoing presence in the Lamb Range and recording an individual for the first time in the north-western Lamb Range area near Koah. Out of the 11 areas searched, northern bettongs could only be detected at those two (of the four recently known) locations, which fall within the Mareeba Shire Council region and across three different RE types. In total, 1,032 photographs of northern bettongs were recorded from nine cameras across the two locations. Northern bettongs were not detected in any of the other nine areas, or from areas that were modelled as having potentially suitable habitat. Rufous bettong were located at 70% of key areas, all negative for northern bettong. The only area with neither bettong species detected was Upper Daintree. Other key areas that were not mapped as being suitable were also surveyed, with no northern bettongs detected. All 11 surveyed areas had introduced mammals present, with 80% capturing cattle and pigs and 40% capturing feral cats. 64% also captured wild dogs, or dingoes, however the survey did not distinguish between the two.

Based on this data, a conservative estimate of extent of occurrence (EoO) is approximately 1,100km² and the area of occupancy 145km². This represents approximately a 70% decline from an estimate of 500km² in 2008.

Population viability

Population viability models indicated that an increase in juvenile mortality rate, particularly from predation by feral cats, was the greatest threat to the northern bettong's survival. Modelled by Whitehead *et al.* (2018) under a high scenario of cat predation, it was found that the northern bettong metapopulation in the Lamb Range could become extinct within the next 10 years.

Non-invasive conservation genetics

Trials were conducted to determine if non-invasive sampling techniques, such as remote DNA collection (using scats, oorts or hair), could be used as a tool for population monitoring into the future, replacing the current time-and-resource-intensive method of cage trapping. Hair, oorts and tissue samples were collected from northern bettong habitat and during the trapping process. Despite the ethical advantages and potential for non-invasive sampling the DNA contained in non-invasive samples is often poor quality and low quantity. Oorts do contain DNA and it may be theoretically possible to identify individual bettongs using DNA fingerprinting (microsatellite genotyping). However, the combination of low success rate, high error rate and expense mean that it is currently unsuitable to use for population monitoring of northern bettongs. However, oort mitochondrial DNA can be used to unambiguously identify the presence of bettongs in an area and could therefore be useful for further monitoring and management. Conversely, the relatively high success rate and cost of extraction and amplification of DNA from hair means it has a high potential to be used for northern bettong population genetic studies.

2. Role in ecosystem function

This Project successfully determined that the northern bettong plays a crucial and irreplaceable role in its ecosystem as a keystone species, as it is fundamental in the dispersal of a unique array of ectomycorrhizal (ECM) truffle fungi. Unlike mushrooms, below-ground truffle fungi require mycophagous (fungi-eating) mammals - like the northern bettong - to dig-up, consume and disperse their spores. ECM fungi are essential for healthy ecosystem functioning as they form symbiotic relationships with woodland trees by attaching to their roots and providing nutrients to the trees in exchange for sugars. As part of this project, Nuske (2018) found that truffle taxa form dominant components of the ECM community on roots within these forests and these taxa were favoured by the northern bettong in areas of their occurrence. Compared to the combined dispersal role from nine other fungus-eating mammal species in the same habitat, the northern bettong was found to consume many more ECM truffle taxa. Up to 77 ECM truffle taxa were unique to the northern bettong's diet. This implies that the northern bettong plays a unique and potentially irreplaceable role in the dispersal of essential ECM truffle fungi in these habitats. The loss of the northern bettong could have a detrimental effect on the truffle biodiversity in these habitats, altering ECM communities, with unknown consequences for plant-fungal interactions and ecosystem health.

3. Fire management

Fire management is an important element of forest and woodland maintenance and inappropriate fire is listed as a key threatening process to the northern bettong. A desktop study and expert elicitation of fire management in northern bettong habitat informed the development of a set of guidelines for managing fire in northern bettong habitat; which can now be accessed for free on the Department of Environment and Science's (DES) website. The guide outlines the many habitat features and fire management challenges that land managers face and offers tailored solutions for individual land manager's habitat management objectives across the landscape (e.g. maintaining cockatoo grass, lantana control and suppressing rainforest encroachment). Depending on which outcomes the land manager requires, there are a range of recommendations for fire management, including fire intensity, patchiness, fire interval, and in what conditions and when to burn. These burning regimes set out by the guidelines may result in positive outcomes for the northern bettong, such as maintaining healthy habitat, providing resource refugia, regaining connectivity, promoting truffle diversity, improving grass diversity and generally improving their habitat.

Key points and discussion

The Northern Bettong Project was highly successful in achieving its original objectives to estimate the current population status, distribution and habitat use of the northern bettong; assess the significance of the northern bettong's role in ecosystem function and; develop appropriate fire management regimes for the northern bettong. These objectives could not have been achieved without the support, knowledge and collaborative efforts of Project partners and other local stakeholders. The following key points were highlighted as significant outcomes from the Project's combined research;

- The northern bettong has suffered a decrease in area of occupancy by about 70% - from 500km² to 145km² in the last three decades
- The number of distinct populations have decreased by 50% - they could only be located in two distinct populations, Mt. Spurgeon (in the Carbine Tableland) and Lamb Range; 90% of records fell within the Mareeba Shire Council region
- Surveys were successful in re-discovering the Carbine Tableland population of the northern bettong in 2016 - which had not been recorded since 2003
- The Lamb Range's northern bettong population is considered 'stable'; the Carbine Tableland's population status is still unknown
- The highest density of northern bettongs was found at Tinaroo Creek (13 bettongs/km²)
- PVA models showed that an increase in juvenile mortality rate, particularly from predation by feral cats, was the greatest threat to the northern bettong's survival when compared with fire and climate change
- As modelled under a high cat predation scenario, the northern bettongs in the Lamb Range could become extinct within 10 years
- Northern bettongs have varying habitat requirements over the course of their day; they prefer nesting sites situated in steep areas with high grass cover and an abundance of grass trees whereas they prefer foraging sites with a higher density of cockatoo grass, a lower density of tree basal area, taller (mature) trees and steeper slopes
- The northern bettong and rufous bettong were negatively correlated, with both species only co-existing at Emu Creek. They did not overlap on any other site surveyed in the Wet Tropics
- Rufous bettong are now found at seven sites (~70%) of historical northern bettong presence/ potential habitat (excludes Upper Daintree) and may be an indication of the marginalisation of habitat due to the impacts of climate change
- Introduced mammals were observed at all 11 areas surveyed for northern bettongs. These include feral cats (found at ~40% of sites) and pigs (80%). Wild dogs, or dingoes, were also found at 64% of sites, though the survey did not distinguish between the two. No red foxes were detected.
- Northern bettongs were detected in three different RE habitat types within the Mareeba Shire Council region only
- At this time non-invasive DNA analysis of scats, hair and oorts was determined to not be a feasible replacement for invasive population sampling techniques (cage trapping)
- The northern bettong was found to consume many more ECM truffle taxa when compared to the combined dispersal role from nine other fungus-eating mammal species in the same habitat; Up to 77 ECM truffle taxa were unique to the northern bettong's diet
- The important role of the northern bettong in maintaining forest health (as an ECM fungal disperser)

classifies them as a keystone species

- Fire research led to the development of a 'Guidelines for managing fire in northern bettong (*Bettongia tropica*) habitat' document, which is available as a PDF on the DES website
- These guidelines aim to instruct land managers how to conduct fire management on their properties targeting specific outcomes such as promoting ECM fungal diversity, cockatoo grass coverage and weed management.

It is clear from the results of this Project that northern bettong populations have suffered drastic reductions over the last three decades. Although, it is promising to see northern bettong populations still holding on in the Carbine Tableland area (population status still unknown) - an area which had not recorded a northern bettong sighting since 2003 - and the Lamb Range population's continued stability. It is likely that the overall population decline is due to several, compounding anthropogenic and natural factors. Changes in climate, land use and land management practices since European arrival in Australia - including changed fire regimes, habitat clearance, land degradation and the introduction of cattle, pigs and predators such as cats – are all likely to be among the drivers. Infectious disease was tentatively ruled out as a causative factor although this could represent a serious future threat with a precedent in the closely related *B. penicillata*. Predation from cats was modelled as being the most important factor in northern bettong population viability, particularly if the cats target juveniles. This affect could also be exacerbated by the northern dispersal of the red fox (*Vulpes vulpes;* a known bettong predator). All 11 surveyed areas had introduced mammals present, including cats, cattle and pigs. No red foxes were detected. While minimising the predation of juveniles is likely to assist in maintaining their population stability, there also needs to be a focus on restoring and maintaining suitable northern bettong habitat and associated regional ecosystem types.

Recommendations

Further research, coupled with coordinated action, is urgently needed in order to halt and reverse the population decline of the northern bettong and prevent potential extinction within the coming decades.

Priority actions:

- Conserve and restore northern bettong habitat
- Address key threats to the northern bettong and its habitat, including fire and pests (cats, cattle, pigs)
- Consider uplisting of the northern bettong to 'critically endangered', including further assessment against relevant criteria and thresholds
- Explore options for an insurance population of northern bettongs

Priority research:

- Clarify population status and viability on the Carbine Tableland
- Refine the population estimate using new habitat data
- Refine the habitat model to incorporate new data
- Improve understanding of the effects of climate, fire, cats, cattle, pigs and dogs on the northern bettong and its habitat
- Clarify the relationship between the northern bettong and rufous bettong (as competitors)
- Explore the potential of DNA to study northern bettongs in a non-invasive way

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PROJECT BACKGROUND

In 2013, WWF-Australia was successful in obtaining a five-year Australian Government grant to conserve and protect the endangered northern bettong (*Bettongia tropica*). This project brought together the unique skills and expertise of partners James Cook University (JCU), QLD Department of Environment and Science (DES) Conservation and Sustainability Services and DES Queensland Parks and Wildlife Service (QPWS); as well as local Traditional Owners, natural resource management (NRM) bodies, private conservation organisations, research institutions, government departments, community groups and volunteers.

INTRODUCTION

Northern bettongs (*Bettongia tropica*) are small, grey rat-kangaroos that move in a low, springy hop (Figure 1). Adults weigh an average of 1.2 kilograms and their average life span is six years. They can be distinguished from the more common rufous bettong (*Aepyprymnus rufescens*) by their smaller size and distinct brush of black fur along the top of the tail. Northern bettongs have a semi-prehensile tail which is used to grasp and carry nesting material.

NORTHERN BETTONG © STEPHANIE TODD / JCU / WWF-AUS

Figure 1. Northern bettong.

Classification

The northern bettong is currently listed as 'endangered' in Queensland under the Nature Conservation Act 1992, 'endangered' nationally under the Environment Protection and Biodiversity Conservation Act 1999 and 'endangered' on the International Union for Conservation of Nature (IUCN) 'Red List of Threatened Species' (IUCN 2018).

Historical populations

Prior to the 1970's, the northern bettong was largely only known from nine museum specimens (Winter 1997). These specimens indicated that they were once distributed down the north-east coast of Queensland from Mount Windsor to the Mackay area. Comprehensive northern bettong surveys conducted 15-30 years ago showed that they were now only detected in four geographically small, fragmented areas between 600 and 1,200 metres altitude, stretching approximately 300km long: Mt. Windsor, Carbine Tableland, Lamb Range and Coane Range (Winter 1997). More recent follow-up surveys have failed to reliably detect the most northerly population of northern bettongs at Mt. Windsor since 1989 and the most southerly population at Mt. Zero near Paluma in the Coane Range since 2003 (Wildnet 2018).

Habitat preferences

Our study area and the northern bettongs' preferred habitat is restricted to a narrow (approximately 10km wide) band of wet, open sclerophyll forest and eucalypt woodland, lying just west of the dense rainforest of the Wet Tropics World Heritage area, primarily on granitic soil types (Figure 2; Johnson & McIllwee 1997). Historical records in the Wet Tropics show that northern bettongs have been primarily found in at least 15 different regional ecosystem (RE) vegetation types, including two 'endangered' types - 7.12.22 and 7.12.21 (Appendix 1). These habitats are unique because it can produce enough of the bettong's main food source, hypogeous fungi (underground fruiting bodies of ectomycorrhizal fungi, also known as truffles; Winter 1997; Laurence 1997, Abell et al. 2006). Though, in the last 200 years since the arrival of Europeans to Australia, there has been severe alteration to these habitats caused by a change in Indigenous fire regimes and as much as 50-70% of tall, open forests have been lost due to rainforest encroachment (Harrington & Sanderson 1994). Therefore, fire plays an important role as a tool in maintaining these open forests and determining the biomass of food resources available to the northern bettong. Northern bettongs are nocturnal and solitary animals, with males and females having a home range size of approximately 20-60 hectares (Vernes & Pope 2001; Whitehead et al. 2018). They spend daytime hours sheltering in nests made of grass or other ground litter and come out to forage at night.

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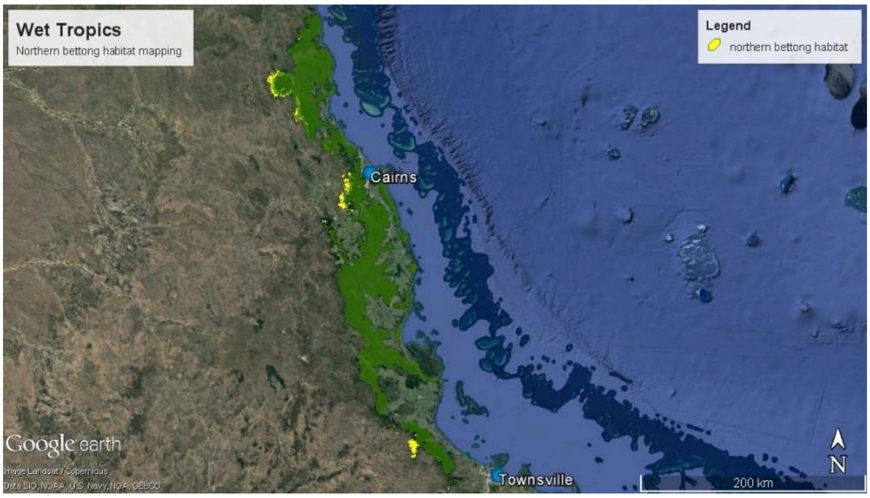

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Figure 2. Left: mapped northern bettong habitat (yellow) in the Wet Tropics World Heritage area (green). Right: Northern bettong habitat in the Lamb Range.

Role in ecosystem function

Northern bettongs depend on truffles as their primary food source throughout the year (Johnson & McIllwee 1998). In turn, northern bettongs play an important role by dispersing truffle spores. Truffles are an essential part of the ecosystem, as they form symbiotic relationships with plants by providing water and nutrients in exchange for sugars (Hawkins *et al.* 2015). In drier times in far north Queensland (primarily July- November), northern bettongs rely less on truffles than in the wet season, and consume more cockatoo grass (*Alloteropsis semialata),* as well as roots, stem, tubers, forbes, lillies and invertebrates (Johnson & McIllwee 1997; Abell *et al.* 2006). Bettongs often dig to find their food, and distinctive diggings are usually found in areas where they are present. When feeding on grasses, they often produce an 'oort' by chewing the base of grass stems, which enables them to extract the nutrients and moisture, then they spit the undigested fibre out. These oorts are important for researchers to help to determine the presence of northern bettongs and can be used as a method for collecting bettong DNA from their saliva, similar to taking a buccal (cheek) DNA swab.

Threats

A major factor in the decline of northern bettongs historically has been the loss or alteration of their habitat. Deviation from the burning regimes originally implemented by Traditional Owners has likely caused significant changes in habitat. Unsuitable fire management has resulted in rainforest plants taking over their habitat forming a closed dense forest, with many wet sclerophyll species unable to germinate in these conditions (Harrington & Sanderson 1994). Overgrazing by introduced herbivores (specifically cattle) can significantly alter vegetation structure, changing the composition of the understorey. Habitat clearing and other human activities continue to erode remaining viable habitat. Additionally, climate change poses a threat to the long-term survival of this species as changes in rainfall can affect food and water availability (Bateman 2012).

Feral animals also may have a large negative impact on northern bettong populations, but these effects are largely unknown. Feral pigs not only alter the northern bettongs' habitat, but may be a major competitor for truffles (Laurence 1997). Introduced predators, especially feral cats and foxes (not yet known to be in the Wet Tropics), prey on small native mammals Australia-wide and have been implicated in the decline of many other bettong species in Australia (Marlow *et al.* 2015).

The IUCN's Red List website (Burbidge & Woinarski 2016) lists the broadly-categorised threats to the northern bettong as:

- Climate change and severe weather (droughts)
- Agriculture and aquaculture (agro-industry plantations and agro-industry grazing, ranching or farming)
- Natural systems modifications (increase in fire frequency/intensity)
- Invasive and other problematic species, genes and diseases (invasive non-native/alien species/disease – feral pigs, feral cats, red fox).

Project context and objectives

The Northern Bettong Project was initiated to investigate their current population status, distribution, habitat use and the effects of fire on their populations. It required a multi-pronged approach and involved many different stakeholders, including state and federal government departments, not-for-profit organisations, Traditional Owners, James Cook University, local community groups and passionate individuals (Figure 3).

Figure 3: Clockwise from top left - Traditional Owners from Girringun Aboriginal Corporation meet with WWF-Australia to discuss the northern bettong; James Cook University and WWF-Aus researchers and volunteers in the Lamb Range; Conservation Volunteers Australia work with researchers; QPWS Rangers, WWF-Aus and volunteers on survey in the Upper Daintree. Source: Jess Koleck/Caitlin Weatherstone WWF-Aus.

This final report outlines the results of the five-year Project in addressing each of its three primary objectives;

Objective 1. Estimate the current population status, distribution and habitat use of the northern bettong;

Objective 2. Assess the significance of the northern bettong's role in ecosystem function;

Objective 3. Develop appropriate fire management regimes for the northern bettong.

OBJECTIVE 1. ESTIMATE THE CURRENT POPULATION STATUS, DISTRIBUTION AND HABITAT USE OF THE NORTHERN BETTONG

a) Population Status

i. Historical Population

Introduction

The first step in conserving the northern bettong is to understand where they are, how many are left and how this has changed over time. From museum specimens collected between 1884 and 1935, it is known that northern bettongs once resided up the north-east coast of Australia from the Dawson Valley near Mackay/Rockhampton to Mt. Windsor near the Daintree (Winter 1997). Studies that have focused over the last three decades (approximately 10 northern bettong generations) have identified that northern bettong populations are generally in decline and have only been detected as four main fragmented populations in the Wet Tropics bioregion; Mt. Windsor, Carbine Tablelands, Lamb Range, Coane Range and possibly the Greater Ravenshoe area (Winter 1997; Laurence 1997). It is known that northern bettong populations are restricted to the western edge of the Wet Tropics region in a narrow band (approximately 10km) of wet sclerophyll forest and open woodland from Mount Windsor in the north to Paluma in the south (Winter 1997; Wildnet 2018). It has historically been recorded from sites between 600 and 1,200m elevation. Its extent of occurrence (EoO) is estimated to be less than 5,000km^2 and its area of occupancy (AoO) is less than 500km^2 (Burnett & Winter 2008).

Methods

An analysis of historical *B.tropica* records in far north Queensland was conducted to determine their distribution and how their populations may have changed over time. Northern bettong records were collected from the Queensland Government's 'Wildnet' database, as well as incidental and reliable sightings provided by the Northern Bettong Recovery Team members.

Results

Analysis of the 294 historical northern bettong records from the Wildnet database (2018) confirmed their persistence in the Wet Tropics region of far north Queensland across five sites between 1922 and 2015 (Figure 4). Most (90%) of the records were within the Lamb Range and Carbine Tableland areas in the Mareeba Shire Council region. There was one recorded sighting in 1922 in the Greater Ravenshoe area and since that time, one other reliable sighting in that general area (Red Road) has been discussed anecdotally (Winter 1997). Over the last 10 northern bettong generations (1986-2016), analysis of the historical records implies that the northern bettong's distinct populations have declined by 75%, with no reliable sighting records from three of the four main populations occurring at Mt. Windsor since 1989 and at both Coane Range and Carbine Tableland since 2003.

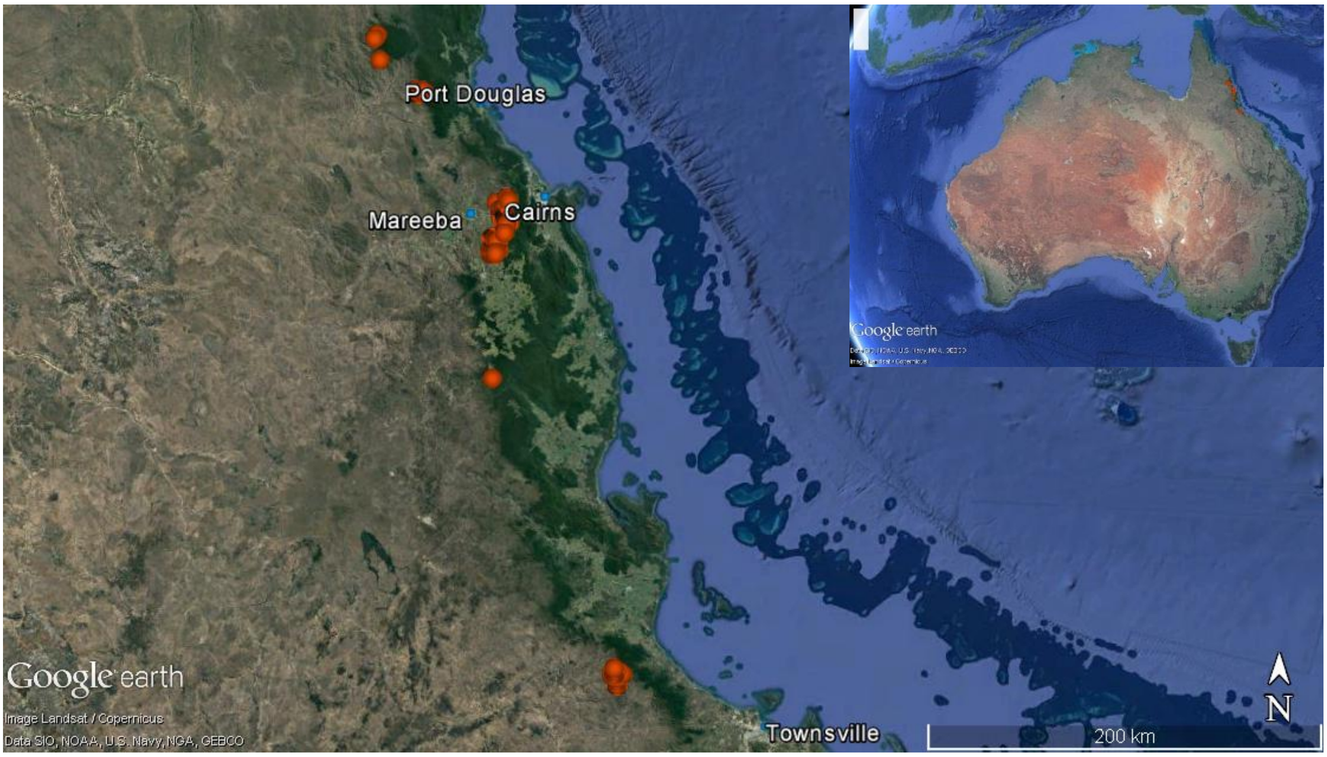

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Figure 4. Historical northern bettong records (n=294; orange dots) from 1922-2015 from north to south; clusters at five population centres; Mt. Windsor, Carbine Tableland, Lamb Range, Greater Ravenshoe and Coane Range. Source: Google Earth 2018, Wildnet 2018

Conclusion

Historically, northern bettongs have been reliably recorded from five main population centres in the Wet Tropics bioregion – Mt. Windsor, Carbine Tableland, Lamb Range, greater Ravenshoe and Coane Range. Although, between 1989 and 2003, northern bettongs could not be located regularly with thorough searches at three of the four main population areas, indicating a sharp decline.

ii. Population viability

Introduction

Widespread population declines of small mammals have occurred throughout Australia. In order to minimise the extent of these declines, it is important to identify and mitigate the main threatening process(es) affecting a species. However, for many endangered species there is limited field data on their potential threats, thus making it difficult for managers to effectively conserve them. A population viability analysis (PVA) is a modelling method used to assess the potential impacts of multiple threatening processes on a population and to estimate the probability of a population becoming extinct over a certain period of time. PVA can be used to highlight the most probable cause of declines or future declines. This knowledge can be used to develop effective management strategies to minimise potential population declines. Additionally, it facilitates pro-management actions to be undertaken, rather than waiting until extensive amounts of field data are collected. Managing a population earlier may assist in minimising or preventing species declines, thus increasing a species' likelihood of survival.

Methods

A PVA was conducted by Whitehead *et al.* (2018) to predict the probability of persistence of northern bettong populations over a 100-year period for each sub-population in the Lamb Range (Bridle Creek, Davies Creek, Emu Creek and Tinaroo Creek), as well as the greater Lamb Range metapopulation. Data on life history characteristics and the abundance and distribution of *B. tropica* were collated from mark-recapture studies undertaken between 1994 and 1997 were used to inform the model. Modelling was undertaken using the PVA simulation computer program Vortex (Version 10) and 1000 iterations of the model. The persistence of northern bettong populations under different scenarios were modelled. These scenarios included an increase in predation of northern bettongs by cats (*Felis catus*), increased fire intensity, increased drought severity and the combination of these factors (increased cat predation + fire and increased drought + fire). Additionally, changes in adult, juvenile and dispersing sub-adults were modelled using sensitivity analysis to determine how sensitive the model was to increasing mortality rates.

Results

Whitehead *et al.* (2018) found that increases in juvenile mortality rate was the greatest threat to the northern bettong populations. An increase in predation rates from feral cats was modelled as having a greater impact than either increased fire or drought severity. Under high scenarios of cat predation (60% increase from current levels, modelling suggested that the bettong metapopulation (all sub-populations) could become extinct within less than 10 years (Figure 5). Predation rates from feral cats may be worsened by the use of inappropriate fire regimes, such as those that result in a loss of grass cover (which bettongs rely upon to hide from predators). Drought and fire had limited impact upon the viability of bettong populations. However, since drought and fire are interlinked, the impacts of predation could be more severe with climate change should predation and fire interact to increase the mortality risk of bettongs. These results can be used to guide management strategies. Based on the PVA, it is recommended that predator populations be assessed and controlled. This would minimise predation, particularly of juveniles, which should assist in maintaining the stability and survival of northern bettong populations.

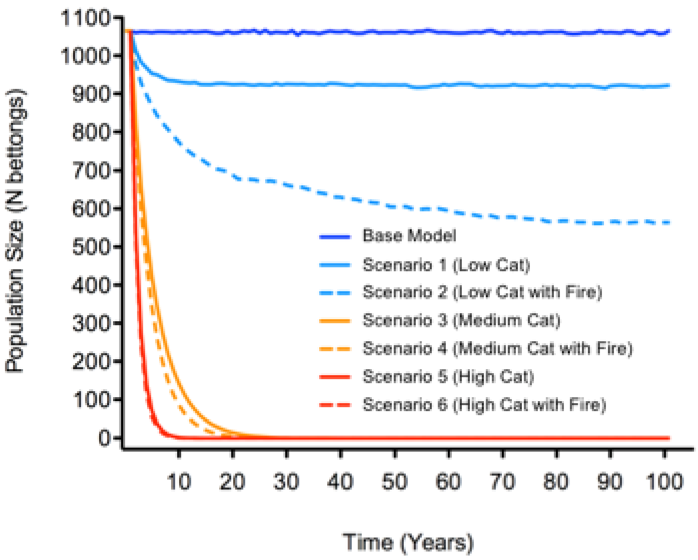

Figure 5. Changes in *Bettongia tropica* metapopulation size and probability of extinction under low, medium and high cat predation, with and without the synergistic effects of fire. Source: Whitehead *et al.* 2018

Conclusion

Models suggest that feral cats are the main threat to northern bettong population viability, and with a high predation scenario, could potentially drive them to extinction within the next 10 years

iii. Current population status and trends

Introduction

A decline in the abundance of northern bettongs may have a substantial impact upon ecosystem functioning, such as fungal dispersal, and may thus threaten the population viability of other species dependent upon the ecosystem. It was therefore important to assess the population trends of the northern bettong and to understand the factors that influence the population.

Vernes and Pope (2006) undertook cage trapping and estimated population density of B. tropica for the four sub-populations on the Lamb Range between 1994 and 1996. Their sampling focused on Davies Creek, with only limited sampling occurring at the other three sub-populations. A comprehensive assessment of the density of B. tropica within its multiple sub-populations was thus required. Additionally, ascertaining the current population density will enable comparisons that assess population trends and stability.

Methods

Cage trapping

Nine four-night cage-trapping sessions were conducted every two to three months between November 2014 and 2016 at Davies Creek (17°01'S, 145°35'E, altitude 670 m above sea level [a.s.l.]), Emu Creek (17°06'S, 145°31'E, altitude 670 m a.s.l.) and Tinaroo Creek (17°09'S, 145°32'E, altitude 680 m a.s.l.; Figure 6). Each site contained 53 medium-sized collapsible cage traps (60 cm x 24 cm x 26 cm), and cages were placed every 100 m along each transect (Figure 7). Between 5 cm and 10 cm of grass was placed on the top and on the sides of the cages to provide shelter for animals.

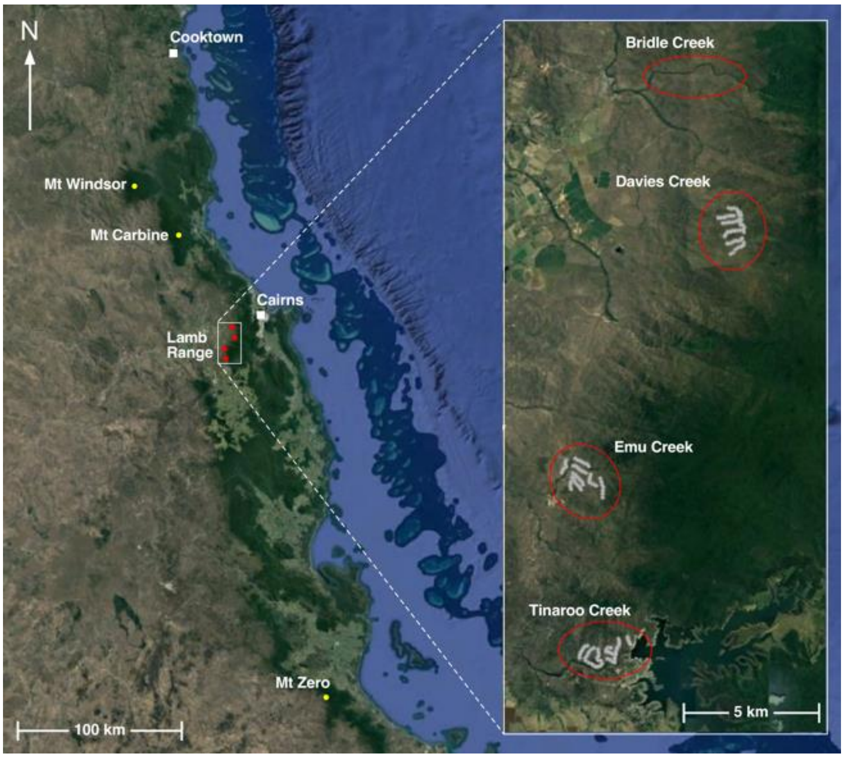

Figure 6. Location of *Bettongia tropica* at the core Lamb Range sub-populations (Bridle Creek, Davies Creek, Emu Creek and Tinaroo Creek) indicated by red dots and peripheral populations (Mt. Windsor, Mt. Carbine and Mt. Zero) shown by yellow dots. Inset shows the study sites at Davies Creek, Emu Creek and Tinaroo Creek (red circles), with the white lines showing the locations of cage trap transects within the study sites. The location of Bridle Creek is also shown.

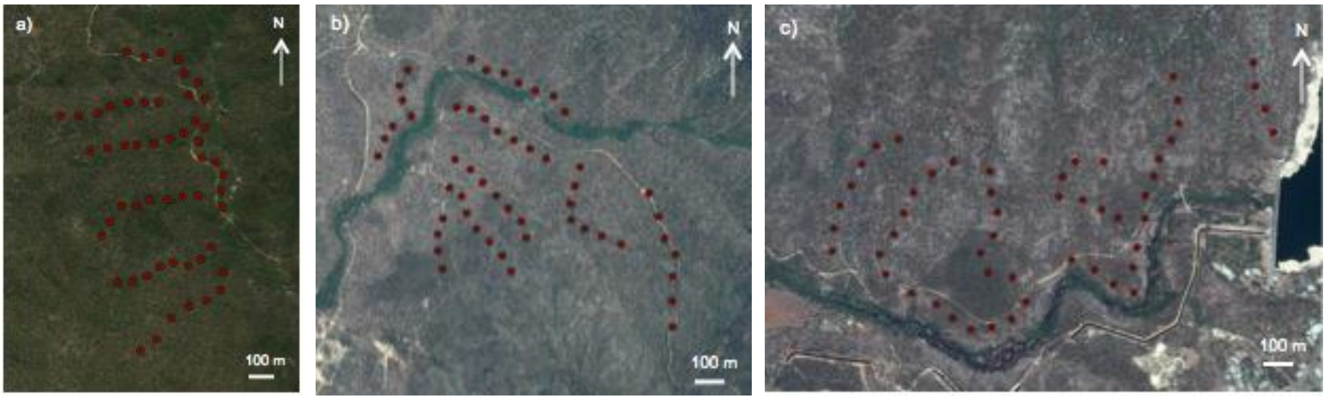

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Figure 7. Trapping grid configuration at (a) Davies Creek, (b) Emu Creek and (c) Tinaroo Creek on the Lamb Range, showing the location of the 53 cage traps (red circles), positioned 100 m apart along seven transect lines at Davies Creek and eight transect lines at Emu Creek and Tinaroo Creek.

Cages were baited and opened in the mid-afternoon with bait replaced each day. Traps were checked between midnight and 4.00am, with all animals released at point of capture. When northern bettongs were captured, they were placed in a cloth bag (Figure 8) and scanned with a microchip reader to detect the presence of a Passive Integrated Transponder (PIT) tag, with the tag number recorded. If no tag was present, one was inserted under the skin into the scruff of the bettong's neck between the shoulder blades. Bettongs were weighed and their hind foot length, head length and hind leg length measured using calipers (Figure 9). Sex, maturity and presence of pouch young were also recorded (Vernes & Pope 2002). A 3mm ear tissue sliver was taken on the first capture and scat samples were collected with every capture.

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Figure 8: Left - cage trap setup. Right - two northern bettongs caught from a cage trap.

Data analysis

In Whitehead's PhD thesis the population density and survival probabilities of *B. tropica* at each sub-population were estimated using Pollock's robust design multi-season mark-recapture analysis. This method is based on the presence/absence of *B. tropica* individuals during each trapping session. Trap success, body condition and the proportion of females with dependent young were calculated.

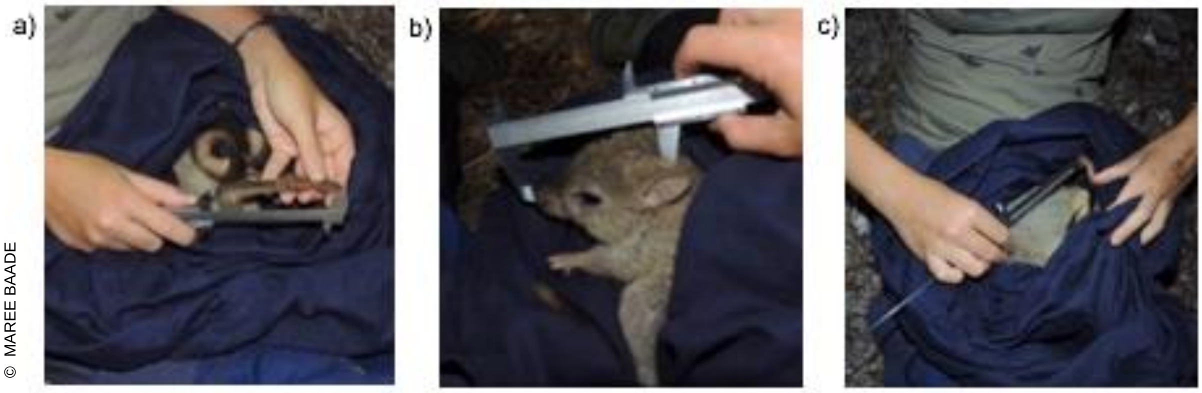


Figure 9: Measuring (a) hind foot length, (b) head length and (c) hind leg length of a northern bettong.

Results

Across 5,712 cage trap nights, there were 1,094 captures of 188 *B. tropica* individuals. Most individuals and captures were recorded at Tinaroo Creek, with the least at Davies Creek (Table 1). There was a total of 2,576 wildlife individuals captured during the study, with northern bettong and northern brown bandicoot being the most commonly captured (Table 2). 'Other' species included *Melomys spp*. and unidentified *Isoodon spp*.

Table 1. Number of individual *Bettongia tropica* caught and total number of captures of males and females at Davies Creek, Emu Creek and Tinaroo Creek.

	Male individuals	Female individuals	Total individuals	Male captures	Female captures	Total captures
Davies Creek	27	16	43	138	111	251
Emu Creek	36	28	64	210	160	370
Tinaroo Creek	38	43	81	209	264	473
All sites (total)	101	87	188	557	535	1094

Table 2. Captures of most common wildlife species from cage trapping sessions.

Species	Common name	DAVIES CK (no. captures)	TINAROO CK (no. captures)	EMU CK (no. captures)	Totals
B. tropica	Northern bettong	246	475	371	1092
D. hallucatus	Northern quoll	63	10	72	145
I. macrourus	Northern brown bandicoot	279	124	333	736
***I. peninsulae* (formerly *obesulus*)**	Cape York brown bandicoot	92	2	80	174
U. caudimaculata	White-tailed rat	50	140	37	227
T. vulpecula	Brush-tailed possum	0	79	68	147
Others					55
TOTALS		730	830	961	2576

Northern bettong individuals at Davies Creek, Emu Creek and Tinaroo Creek were caught up to 25, 25 and 27 times respectively (Figure 10). Across all sites, >70% of individuals (132 out of 188 individuals) were captured more than once, with individuals on average being caught six times throughout the duration of the study.

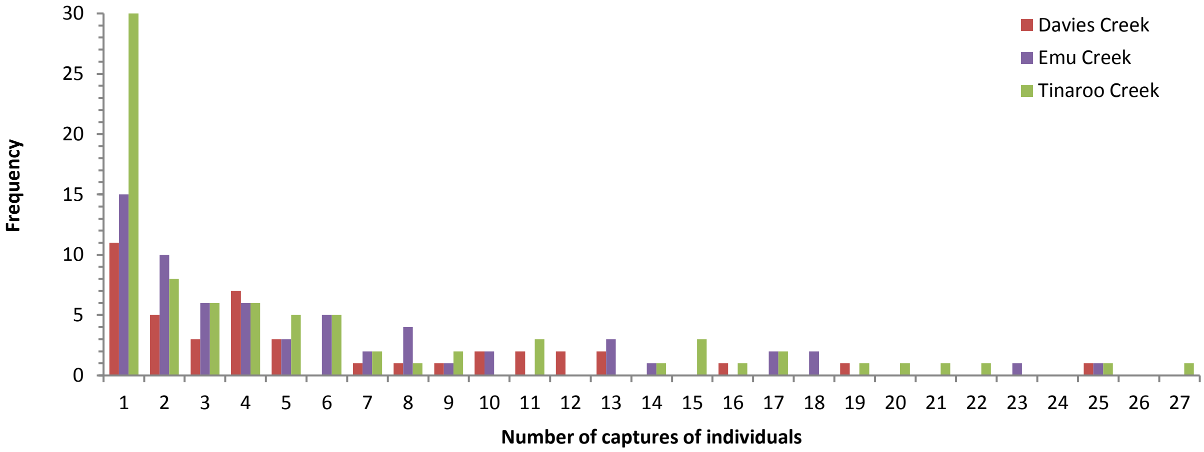


Figure 10. Capture frequency of *Bettongia tropica* individuals at Davies, Emu and Tinaroo Creeks.

At Davies Creek, Emu Creek and Tinaroo Creek, population density averaged 7.17 bettongs/km2, 8.82 bettongs/km2 and 13.00 bettongs/km2 respectively (Table 3). Density estimates at Tinaroo Creek were substantially higher than the other sites. Trap success was lower in the wet season than during the dry season, which was likely due to bettong food resources occurring at lower density during the dry season. Body condition, survival rates of adults (>80%) and the number of females with young (>70%) were similar across all sub-populations and seasons. This indicates there are sufficient food resources on the Lamb Range to maintain a similar population density throughout the year across the three sub-populations.

Table 3. The density of *B.tropica* at each site

Lamb Range site	Density estimate (northern bettongs per km^2)	No. northern bettongs at each site (mean ± SE)
Davies Creek	7.2	33.23 (±2.14)
Emu Creek	8.8	29.21 (±2.72)
Tinaroo Creek	13	34.99 (±1.95)

Conclusion

Cage trapping was successful in capturing 188 northern bettong individuals, with 70% of individuals being captured more than once, indicating their willingness to enter traps. Population density was highest at the site with the highest rainfall (Tinaroo Creek), and thus higher availability of food (truffle fungi). Population health parameters were similar across all three sites in the Lamb Range, indicating a stable population.

b) Population distribution

i. Fine-scale distribution and movement patterns

Context

Knowledge of the spatial distribution of northern bettongs can provide an insight into their habitat requirements and behaviours. This information can assist in devising management strategies to increase long-term habitat stability and thus population viability.

Methods

Also presented in Whitehead's PhD thesis, the movement patterns, home range distribution and social interactions of B. tropica were investigated using data obtained approximately every 10 minutes from 41 Global Positioning System (GPS) collars. Tracking collars were deployed on northern bettong at each site during five cage trapping sessions (Figure 11), with 10 collars deployed during each trapping session. The home ranges and movement patterns of 41 individuals (where collars recorded ≥ 3 days of data) were analysed. Kernel Brownian Bridge Movement Models (BBMM) were undertaken to estimate the home range size and the size of core foraging and nesting areas for each bettong. Overlap between individuals and the movement trajectory (angle of movement) and speed of travel of these individuals were also assessed.

Figure 11. Northern bettong with GPS collar attached.

Results

Northern bettongs had home ranges of 20.90 ± 1.55 ha (mean ± SE), with home ranges largely overlapping between individuals (Figure 12a). Overlap between home ranges indicates that defending access to the entire home range was inefficient. Interestingly, within their home ranges, bettongs had separate (non-overlapping) core foraging areas (5.53 ± 0.42 ha) and nesting areas (0.67 ± 0.10 ha) (Figure 12b and 11c). An average of six nesting areas were used over an average of 25.43 ± 1.65 days.

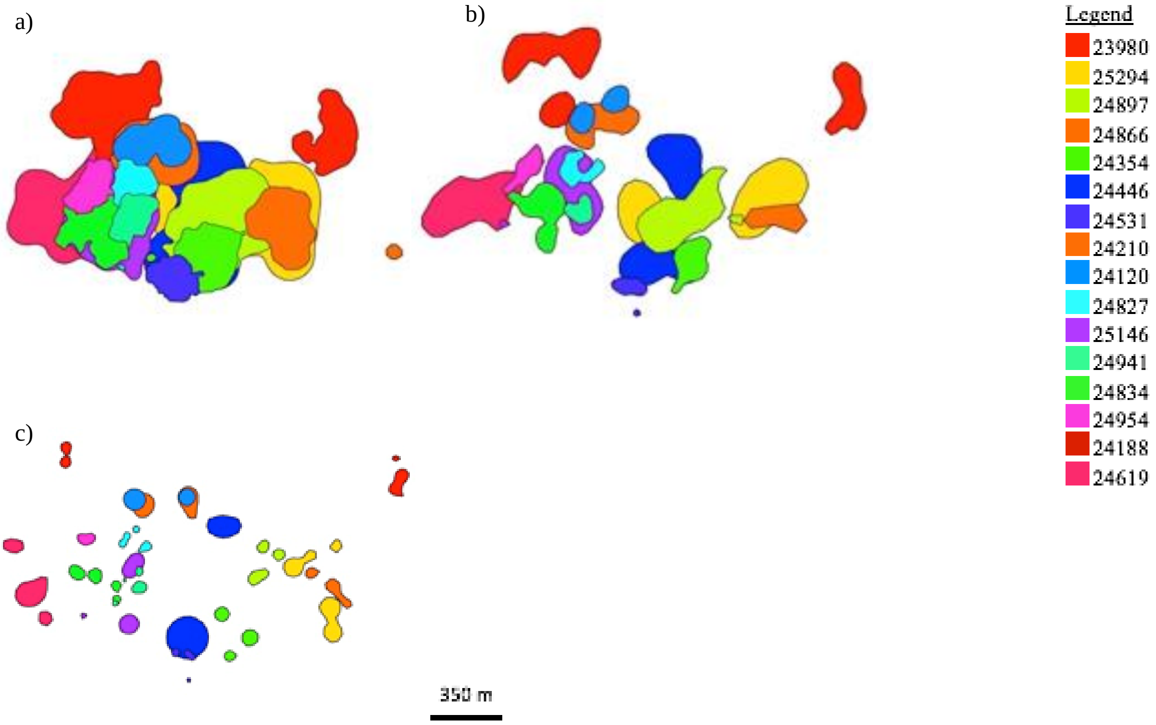


Figure 12. Overlap of northern bettong individuals (a) home ranges, and (b) core foraging and (c) nesting areas at Tinaroo Creek. The microchip numbers of individual bettongs are shown in the legend.

Across all sites, males had larger home ranges than females, with home ranges of both genders increasing during the dry season. Home ranges were similar between sites, indicating that the density of food resources was sufficiently similar between sites. The distribution of males appeared influenced by the distribution of females (seeking mating opportunities) and food resources, whilst females were influenced only by the distribution of food resources. Northern bettongs undertook rapid and medium paced movements when travelling between resource patches, and then moved slowly at irregular angles whilst foraging. Fast, linear movements are effective for travelling quickly across areas with minimal resources or few mating opportunities, whilst slower movements maximised the time bettongs spent within areas with high density of resources.

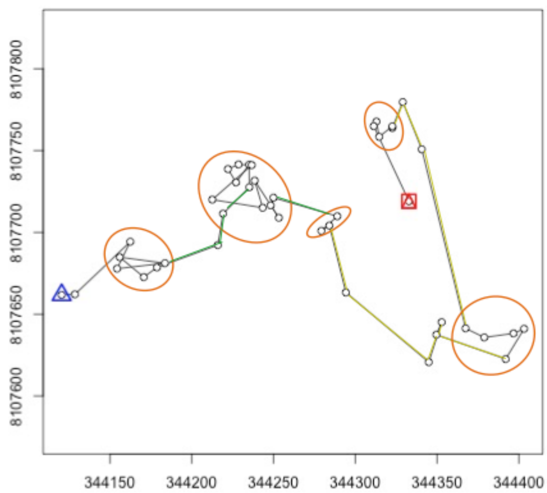


Figure 13. Example of a movement pattern of a northern bettong travelling at slow, medium and rapid paces during one night (7pm to 3am). Slow movement patterns with fixes close together are thought to indicate foraging and are circled in orange. Medium and rapid movements are highlighted in green and yellow respectively. The blue triangle represents the starting point of travel (after *B. tropica* emerge from their nest), whilst the red square indicates the nesting area when *B. tropica* finish foraging for the night. The numbers along the x- and y-axes are spatial co-ordinates for plotting the GPS fixes.

Conclusion

Northern bettongs had home range sizes of approximately 20ha (compared with Vernes and Pope's previous study in 2001 which estimated 60ha. These differences are likely due to technology and survey methodology), with males' larger than females and both genders' larger in the dry season. Overlaps between their home ranges indicates that defending access to the entire home range was inefficient. Interestingly, within their home ranges, bettongs had separate (non-overlapping) core foraging areas and nesting areas. Separate core areas suggest that northern bettongs defend areas with high resource density and are somewhat territorial, a trait not previously recorded for this species.

ii. Microhabitat requirements

Context

Information regarding microhabitat selection is crucial for endangered species conservation, as it provides insight into the important factors that govern habitat use and thus need to be conserved.

Methods

In another chapter of Whitehead's PhD thesis, for three sub-populations on the Lamb Range, the microhabitats that the northern bettong used while nesting and foraging was determined. Microhabitat requirements were ascertained by conducting vegetation surveys at 90 nesting and foraging areas of 18 GPS-collared B. tropica and comparing with the microhabitat at 90 areas not known to be used for nesting or foraging (random areas). Collared bettongs were radio-tracked to their nest and the nesting material they used, and the design of their nest was recorded. Additionally, six sessions of camera trapping were undertaken, whereby 30 cameras (Reconyx white-flash, heat-and-motion sensor camera traps) were deployed at each site. Cameras were baited and operated between 5.00pm and 7.00am. Each camera trapping session comprised of 12 nights targeting northern bettongs and 12 nights for predators and competitors every two to three months. A meat bait was used to target predators. At each site, 4,320 camera trap nights were undertaken (12,960 total across all sites).

Results

In total, 4,320 camera trap nights occurred at each study site resulting in a total of 154,047 camera images with animal detections. Northern bettongs comprised between 17% and 31% of all camera captures across the three sites. In contrast, predator and competitor species constituted less than 4% of captures at each site. There was a ratio of around one predator image per 60-70 images of northern bettongs and an average of one competitor to 92 images of northern bettongs across all three sites. Many other species were detected on camera traps, with Emu Creek having a higher diversity of species than Davies Creek or Tinaroo Creek (Table 4).

Table 4. All Species detected from camera trapping at Davies Creek, Emu Creek and Tinaroo Creek. 'X' indicates that the species was detected at the site.

Common name	Species name	Davies Creek	Emu Creek	Tinaroo Creek
MAMMALIA				
Metathera				
Northern bettong	*Bettongia tropica*	X	X	X
Rufous bettong	*Aepyprymnus refescens*		X	
Northern quoll	*Dasyurus hallucus*	X	X	X
Swamp wallaby	*Wallabia bicolor*		X	X
Agile wallaby	*Macropous agilis*	X	X	X
Whiptail wallaby	*Macropus parryi*	X	X	X
Red-legged pademelon	*Thylogale stigmatica*		X	X
Unknown macropods	various	X	X	X
Brush-tailed possum	*Trichosurus vulpecula*	X	X	X
Common ringtail possum	*Pseudocheirus peregrinus*		X	
Coppery brushtail possum	*Trichosurus johnstonii*	X		X
Bandicoot	*Isoodon spp.*	X	X	X
Sugar glider	*Petaurus breviceps*		X	
Monotreme				
Short-beaked echidna	*Tachyglossus aculeata*	X	X	X
Placental				
Black-footed tree rat	*Mesembriomys gouldii*		X	
Rattus sp.	*Rattus sp.*	X	X	X
Grassland melomys	*Melomys burtoni*	X	X	X
Fawn-footed melomys	*Melomys cervinipes*		X	X
Pale field rat	*Rattus tunneyi*	X		
Giant white-tailed rat	*Uromys caudimaculatus*	X	X	X
Introduced placental				
Wild dog or dingo	*Canis lupus*	X	X	X
Cow	*Bos taurus*		X	
Feral pig	*Sus scrofa*	X	X	X
Feral cat	*Felis catus*			X
REPTILIA				

Lace monitor	*Varanus sp.*	X	X	X

Figure 13. Example of species captured on camera traps, including (a) northern bettong (eating fungi), (b) ringtail possums, (c) black-footed tree rat, and (d) feral cat.

Bettongia tropica mainly constructed nests from grass (*Poaceae* spp.) or nested under the ‘skirts’ (leaves) of grass trees (*Xanthorrhoea johnsonii*) (Figure 14). Different habitat parameters were important for nesting and foraging. Nests were situated in steep areas with high grass cover and an abundance of grass trees. Whilst foraging, *B. tropica* selected habitats with a higher density of cockatoo grass (*Alloteropsis semialata*), a lower density of tree basal area, more tall trees and steep slopes.

Predation risk appeared to influence both nesting and foraging microhabitat selection of northern bettongs. Across all sites, mammalian predators detected on camera traps included wild dogs or dingoes (*Canis lupus*), with one cat also detected at one site (Tinaroo Creek). Feral pigs (*Sus scrofa*) occurred throughout the landscape, while rufous bettongs (*Aepyprymnus rufescens*) were detected at Emu Creek. Nesting areas appeared to be chosen for camouflage while resting, whilst foraging areas were more open to allow rapid escape from predators. Further research into predation pressures would benefit the conservation of this species. Additionally, northern bettongs may benefit from management focusing on protecting and maintaining habitats with high levels of grass cover, grass trees, cockatoo grass and tall trees on steeper slopes.

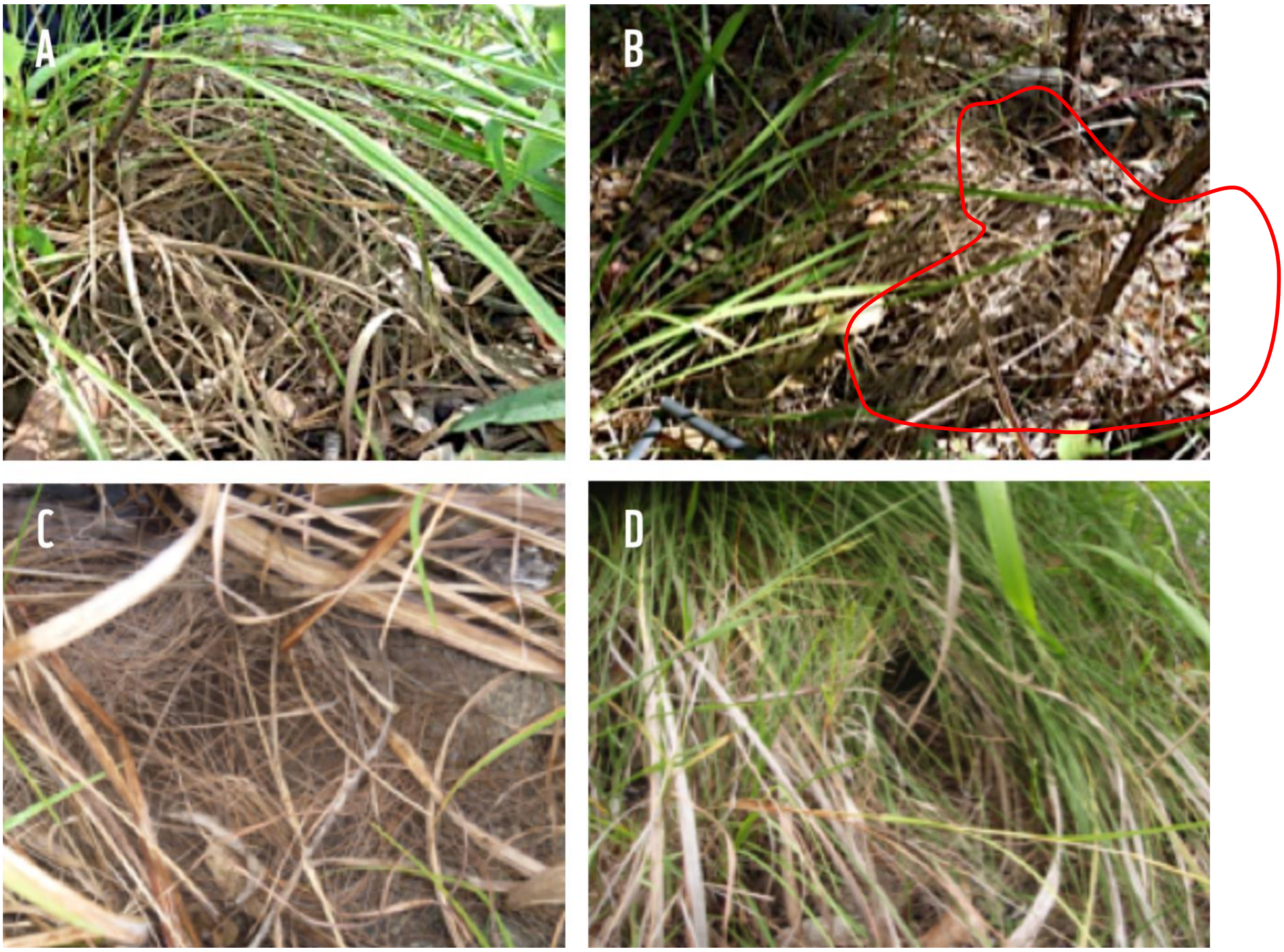


Figure 14. Nests of northern bettong constructed from (a) and (b) grass, with (b) showing the top view outlined in red, (c) grass and *Allocasuarina sp.* needles, (d) under the skirts of grass trees.

Conclusion

Northern bettong were observed on 17-31% of camera traps in the Lamb Range. It was found that they had different habitat requirements for nesting and foraging - nests were situated in steep areas with high grass cover and an abundance of grass trees. Whilst foraging, habitats with a higher density of cockatoo grass, a lower density of tree basal area, more tall trees and steep slopes were favoured. Feral mammalian predators and competitors were observed across the Lamb Range, with the rufous bettong only co-existing with northern bettongs at one site (Emu Creek).

iii. Broad Distribution

Introduction

Prior to this Project's research, northern bettong distribution was known to occur at possibly four to five main sites in the Wet Tropics region of far north Queensland, although recent searches (since 2003) have failed to detect the northern bettong at three of the four locations (Winter 1997; Laurence 1997). We set out to determine northern bettong distribution within and outside of their currently known range and spanning the Wet Tropics region using the habitat model developed by the Queensland Herbarium in 2012 (Figure 15).

Methods

Wildlife sensor cameras (Reconyx white flash and infra-red; and Scoutguard cameras) were deployed at 11 different key areas in far north Queensland for four to six weeks at a time over a three-year period between 2015 and 2018 to define the northern bettong's distribution within and beyond known historical populations in the Wet Tropics region. A minimum of 19 cameras were deployed at each location, depending on available habitat, habitat type and site access.

Sites where there were historical records of northern bettongs or sites with potential habitat were examined to see if any animals remained in these areas. Potential northern bettong habitat was identified in the habitat model maps and further areas for investigation were suggested by expert members of the Northern Bettong Advisory Group. A total of 11 key areas out of a possible 16 were chosen to focus search efforts for the northern bettong between Paluma in the south and Mt. Windsor in the north (Figure 16, Table 5).

Cameras were positioned at survey sites in a 500m-1000m grid or transect and on suitable trees one metre from the ground. Cameras were angled using rocks at 45 degrees from the bait container and placed out from the tree 1.5m. Cameras were baited with sturdy poly-pipe containers comprising peanut butter balls (made of oats, peanut butter, vanilla essence, anchovies and truffle oil), pegged into the ground for longevity. Cameras were locked to trees in lock boxes for security. Each camera, depending on the model and brand, was set to a similar specification including high sensitivity, rapid fire, between evening hours (6pm-7am) and each taking three photos per trigger. The cameras were deployed at each site for four to six weeks. Data was then processed and analysed using the 'Camelot' program.

Broad habitat preference data was collected at every site. Majority of the mapped habitat area featured on poor granitic soils, in National Park, State Forest and Forest Reserve tenured land, and was within 10km of wet tropical rainforest and its associated high nutrient basaltic soils. Targeted habitats included open woodland dominated by *Eucalyptus platyphylla*, *Eucalyptus tereticornis, Corymbia citriodora*, ironbarks (inc. *Eucalyptus crebra*) and/or bloodwoods (inc. *Corymbia intermedia*), she-oak forest dominated by *Allocasuarina sp. (*inc. *Allocasuarina torulosa)*, open, wet sclerophyll forest dominated by *Syncarpia glomulifera*, *Eucalyptus grandis* and/or *Eucalyptus resinifera* and closed, wet sclerophyll forest/ rainforest edges dominated by *Eucalyptus grandis* with a rainforest understorey. This included up to 15 RE's in which northern bettongs had previously been recorded (Appendix 1; Queensland Government 2018). Habitat variables were collected at each camera site and included; large trees in area, density of cockatoo grass, cockatoo grass flowering stage, understorey diversity and species, slope and soil type.

Figure 15. Map of potential northern bettong habitat between Townsville and Cooktown, Far North Queensland – colour coded as potentially separate populations (blue- southern, purple- central, red – northern)

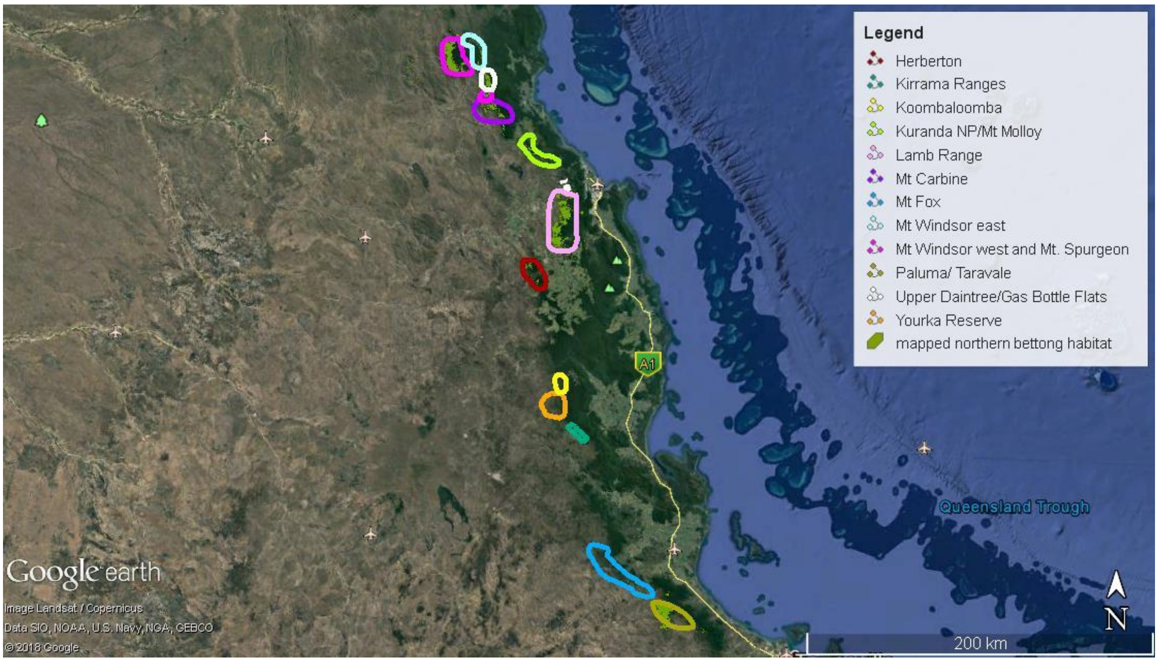


Figure 16. Map of 11 key areas to search for northern bettong using sensor cameras in the Wet Tropics.

Table 5. Site selection for sensor camera surveys in the Wet Tropics region between 2015 and 2018.

Location of camera sites	Latitude	Longitude	Historical records present (Wildnet)	Within mapped habitat (Qld Herbarium 2012)	Traditional Owners/ Native Title claim	Land Tenure type
Mount Windsor	-16.297490	144.96847	Present	Yes	North Queensland Land Council Aboriginal Corporation and Cape York United Number 1 Claim	National Park
Upper Daintree/ Gas Bottle Flats	-16.3593	145.1793	X	Yes	North Queensland Land Council Aboriginal Corporation	National Park
Mount Spurgeon / Carbine Tableland	-16.4308	145.1576	Present	Yes	North Queensland Land Council Aboriginal Corporation	National Park
Kuranda National Park/ Mt Molloy	-16.7622	145.4798	X	Yes	North Queensland Land Council Aboriginal Corporation & Cairns Regional Claim Group	National Park/ State Forest/ Forest Reserve
Koah/northern Lamb Range	-16.8854	145.5344	X	No	Cairns Regional Claim Group	State Forest
Herberton/ Walsh River	-17.3295	145.401	X	Yes	Bar Barrum (Mbabaram) & Jirrbal people	State Forest
Greater Ravenshoe / Koombaloomba	-17.8851	145.5307	Present	No	Jirrbal people	National Park/ State Forest
Yourka Reserve/ Einasleigh uplands	-18.0056	145.4896	X	No	Jirrbal people	Bush Heritage Sanctuary
Kirrama Ranges/ Budjuballa Station	-18.1157	145.6193	X	No	Jirrbal & Girramay people	Private land
Mount Fox	-18.9012	146.9661	X	Yes	Warrgamay & Gugu badhun people	Private land
Taravale/ Paluma	-18.17128	145.61939	Present	Yes	Gugu Badhun and North Qld Land Council Aboriginal Corporation	State

Results

Camera trapping

A total of 587 sensor cameras were deployed to detect northern bettongs in 11 key areas from 2015-2018 over a 95,273ha area of the Wet Tropics bioregion from Mt. Windsor in the north to near Paluma in the south. An average of 49 cameras were deployed at each location (19-90 cameras; Table 6). After a total of 120 survey days, 18,197 trap nights and over half a million photos analysed, the cameras detected the presence of northern bettongs in two areas out of 11 – at the northern end of the Lamb Range at Koah in Bilwon State Forest and at Mt. Spurgeon on the Carbine Tableland (Figure 17; Appendix 2). A total of 1,032 photographs of northern bettong on eight cameras were captured at Mt. Spurgeon and 115 photographs were captured on one camera of at least one male individual at Koah (Figure 18). The bettongs were detected at Mt. Spurgeon in a small 5km² area. There were no northern bettongs detected at the two previously known populations at the Coane Range and Mt. Windsor (Appendix 2).

There were 103,377 total captures of wildlife from at least 73 species across 10 of the Wet Tropics sites (1 site awaiting full analysis; Appendix 2). The sites with the highest species diversity were Yourka Sanctuary (n=32), Coane Range (n=30) and Upper Daintree (n=28) and the poorest diversity was recorded at Mt. Windsor (n=11). Rufous bettongs were detected at 70% of the sites, including in the areas that historically recorded northern bettong. There were no rufous bettong detected at sites with northern bettong. At least 11 different macropod species were detected across the sites as well as two quoll species and three species of bandicoot. Introduced mammals were detected at every site, with the exception of Koah. Feral cats were detected at 40% of the sites, and cows and pigs were detected at 80% of sites. Wild dogs, or dingoes, were also detected at over 60% of sites, though the survey did not distinguish between the two. No red foxes were detected.

The northern bettong's extent of occurrence was estimated to be 1,100km² and the area of occupancy was 145km².

Figure 17. New sightings of northern bettongs during camera trapping survey (yellow) compared with the current known extent of occurrence (light pink) and area of occupancy (dark pink).

Table 6. Summary of camera sites

Location of camera sites	Month of camera deployment	Cameras deployed total (no.)	Trap nights (no.)	Survey area covered (ha)
Mount Windsor	2016	90	2,790	20,627
Upper Daintree/ Gas Bottle Flats	Sept-Oct 2017	86	2,666	1,702
Mount Spurgeon / Carbine Tableland	2016	56	1,736	2,930
Kuranda National Park/ Mt Molloy	2016	43	1,333	8,435
Koah/northern Lamb Range	Dec 2017-Jan 2018	34	1,054	1,996
Herberton/ Walsh River	Sep-Oct 2017	48	1,488	9,062
Greater Ravenshoe / Koombaloomba	Dec 2017-Jan 2018	27	837	873
Yourka Reserve/ Einasleigh uplands	2015; Nov-Dec 2017	19 and 40	1,829	11,084
Kirrama Ranges/ Budjuballa Station	July-Aug 2017	40	1,240	8,526
Mount Fox	2016	19	589	21,964
Coana Range/ Paluma	July-Aug 2017	85	2,635	8,074
TOTALS		587	18,197	95,273

Figure 18. Northern bettong individuals captured on sensor cameras (left; Mt. Spurgeon and right; Koah)

<u>Broad habitat use</u>

Habitat data was collected at each of the camera survey sites, including presence of tree species, grass species and diversity and presence of grass trees (Table 7). A total of 15 different regional ecosystem (RE) types were searched using camera trapping. Northern bettongs were detected in three different RE types - 7.12.27 and 7.12.69 at Mt. Spurgeon and 9.5.9 in Koah (refer to Appendix 1 for RE descriptions).

Table 7. Habitat of camera survey sites

Location of sites	Habitat type present at sites (Dominant species include: Open woodland = C. citriodora, C. intermedia, ironbarks, stringybarks, Allocasuarina forest = Allocasuarina sp., Wet sclerophyll = E. grandis, E.resinifera, S. glomulifera, Rainforest = E. grandis)				Grass trees present (√= yes, x = no)
	Open woodland	Allocasuarina forest	Wet sclerophyll	Rainforest	
Mount Windsor	√	√	√	x	√
Upper Daintree/ Gas Bottle Flats	√	√	√	√	√
Mount Spurgeon / Carbine Tableland	√	√	√	x	√
Kuranda National Park/ Mt Molloy	√	√	x	x	√
Koah/northern Lamb Range	√	√	√	x	√
Herberton/ Walsh River	√	√	√	x	√
Greater Ravenshoe / Koombaloomba	√	√	√	x	√
Yourka Reserve/ Einasleigh uplands	√	√	x	x	√
Kirrama Ranges/ Budjuballa Station	√	√	√	x	√
Mount Fox	√	x	x	x	√
Taravale/ Paluma	√	√	√	x	√

Conclusion

Northern bettongs were detected on camera traps at only two areas out of 11 searched – Mt. Spurgeon and the Lamb Range – in three different RE habitat types. This is the first record of northern bettongs at Mt. Spurgeon since 2003 and the first record of at least one individual in Bilwon State Forest, Koah (in the north-western Lamb Range). The northern bettong's EoO was estimated to be 1,100km² and the AoO was found to be 145km². Northern bettong and rufous bettong detection did not overlap on sites. Feral mammals were present at every site, with the most numerous being feral pigs and cattle, both at 80% of the same sites.

c) Non-invasive conservation genetics

Introduction

In conservation genetics research, DNA is isolated and analysed with the aim of answering questions that will improve the management of rare and threatened species (Allendorf et al. 2010). One approach to conservation genetics involves investigating the diversity of alleles within and between populations; which is known as population genetics (Brookes 1999; King et al. 2013). Population genetic parameters are influenced by population size, natural or sexual selection and gene flow (connectivity), and thus results from population genetic studies can provide information on biologically and conservation significant processes (King et al. 2013; Lowe and Allendorf 2010). Another approach in conservation genetics is the use of molecular assays (e.g. genotyping, sequencing) to distinguish between species, populations or individuals. The results of these studies can benefit conservation by providing information on the presence, distribution and abundance of threatened species (Luikart et al. 2010).

Traditionally, DNA for conservation genetic studies has been obtained from tissue (e.g. ear biopsy) of live trapped animals or from voucher specimens (Piggott and Taylor 2003; Pope et al. 2000; Pope et al. 1996). The quality of DNA obtained from tissue samples is high and can be subjected to a number of applications. However, there can be high ethical costs associated with live trapping; capture can be very stressful for individuals and trap deaths do sometimes occur, which is particularly undesirable for endangered species (Piggott and Taylor 2003).

Non-invasive genetic sampling provides an alternative to live trapping, which involves the collection of shed material such as faeces, hair or feathers and extracting DNA from it to answer conservation genetic questions (Rodgers and Janečka 2013; Waits and Paetkau 2005). In the literature, there are examples of non-invasive samples being used successfully for microsatellite genotyping based population genetic studies and for individual identification in non-invasive genetic mark-recapture studies estimating population abundance (Schwartz et al. 2007; Creel et al. 2003; Kery et al. 2011; Rodgers and Janečka 2013; Sloane et al. 2000; Zielinski et al. 2013).

Mitochondrial DNA (mtDNA) sequencing from non-invasive genetic material has been informative in species identification, phylogeography and broader population genetics studies (Alacs et al. 2010; Frankham 2010; Moritz 1994; Reis-Filho 2009; Waits and Paetkau 2005). There are many copies of the mitochondrial genome per cell (as opposed to a single copy of the nucleic genome), making mtDNA fragments easier to amplify from low quality or quantity DNA found in non-invasive samples (Alacs et al. 2010). Furthermore, some regions of mtDNA are relatively conserved enabling cross-species utility of PCR primers (Kocher et al. 1989). This is important when working with novel species and with samples of ambiguous origin (Kocher et al. 1989).

Northern bettongs are a small, shy and nocturnal endangered marsupial, making them an ideal candidate to study using non-invasive genetic sampling methods (Johnson and McIlwee 1997). Northern bettongs, amongst other macropods, are known to produce 'oorts'. Oorts consist of a wad of tough grass fibres which is spat out after the juicy, nutritious part of the grass base (such as cockatoo grass) has been consumed (Figure 19). These can be readily found in some areas of bettong habitat at the end of the dry season when the bettongs preferred food source (truffle fungi) is scarce (Abell et al. 2006). Oorts may contain traces of bettong saliva; however there have been no prior attempts to use them as a non-invasive source of DNA for conservation genetics.

As part of this study, it was proposed to investigate the use of novel non-invasive samples (oorts and hair) as a source of DNA for species identification and DNA fingerprinting, in order to survey distribution/occurrence and population genetics of the northern bettong. Specifically, the objectives were:

1. To develop and test molecular-based non-invasive survey methods as a tool for landscape scale population monitoring

a) Trial suitable extraction protocols, with regard to sample age and storage, extraction media and method and potential cost.

b) Use a short fragment of the mitochondrial gene cytochrome b to identify if the samples are from the target species

c) Trial the amplification of previously published microsatellite markers in this laboratory -use microsatellite DNA 'fingerprinting' to distinguish individuals

d) Determine if hair trapping and oort collection are suitable replacements for cage trapping (the current method for population monitoring)

2. To assess the genetic diversity and gene flow of the endangered northern bettong using DNA obtained from tissue samples, and if possible using DNA from oorts and other non-invasively collected samples (i.e. hair)

a) relate this to its conservation and population viability

b) determine if there has been a decline in genetic diversity and gene flow in the last 15-20 years by comparing data with Lisa Pope's results

Methods

Sample collection

As part of this study to be presented in Stephanie Todd's PhD thesis (in preparation), Oorts were collected from around the Mt. Fox, Mt. Windsor, Mt. Spurgeon, Blencoe Falls and the Lamb Range areas in 2014, 2015 and 2016. In particular, targeted surveys in the Lamb Range resulted in high numbers of fresh oorts (pale, compact) being collected from Lake Tinaroo. It was not known if these were produced by northern bettongs, rufous bettongs, or other species. These were taken back to the lab and stored frozen until used.

Hair and tissue (ear biopsy) samples were also collected from northern bettongs between 2014 and 2016 during the cage trapping surveys in the Lamb Range. Hair was collected using sticky tape to 'wax' a number of hairs such that the follicle remained intact. This was designed to mimic the mechanism of sticky hair traps used in non-invasive sampling. Tissue was sampled by taking a 1-2mm strip ear biopsy. Samples were stored in 70% ethanol until used.

JCU Cairns Molecular Lab

Extraction trials

A number of extraction protocols and reagents were used in an attempt to extract DNA from noninvasive samples. Methods trialled included; Chelex® (a chelating extraction medium), high salt extraction, Favrogen tissue kit (hair), custom hair lysis buffer, Favrogen stool kit (oorts), QIAGEN tissue kit (hair) and QIAGEN stool kit (oorts), with little success. However, DNA was successfully extracted from 165 tissue samples, using freshly prepared reagents and a high salt extraction protocol.

Extractions were checked by visualizing DNA on agarose gels or using Nanodrop spectrophotometry. Alternatively, PCR of an easily amplified mitochondrial fragment was also performed to test for the presence of low quantities of DNA. Positive (tissue DNA) and negative controls were included in reactions.

PCR trials

To amplify mitochondrial DNA, primers were used for the gene Cytochrome b, and shorter subsection of this gene (Macyt 10; Table 8). To amplify microsatellites, three Bt (northern bettong specific) primers - developed by Lisa Pope - were used, with fluorescent labels to allow multiplexing during genotyping. Because the Bt primers failed to amplify any bettong DNA (including tissue) a Taguchi PCR optimization matrix was performed in order to troubleshoot and optimize the reaction conditions.

Genotyping

DNA isolated from twelve of the tissue samples was sent to the Australian Genome Research Facility (AGRF) for amplification and genotyping of the six microsatellite markers used by Pope et al. (2000) (Table 8). The purpose of this was to further troubleshoot the lack of success from amplifying these primers, and to pilot the quality and resolution of genetic data obtained from present-day samples. Additionally, a range of template DNA concentrations were submitted in order to determine the minimum quantity of DNA necessary for genotyping which may be a limiting factor for genotyping non-invasively collected samples.

Diversity Array Technology (DArT) was chosen for the remainder of the population genetic and connectivity analysis, due to the higher resolution and whole genome coverage that this next generation SNP genotyping method provides. A total of 165 DNA samples (from tissue) have recently been sent off to DArT for genotyping and results are yet to be analysed.

Australian Museum Wildlife Genomics Lab

Extraction

DNA was successfully isolated from B. tropica hairs using a slightly different version of the high salt method used at JCU. The main differences were that samples were left to lyse overnight instead of 30

minutes and cold (-20°C) ethanol (instead of room temperature) was added. Approximately 10-20 hairs per sample were used.

DNA was successfully isolated from oorts with a QIAGEN forensic 'DNA investigator' kit, using the manufacturer's 'chewing gum' protocol. This kit provides carrier RNA which helps extract low quantities of DNA from samples. Only very fresh-looking oorts were successful.

PCR

The same primers for Macyt10 were used, as described above, to amplify mitochondrial DNA in hair and oort samples. Additionally, a short fragment of nucleic DNA (RAG1) (Table 8), was amplified, the sequence of which is uninformative, but it is believed the PCR success of this gene would give a good indication of which samples it is possible to amplify microsatellites from.

A set of 10 unlabelled microsatellite primer pairs that have been used previously for B. tropica, or closely related B. penicillate, were tested with hair samples that had been shown to contain nucleic DNA. A premixed Bioline Red® master mix and taq polymerase were used in 10uL reactions with 2uL of template.

As different sources reported different optimum annealing temperature for these primers, a 62-50degree touchdown PCR was used for all 10 primers. Eight of these primer pairs were also tested with three oort samples that had been shown to contain some DNA using similar reaction conditions.

Sequencing and species identification

All oorts that amplified for Macyt10 were sent to AGRF for Sanger sequencing in order to determine if they were from northern bettongs. Sequences were aligned, checked and edited in Sequencher® with references to chromatograms. Reference Cytochrome b sequences for northern bettongs (and other potential species) were obtained from GenBank (Accession #AY237237) and comparison with these references was used to determine species.

Figure 19. Oort (bettong spit-ball).

Results

Bettong genetic diversity

The six microsatellite markers genotypes by AGRF were sufficient to distinguish the twelve individuals from each other, i.e. each individual had a unique genotype. Total heterozygosity was 70% and allelic diversity (mean no. alleles per locus) was 5.83 ± 0.87 (Table 8). Template concentration didn't appear to make a difference, and genotypes were obtained from samples with as little as 20ng DNA.

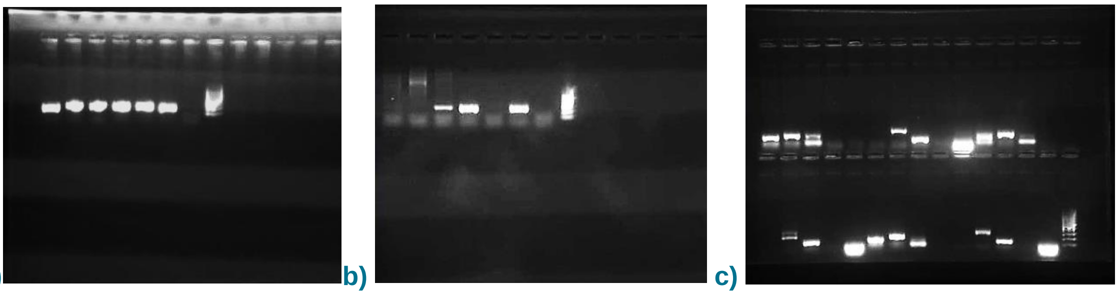
Table 8. Allelic richness and heterozygosity of six microsatellite markers genotyped for 12 northern bettongs.

Marker	Number of Alleles	Heterozygosity
Bt64	6	0.58
Bt76	6	0.75
Bt80	4	0.75
Y151	9	0.92
Y170	7	0.58
Y76	3	0.67
Mean(±SE)	5.83±0.87	0.71±0.05

Success of hair samples

Using the Australian Museum version of high salt method for hair extractions produced enough genomic DNA to produce visible bands on an agarose gel (Figure 20) and comparison with a known ladder indicated that it was of high molecular weight (good quality), but concentration was low (<16ng/uL). All hair samples tested amplified for Macyt10 and most (67%) amplified for RAG1.

Seven out of 10 microsatellite primer sets produced enough DNA to visualise (in an agarose gel) for at least hair one sample. Agarose gels are unable to resolve polymorphisms, so all of these markers may not be informative in northern bettongs, but this result is very promising for the ability of hair DNA to be used to genotype (fingerprint) this species. At the Australian Museum unlabelled primers were used and this may have been the reason for improved success. Previously at JCU, fluorescently labelled primers were used, which are necessary for genotyping but have high molecular weight so interfere with primer properties.



a) b) c)

Figure 20. Samples of agarose gel elecrtrophesis images used to check the presence of DNA: a) bands from hair DNA apmplified by Macyt10 b) bands from orrt DNA apmplified by Macyt10 and c) Microsatellite markers from hair DNA

Success of oort samples

Only very fresh-looking oorts - and those that had been stored frozen - produced any results. Approximately 60% of fresh oort samples were able to be amplified using *Macyt10*, although template DNA concentration was mostly very low. Success with amplification of nuclear DNA in oorts was lower; however, four microsatellite primer pairs produced gel bands in at least one sample (Figure 20).

Bettong distribution

Oort *Macyt10* sequence data revealed that samples from Mt. Fox and Mt. Windsor were from rufous bettongs (*Aepyprymnus rufescens*) and not northern bettongs (Table 10). Mt. Windsor oorts were quite large while the Mt. Fox oorts were comparatively quite small, indicating that different size oorts are likely to be due to plant taxa rather than the animal species that produces them. All Lamb Range oorts were from northern bettongs.

Table 10. DNA extraction and species identification of oort samples using *Macyt10* sequences

Date collected	Date extracted	Extraction method	Site area	Collector	Species
24/04/2015	7/02/2017	QIAGEN stool kit	Tinaroo	S. Nuske	-
18/10/2016	7/02/2017	QIAGEN stool kit	Spurgeon	S Todd	-
18/10/2016	7/02/2017	QIAGEN stool kit	Spurgeon	S Todd	-
25/10/2016	7/02/2017	QIAGEN stool kit	Tinaroo	Rhys Sharry, S Todd	-
25/10/2016	7/02/2017	QIAGEN stool kit	Tinaroo	Rhys Sharry, S Todd	-
16/06/2016	7/02/2017	QIAGEN stool kit	Blencoe falls	Lana Little	-
10/08/2016	14/02/2017	Investigator kit	Windsor	S Todd	*A. rufescens*
18/12/2014	14/02/2017	Investigator kit	Davies	S. Nuske	-
28/06/2016	14/02/2017	Investigator kit	Paluma	Girrungun Rangers	*A. rufescens*
28/06/2016	14/02/2017	Investigator kit	Paluma	Girrungun Rangers	*A. rufescens*
29/06/2016	14/02/2017	Investigator kit	Paluma	Girrungun Rangers	*A. rufescens*
28/06/2016	14/02/2017	Investigator kit	Paluma	Girrungun Rangers	*A. rufescens*
25/10/2016	21/02/2017	Investigator kit	Tinaroo	Rhys Sharry, S Todd	-
25/10/2016	21/02/2017	Investigator kit	Tinaroo	Rhys Sharry, S Todd	-
25/10/2016	21/02/2017	Investigator kit	Tinaroo	Rhys Sharry, S Todd	-
25/10/2016	21/02/2017	Investigator kit	Tinaroo	Rhys Sharry, S Todd	-
25/10/2016	21/02/2017	Investigator kit	Tinaroo	Rhys Sharry, S Todd	*B. tropica*
25/10/2016	21/02/2017	Investigator kit	Tinaroo	Rhys Sharry, S Todd	*B. tropica*
25/10/2016	21/02/2017	Investigator kit	Tinaroo	Rhys Sharry, S Todd	-
25/10/2016	21/02/2017	Investigator kit	Tinaroo	Rhys Sharry, S Todd	*B. tropica*
25/10/2016	21/02/2017	Investigator kit	Tinaroo	Rhys Sharry, S Todd	-
25/10/2016	21/02/2017	Investigator kit	Tinaroo	Rhys Sharry, S Todd	-
25/10/2016	21/02/2017	Investigator kit	Tinaroo	Rhys Sharry, S Todd	-
25/10/2016	21/02/2017	Investigator kit	Tinaroo	Rhys Sharry, S Todd	-
7/09/2016	24/02/2017	Investigator kit	Windsor	S Todd	-
2016	24/02/2017	Investigator kit	Blencoe falls	Girrungun rangers	-
2016	24/02/2017	Investigator kit	Blencoe falls	Girrungun rangers	-
2016	24/02/2017	Investigator kit	Blencoe falls	Girrungun rangers	-
16/06/2016	24/02/2017	Investigator kit	Blencoe falls	Lana Little	*A. rufescens*
18/10/2016	24/02/2017	Investigator kit	Mt Spurgeon	S Todd	-
25/10/2016	24/02/2017	Investigator kit	Tinaroo	S Todd/Rhys Sharry	*B. tropica*
25/10/2016	24/02/2017	Investigator kit	Tinaroo	S Todd/Rhys Sharry	*B. tropica*
25/10/2016	24/02/2017	Investigator kit	Tinaroo	S Todd/Rhys Sharry	*B. tropica*
25/10/2016	24/02/2017	Investigator kit	Tinaroo	S Todd/Rhys Sharry	*B. tropica*
25/10/2017	24/02/2017	Investigator kit	Tinaroo	S Todd/Rhys Sharry	*B. tropica*
25/10/2017	24/02/2017	Investigator kit	Tinaroo	S Todd/Rhys Sharry	*B. tropica*

Further research

This research was conducted as part of a larger study to be presented in Todd's PhD thesis (in preparation) which aims to understand how landscape heterogeneity influences northern bettong genetic diversity and connectivity. Future work will include hair trapping trials required to optimise the field collection of hair non-invasively, and this method will be the primary means of obtaining DNA. Hair trapping and DArT genotyping will be used to provide important population genetic and connectivity information in the Lamb Range and Mt. Spurgeon. This will supplement upcoming results from DArT analysis of the Lamb Range tissue samples.

Conclusion

Despite the ethical advantages and potential for non-invasive sampling the DNA contained in non-invasive samples is often poor quality and low quantity (Creel et al. 2003; Paetkau 2003; Taberlet et al. 1999). Oorts do contain DNA and it may be theoretically possible to identify individual bettongs using DNA fingerprinting (microsatellite genotyping) however, the combination of low success rate, high error rate and expense mean that it is currently an unsuitable approach to population monitoring of northern bettongs. However, oort mitochondrial DNA can be used to unambiguously identify the presence of bettongs in an area and could therefore be useful for further monitoring and management.

Conversely the relatively high success rate and cost of extraction and amplification of DNA from hair means it has a high potential to be used for northern bettong population genetic studies, with either SNP or microsatellite genotyping.

OBJECTIVE 2. ASSESS THE SIGNIFICANCE OF THE NORTHERN BETTONG'S ROLE IN ECOSYSTEM FUNCTION

Introduction

The northern bettong's main food source are truffles, fungi that fruit below ground. Truffles need animals, like the northern bettong to eat them so that their spores can be dispersed within the appropriate habitat (Claridge & May 1994). Most truffles are ectomycorrhizal (ECM), meaning that they form symbiotic relationships with plants by growing in and around their roots and providing them with hard-to-access nutrients in exchange for sugars (Hawkins *et al.* 2015). In this way, ECM fungi are highly important for plant health and survival and ecosystem's nutrient cycling and function. Additionally, animals like the northern bettong are important for maintaining the diversity of ECM truffle fungi and are integral to an ecosystem's healthy function.

In Australia, many mammals consume and disperse fungi. However, members of the Potoroidae family (including northern bettongs) are known to consume a high proportion of ectomycorrhizal fungus in their diet and are considered fungal specialists. However, it is unknown whether fungal specialists perform a unique and irreplaceable dispersal role for truffle ECM fungi, over and above the combined dispersal role performed by other mammals (generalists; Nuske *et al.* 2016).

We set out to determine the role in which the northern bettong played as a disperser of truffles in their habitat compared to other mycophagous mammals in the same location, and ultimately to determine if they are a keystone species. This information will help determine whether truffle diversity will be compromised in areas where we have already lost northern bettongs (or other fungal specialists).

Methods

For Nuske's PhD thesis (2017), soil, tree roots and mammalian scat were collected and analysed for the abundance and diversity of ECM fungi at up to three locations in the Lamb Range, far north Queensland.

Over a two-year period (2014-2015), mammalian scat was collected via cage trapping at Tinaroo Creek, Emu Creek and Davies Creek using the method described in the previous sections. Additionally, 50 Elliot traps were also set to capture small mammals such as rats and *Antechinus* at Tinaroo Dam and Davies Creek during two sampling periods (Nov-Dec 2014 and Feb-Mar 2015). The scats were collected from the base of Elliot traps and from the plastic liner under each cage trap. Scats were stored on ice in the field and then transported to a freezer within four days.

Tree root and soil samples were collected at two sites in the Lamb Range; Tinaroo Creek and Davies Creek, in the early wet season (Feb-Mar) and the late dry (Nov-Dec). This was conducted around the same sites as the cage trapping occurred, with each of the six plots spaced 500m apart. Topsoil cores were collected from 40 locations and the top 10cm was raked for 60 person-minutes and fine roots collected. Elliot trapping and soil and root collection was conducted within three weeks of the cage trapping.

In the laboratory, a sample of each scat, soil and tree root was taken for DNA extraction. The DNA was extracted using PowerLyser PowerSoil DNA Isolation kit and amplified using ITS3-Mix1 and barcoded ITS4-Mix1 primers.

Fungal DNA was sequenced for all samples. Fungal taxa were determined by comparing to online databases or sequences from truffles collected from Davies Creek. The diversity and relative abundance of ECM fungi were compared between mammal species and between soil and root samples to determine the importance of the dispersal role performed by northern bettongs.

Results

An analysis that compares the whole fungal community within northern bettong and generalist mammal scats revealed that there were significant differences between them, above and beyond differences between sites and seasons (Nuske 2017). Northern bettongs had a higher number of truffle species and at a higher relative abundance in their diet compared to generalist mammals (Figure 21). The average number fungal species per sample was higher in northern bettong scats compared to generalist scats, including ECM and truffle taxa (Table 11). Northern bettongs had 77 truffle taxa unique to their scats, compared to 15 for all nine species of generalist mammals (Figure 21).

Additionally, we found that the dominant mycorrhizal taxa (cumulatively > 90% of the relative abundance) associating with tree roots were truffle taxa (and not mushroom or other taxa). These same truffle taxa (Mesophelliaceae and Hysterangiaceae) were also favoured by the northern bettong (Figure 21). Over 85% of truffle taxa from root samples were shared with northern bettong diets, whereas only 52% were shared with diets of generalist mammals (Figure 22).

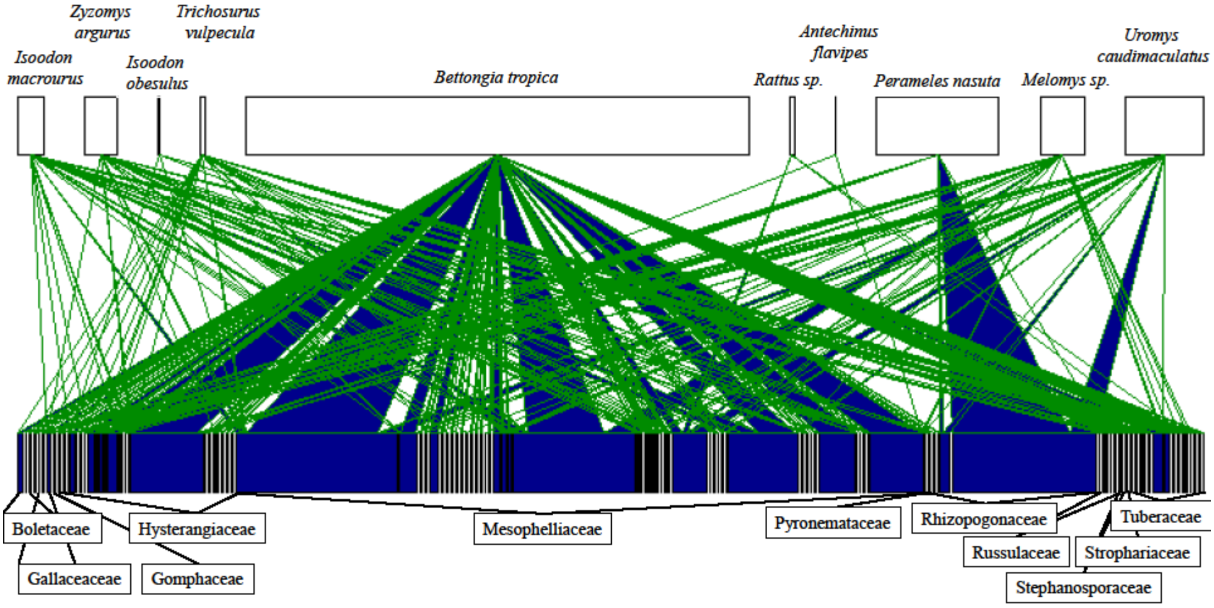


Figure 21: Bipartite network of mammal species (upper level) and the truffle molecular species within each mammal species' diet (lower level). Truffle species are labelled according to truffle family. Width of boxes and arrows is proportional to the relative abundance of truffle taxa for each truffle-mammal interaction.

Table 11. Sample numbers (N) and mean ± SE molecular species richness per sample (total molecular species richness per mammal species) for the fungal specialist (*Bettongia tropica*) within Potoroidae and all non-bettong samples combined (Generalists) across different subsets of the data (all fungi, ectomycorrhizal fungi and truffle fungi).

	All fungi		**ECM fungi**		**Truffle fungi**	
Mammal species	N	Mean ± se (total)	N	Mean ± se (total)	N	Mean ± se (total)
Specialist	93	188.1 ± 9.34^{b} (4176)	92	10.0 ± 0.75^{b} (254)	89	8.6 ± 0.80^{b} (135)
Generalists	120	101.2 ± 8.25^{a} (5266)	108	4.1 ± 0.32^{a} (159)	85	3.8 ± 0.44^{a} (73)

^{a,b}: Different superscript letters represent significant differences in *Tukey* HSD comparisons between *B. tropica* and generalist mammal species ($P < 0.05$).

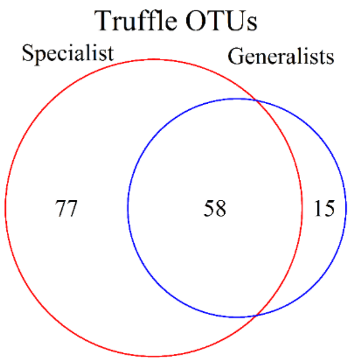


Figure 22. Venn diagram displaying the number of truffle taxa shared (overlapping circles) and not shared across samples (red for specialist and blue for generalist samples).

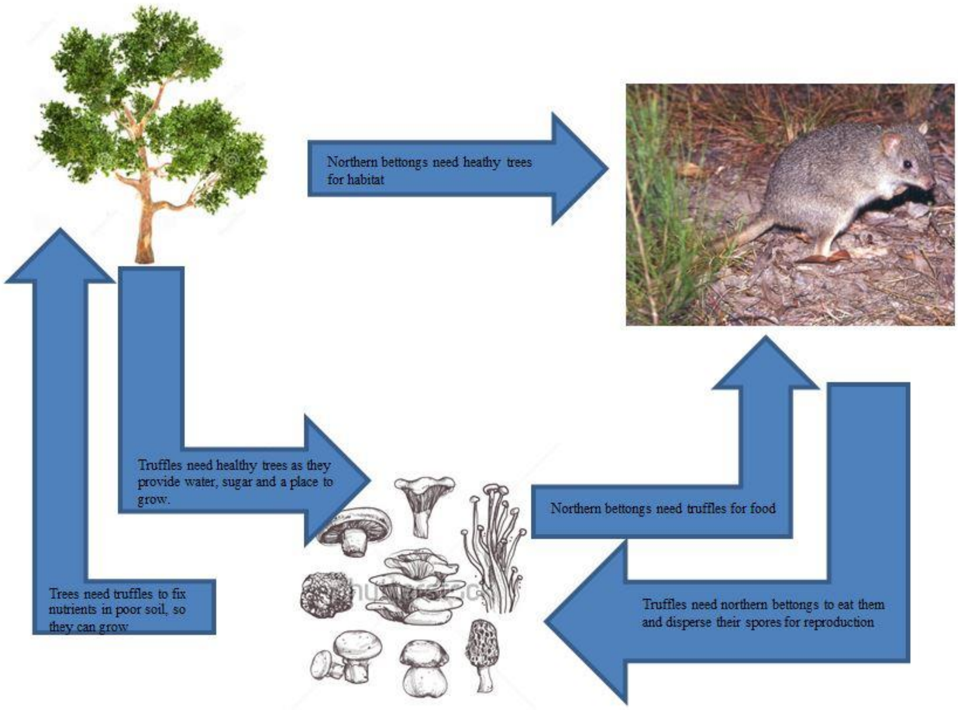


Figure 23. Illustration of the northern bettong's role in its habitat.

Conclusion

Compared to the combined fungal diet of nine generalist fungal-eating mammals, the northern bettong consumed a unique fungal community, higher diversity and more unique truffle taxa. Additionally, more truffle taxa from northern bettong diets were shared with mycorrhizal communities associating with tree roots than generalist mammals.

The findings of this study confirm that the northern bettong is an important and unique species in that disperses a high proportion of ECM truffle taxa which attach to tree roots. If the northern bettong were to disappear from areas or become extinct, it is likely that this will have a detrimental effect on the richness of fungal taxa over time. This would cause a shift in mycorrhizal communities, with unknown effects on tree health, nutrient dynamics and ecosystem functioning. Further research is urgently needed to test these affects. Targeting areas where we have lost northern bettong populations for reintroductions is likely to help understand these effects.

OBJECTIVE 3. DEVELOP APPROPRIATE FIRE MANAGEMENT REGIMES FOR THE NORTHERN BETTONG

Introduction

Fire management is an important issue when considering northern bettong conservation, and if done incorrectly, can negatively affect northern bettong habitat and thus their populations. Since European settlement, there have been vast changes in the way people manage the land, including fire management. In the Wet Tropics region, these changes in fire regimes have caused the loss of up to 70% of wet sclerophyll/ecotonal habitat bordering the rainforest, which includes some of the northern bettong's known range (Harrington & Sanderson 1994). A lack of fire in wet sclerophyll habitats has caused the rainforest to encroach on previously open forest with a grassy understorey, which doesn't allow for the germination of wet sclerophyll trees anymore, particularly *Eucalyptus* species. This means there is less available habitat for the northern bettong to occupy.

It is currently known that northern bettongs and their primary food sources, truffles and cockatoo grass, are fire adapted and/or rely on fire for their survival. Low to moderately intense burns have been shown to not negatively affect northern bettongs (Vernes & Haydon 2002; Figure 26).

This Project looked at addressing one of the biggest threats to the northern bettong: inappropriate fire patterns. A range of land managers, government agencies, traditional owners, community groups and scientists worked together to develop fire management approaches at confirmed northern bettong sites in order to sustain or increase their populations through habitat restoration. These prescribed burns aim to increase food resources and available habitat for northern bettongs (Figure 24).

Figure 24. Fire approaching a sensor camera at Yourka Reserve.

Methods

The best management fire practices and historical and current knowledge were collated in relation to northern bettong habitat and these were used to develop four guidelines to managing fire in northern bettong habitat. The four site-specific guidelines were then compiled into one field guide; 'Field guide for managing fire in northern bettong habitat'.

The area of scope of this field guide applies to northern bettong habitat in the Wet Tropics bioregion, specifically two habitat types with common fire management requirements; open forests and woodland and open, tall wet sclerophyll forests.

Appropriate fire management objectives were devised by experts based on the need by land managers and the habitat requirements of the northern bettong. Traditional Owner best fire management practices and advice were sought in the preparation of this field guide.

Results

Through the process of this study, 'A Guideline to fire management in northern bettong habitat' was published and is now free to download from the DES website.

Depending on which northern bettong habitat management issue the landholder needs to address (i.e. maintaining cockatoo grass, reducing lantana), there are recommendations on fire intensity, patchiness, fire interval, and in what conditions and when to burn (Figure 25). These burning regimes may result in positive outcomes for the northern bettong, such as maintaining healthy habitat, providing resource refugia, regaining connectivity, promoting truffle diversity, improving grass diversity and improving habitat (reducing thickening/early stage of transitioning; Figure 25).

Fire parameters	Fire characteristics	
	Open forest of the foothills and ranges	**Tall open forest**
Suggested conditions (soil moisture)	<130 KBDI Thatch and long unburnt fuels will burn under lower KBDI of near 90 Dew point (reliable, typically below 17°C)	<170 When rain can reliably be expected or there is good return soil moisture Relative humidity 50–75% range
Fire Danger Rating (FDR)	<12	<14* (*with an accompanying rising relative humidity)
Interval (min, max time between fire)	2–5 years (moist grassy open forest and dry grassy open forest) 6–10 years (grassy to shrubby)	3–5 years (grassy understorey) 6–10 years (shrubby understorey)
Intensity (fire height)	Low to moderate <0.5–1.5 m	Low to moderate <0.5–1.5 m
Patchiness (area unburnt)	30–75% Grass curing: 60–80%	20-40% Grass curing: 80–90%
Season	April-Jun (a longer wet winter may see burning extend beyond a typical end in early June, to carry into August)	In conjunction with first storm burst ~50–75mm (Nov-Jan, burning typically occurs within ~3 days of a rain event on clear, sunny weather)
Severity	Low to moderate	Low to moderate

Figure 25. Guidelines for fire management parameter ranges for maintaining healthy habitat and home range scale refugia. Source: EHP 2017.

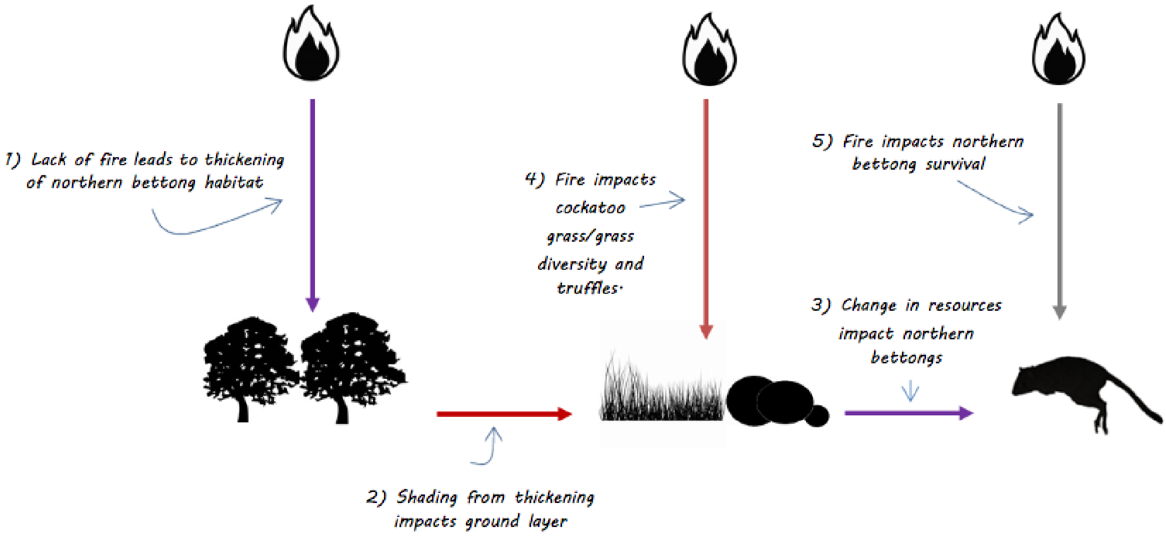


Figure 26. Possible relationship pathways between fire and northern bettongs (EHP 2017)

Conclusion

Fire management is an important tool in the conservation of the northern bettong and its habitat. The implementation of fire management outlined in the field guide, is aimed at restoring and/or increasing areas of northern bettong habitat and ultimately, their populations. However, continued monitoring of these habitats, before and after burns (both short and long-term) will increase our understanding of these interactions and help adaptively manage these areas for the northern bettong.

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KEY POINTS

- The northern bettong has suffered a decrease in area of occupancy by approximately 70% - from 500km² to 145km² in the last three decades
- Their number of populations have decreased by 50% - They could only be located in two distinct and disjunct populations at Mt. Spurgeon and Lamb Range; 90% of all records fell within the Mareeba Shire Council region
- We were able to validate the presence of a northern bettong population on the Carbine Tableland at Mt. Spurgeon, an area where they had not been recorded since 2003
- We discovered at least one individual via camera trapping in a previously un-surveyed area in the northern Lamb Range at Koah
- Cage trapping in the Lamb Range captured 188 northern bettong individuals
- The Lamb Range's northern bettong population is considered 'stable'; the Carbine Tableland's population status is still unknown
- The highest density of northern bettongs was found at Tinaroo Creek (13 bettongs/km²)
- PVA models indicate that increases in the juvenile mortality rate is the greatest threat to the northern bettong
- Under scenarios of high levels of feral cat predation, the modelling suggests that the northern bettong metapopulation in the Lamb Range could become extinct within less than 10 years.
- Northern bettongs have varying habitat requirements over the course of their day; they prefer nesting sites situated in steep areas with high grass cover and an abundance of grass trees whereas they prefer foraging

sites with a higher density of cockatoo grass, a lower density of tree basal area, taller (mature) trees and steeper slopes

- The northern bettong and rufous bettong were negatively correlated, with both species only co-existing at Emu Creek
- Rufous bettong are now found at seven sites (~70%) of historical northern bettong presence/ potential habitat (excludes Upper Daintree)
- Introduced mammals were observed at all 11 areas surveyed for northern bettongs. These include feral cats (found at ~40% of sites) and pigs (80%). Wild dogs, or dingoes, were also found at 64% of sites, though the survey did not distinguish between the two. No red foxes were detected.
- Northern bettongs were detected on cameras in three regional ecosystem types only within the Mareeba Shire region
- Oort analysis was successful in identifying the presence of the northern bettong in an area compared with other macropod species
- Non-invasive DNA analysis of scats, hair and oorts was determined to not be a feasible as a replacement to invasive population sampling techniques (cage trapping)
- Hair trapping may be a more feasible remote monitoring method
- The northern bettong was found to consume many more ECM truffle taxa when compared to the combined dispersal role from nine other fungus-eating mammal species in the same habitat; Up to 77 ECM truffle taxa were unique to the northern bettong's diet
- The important role of the northern bettong in maintaining forest health (as an ECM fungal disperser) classifies them as a keystone species
- Fire research led to the development of a 'Guidelines for managing fire in northern bettong (*Bettongia tropica*) habitat' document, which is available as a PDF on the Department of Environment and Science's website
- These guidelines aim to instruct land managers how to conduct fire management on their properties targeting specific outcomes such as promoting ECM fungal diversity, cockatoo grass coverage and weed management.

DISCUSSION

Objectives

The Northern Bettong Project (2013-2018), led by WWF-Australia in collaboration with partners JCU and DES, succeeded in delivering its three objectives:

1. Estimate the current population status, distribution and habitat use of the northern bettong;
2. Assess the significance of the northern bettong's role in ecosystem function;
3. Develop appropriate fire management regimes for the northern bettong.

The combined skill and expertise of partners, as well as over 100 individuals across the Wet Tropics region and beyond - local Traditional Owners, natural resource management bodies, private conservation organisations, research institutions, government departments, independent scientists, community groups and volunteers - enabled the success of this large-scale, multidisciplinary project. Indeed, one of the biggest successes to come out of this project was the scale of collaboration. Together, and with a lot of hard work and dedication to the northern bettong, not only were we able to complete project milestones, but we forged strong working relationships and increased public awareness of this little-known macropod species immensely.

Historical and current population status

From extending south to Rockhampton pre-1920's, to existing in four or five populations in the 1980's to now being found in only two populations, it is clear that the northern bettong is headed for extinction if the threats are not addressed and ameliorated. The results of camera surveys found that the northern bettong is now limited to an area of occupancy of <145km²; down from 500km² which was estimated in 2008 (Burnett and Winter 2008). 90% of all recent records are within the Mareeba Shire Council region on the western slopes of the Carbine Tableland and the Lamb Range and are restricted to open woodland and wet sclerophyll forests in a narrow band adjacent to World Heritage listed Wet Tropics rainforest. There is still some hope that there may be northern bettong populations persisting in low densities at Mt. Windsor, greater Ravenshoe and in the Coane Range (last records were 1989, 1922 and 2003 respectively), but with a considerable amount of search effort dedicated to those areas over the last 15-20 years with no success in detecting them, the chances are low. Areas to the north of Mt. Windsor in Cape York, the eastern side of the Lamb Range near Cairns, remote terrain near the Carbine Tableland and the Dawson Valley near Rockhampton were not surveyed as part of this study - although have been surveyed for the northern bettong over the last 30 years – and have no substantiated records. Fortunately, the only confirmed ongoing population in the Lamb Range appears to be stable. However, the status of the second population at Carbine Tableland is unknown.

The discovery of at least one individual on the north-west side of the Kennedy Highway in Koah (1km outside the mapped habitat area) extends the Lamb Range population by 2km west and gives hope to more populations being discovered in the future, outside of the areas searched within this Project. It also questions the accuracy of the habitat mapping model and suggests that an updated model should be created using the Project's new data insights. The majority of the land tenure of mapped northern bettong habitat was within National Park and State Forest/ Forest Reserve tenure, and therefore it was mostly these areas which were searched. It will be important in the future to carry out targeted surveys on private land in order to gain a more accurate picture of distribution and abundance, particularly on cattle properties and other agricultural enterprises in the Lamb Range and wider Mareeba Shire Council area. It would be our hope that this may extend the areas of available northern bettong habitat and thus extend their population capacity.

Population viability and threats

It is clear from the results of the project that northern bettong populations have suffered drastic reductions over the last three decades. It is likely that the population decline is due to several, compounding anthropogenic and natural factors. Changes in climate, land use and land management practices since European arrival in Australia - including changed fire regimes, habitat clearance, land degradation and the introduction of cattle, pigs and feral predators such as cats – are all likely to be among the drivers. Two of the 15 regional ecosystem types for northern bettong habitat are considered 'endangered', therefore restoring and protecting these habitats into the future should maintain a priority. Although, of the 15 RE types searched, northern bettongs could only be detected on cameras in three RE types of 'no concern' and 'of concern' biodiversity status, and this is where efforts should primarily focus.

Predation from feral cats was modelled as being the most important factor in northern bettong population viability, particularly if they target juveniles. Though, this impact may be exacerbated with additional pressures from climate change, which will likely affect drought and fire in the region and cattle grazing, which affects grass cover. This affect could also be exacerbated by the northern movement of the red fox (Vulpes vulpes; a known bettong predator) into northern bettong habitat, which is a possibility in the southern extent of the northern bettong's range near Paluma. Minimising the predation of juveniles would appear to assist in maintaining their population stability, although due to the likelihood of being able to reduce feral cat numbers, its perhaps not the most important threat to focus on. Feral pigs and cattle were detected at 80% of sites, and this may produce a significant negative effect on northern bettong habitat. A focus on restoring and maintaining suitable northern bettong habitat by removing ferals (with high levels of grass cover, grass trees, cockatoo grass and tall trees on steeper slopes) and associated RE types would not only provide sufficient grass cover and thus protection from predators, but it would reduce feral flora and fauna populations, such as cattle and lantana, and help to reduce their effect on the northern bettong and its habitat.

Camera surveys in the Wet Tropics detected feral cats at ~40% of sites, whereas the cameras focused in the Lamb Range detected only one cat in northern bettong habitat. Feral cats in Australia are notoriously difficult to detect in the landscape and are very wary of baits and cameras in general (Stokeld et al. 2015). Several wild dogs or dingoes were observed (at >60% of key areas) and it is predicted that they have a positive influence on northern bettongs - as they do for other bettong species in Australia – in deterring feral cats, although this has not been tested in relation to northern bettong (Dickman 1996). The red fox has been implicated in the decline of several bettong species nationally (Kinnear et al. 2002) and there have been unsubstantiated reports of their presence in the Wet Tropics. Although, they were not detected on cameras or by any other means in northern bettong habitat throughout this project. If foxes were to establish in far north Queensland, this could be disastrous for the northern bettong.

Contrary to a previous study by Winter (1997), although consistent with recent research conducted in 2010 (Bateman), we found that the rufous bettong and northern bettong were negatively correlated. Both bettongs were detected at just one site at Emu Creek in the Lamb Range. This may indicate competition between the two species, for example for food or habitat. Rufous bettong are a larger and more common Potoroid and have a more varied diet and therefore are able to occupy a larger range of habitats then the northern bettong. Interestingly, rufous bettong were detected at every historical northern bettong site or mapped habitat except one. It is unclear, though, whether the rufous bettong moved into available habitat as the northern bettong declined, or whether the northern bettong was pushed out of the habitat by its larger and more boisterous relative.

Non-invasive conservation genetics

It was found that oorts do contain buccal cells of the animal that produced them, and it is sometimes possible to isolate DNA from them. However, DNA is generally of low quantity and quality making success rates low and only fresh oorts are viable. Furthermore, successful extraction is relatively expensive and requires a commercial forensic kit. There are several reasons oorts have little useful DNA. Once cells are separated from the organism their DNA begins to degrade. This exacerbated with exposure to the sun and heat, and rain can wash away cells further reducing DNA (Taberlet et al. 1999; Waits and Paetkau 2005). Degradation of DNA not only reduces the extraction success it can lead to errors during amplification and genotyping or poor sequencing (Creel et al. 2003). This is problematic in DNA fingerprinting and population genetics where allelic dropout or other errors can lead to biased results (Creel et al. 2003; Piggott et al. 2004; Taberlet and Luikart 1999; Taberlet et al. 1999; Waits et al. 2001).

Plants often contain compounds that inhibit PCR amplification, making this step tricky in samples where animal cells are mixed with plant matter (Piggott et al. 2004). Several protocols have been developed to remove these compounds, including QIAGEN's Inhibex® buffer which is designed to precipitate out problematic plant alkaloids. Such protocols are frequently used to isolate DNA from animal faeces with good success (Waits and Paetkau 2005). However, faeces differ from oorts in that it spends greater time in contact with the gastrointestinal tract lining than the grass would spend in contact with the buccal lining of a bettong (Smith and Burgoyne 2004). This may result in fewer cells available for extraction of DNA and may explain why faecal extraction protocols were unsuccessful.

Also, as part of this study to be presented in Todd's PhD thesis (in preparation), her research showed that fresh frozen northern bettong hair follicles contain small quantities of high molecular weight (quality) DNA which can be extracted economically using a high salt protocol. However, overnight lysis is essential to maximise the amount of DNA obtained from the hair follicle. The success from amplifying microsatellite markers is promising for DNA fingerprinting with hair, but further work is needed to realise this potential, including optimizing multiplex reactions and ensuring cross species markers are polymorphic for northern bettongs. Hair is also ideally suited for species identification, due to the hair shaft containing mitochondrial DNA (cell nuclei degrade in the hair shaft). Whereas nuclear DNA is only found in the hair follicle (Waits and Paetkau 2005). Hair sampling has the added advantage that the process of hair trapping is active and systematic, making it more suitable for quantitative surveys than passive oort collection (Lukacs and Burnham 2005)

Through non-invasive genetic sampling of oorts, this research was able to identify oorts coming from Mt. Windsor, Mt. Fox and Blencoe Falls as coming from rufous bettongs and not from northern bettongs. This shows that indeed other species make oorts that look similar to those produced by northern bettongs and added to the building evidence that northern bettongs no longer persisted in these areas.

The microsatellite genotyping results showed that in the Lamb Range northern bettongs appear to be genetically healthy, with no marked decline in heterozygosity or allelic diversity since the late 1990's (Pope et al. 2000). In this study, total heterozygosity was 70% which is similar to that found by Pope et al. (2000; 75%). This was only a trial with a small sample size; however, 70% heterozygosity is quite high and comparable to other species that have not experienced range contractions (see Pope et al. 2000 for further references). Allelic diversity (mean no. alleles per locus) was 5.83 ± 0.87, which is comparable to Pope's estimates for Emu Creek and Tinaroo (5.71 ± 1.98 and 5.29 ± 2.43, respectively) but lower than her estimate for Davies Creek (7.14 ± 3.02).

Role in ecosystem function

The importance of the northern bettong as a disperser of fungi and a keystone species in the ecosystem was found to be highly significant. The northern bettong was found to consume (and disperse) a unique array of ectomycorrhizal fungi when compare with other mycophagous mammals in the area. The decline of the northern bettong may have significant implications for the habitats in which it no longer resides, possibly affecting tree health and ecosystem function. Further studies are needed to confirm the link between bettong decline and decline in truffle diversity. Areas where bettongs have recently gone extinct could be targeted for reintroductions to help maintain truffle diversity.

Fire management

The implementation of the ‘Guide to fire management in northern bettong habitat’ has the potential to drive an improvement in conservation, management and restoration of northern bettong habitat. Moreover, the northern bettong will not be the only species to benefit from better fire management, with the threatened yellow-bellied gliders and northern quolls also benefitting from a decrease in rainforest encroachment, and fewer high intensity wildfires. The guide is user friendly and flexible, with land managers tailoring fire strategies to deliver on specific land management objectives. Although the guide is available for download for free on the DES website, we are unsure of how many landholders are putting this into practice. Further contact with land managers, particularly in the Mareeba Shire mapped northern bettong areas, would assist in the uptake of the guide and successful implementation of it.

RECOMMENDATIONS

While it is clear from the results of this project that northern bettong populations have suffered drastic reductions over the last three decades, we are now closer to understanding what needs to be done to reverse this decline and are now in a much stronger position to make it happen. Coordinated action, coupled with applied research, is urgently needed in order to halt and reverse the population decline of the northern bettong and prevent potential extinction within the coming decades (or less). This may include ongoing projects such as; large-scale habitat restoration of previously known northern bettong habitat, including cattle and pig exclusion; restoration and maintenance of open woodland and forests (with relevant RE's a priority) through 'right-way' fire and weed management; further research into the northern bettong's main threats (especially the effect of feral animals); and reducing the number of feral predators (especially feral cats). These measures may also benefit other threatened species in these habitats such as the northern quoll (*Dasyurus hallucatus)*, yellow-bellied glider (*Petaurus australis*) and mahogany glider (*Petaurus gracilis*). Once the threats to the northern bettong have been substantially addressed, a viable 'insurance population' in the form of a captive breeding program - or otherwise - would also be an ideal next step. This would ensure, that in the event of extinction of one or both of the known populations, these individuals can be used to restore northern bettong populations in the wild to suitable habitat. This captive population could also be used to translocate new populations to suitable habitat, either historical and/or new sites. Also, a potential uplisting of the northern bettong from 'endangered' to 'critically endangered' might more accurately reflect their recent decline in population and further emphasise their plight.

Priority actions:

- Conserve and restore northern bettong habitat
- Address key threats to the northern bettong and its habitat, including fire and pests (cats, cattle, pigs)
- Consider uplisting of the northern bettong to 'critically endangered', including further assessment against relevant criteria and thresholds
- Explore options for an insurance population of northern bettongs

Priority research:

- Clarify population status and viability on the Carbine Tableland
- Refine the population estimate using new habitat data
- Refine the habitat model to incorporate new data
- Improve understanding of the effects of climate, fire, cats, cattle, pigs and dogs on the northern bettong and its habitat
- Clarify the relationship between the northern bettong and rufous bettong (as competitors)
- Explore the potential of DNA to study northern bettongs in a non-invasive way

PUBLICATIONS

List of publications resulting from the Northern Bettong Project

Department of Environment and Heritage Protection's (EHP) (2017), 'Field Guide for managing fire in northern bettong habitat', *https://www.ehp.qld.gov.au/wildlife/threatened-species/documents/field-guide-managing-fire-northern-bettong-habitat.pdf*

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APPENDIX 1.

Regional Ecosystem types for current and historical northern bettong records in the Wet Tropics bioregion (Source: Queensland Government 2018)

RE Type	Vegetation description	Biodiversity status
7.12.21	Eucalyptus grandis open forest to woodland, or Corymbia intermedia, E. pellita, and E. grandis, open forest to woodland, (or vine forest with these species as emergents) on granite and rhyolite	endangered
7.12.22	Eucalyptus resinifera +/- E. portuensis +/- Syncarpia glomulifera tall open forest to tall woodland (or vine forest with these species as emergents) of granite and rhyolite uplands and highlands	endangered
7.11.35	Eucalyptus portuensis +/- Corymbia citriodora woodland to open forest on metamorphics	of concern
7.11.51	Corymbia clarksoniana and/or Eucalyptus drepanophylla open forest to woodland on metamorphics	of concern
7.12.51	Eucalyptus resinifera, Syncarpia glomulifera, E. portuensis, Corymbia abergiana, +/- C. leptoloma woodland, of rocky hills on granite and rhyolite in the Paluma-Seaview (south-west) subregion	of concern
7.12.61	Eucalyptus tereticornis +/- E. granitica woodland to open forest of foothills and uplands on granite and rhyolite	of concern
7.12.69	Eucalyptus drepanophylla and/or E. granitica +/- Corymbia clarksoniana +/- C. erythrophloia woodland on uplands on granite and rhyolite	of concern
7.12.19	Simple microphyll vine-fern forest with Balanops australiana, Elaeocarpus spp. +/- Trochocarpa bellendenkerensis +/- Uromyrtus spp. +/- Agathis atropurpurea of cloudy wet highlands on granite and rhyolite	no concern
7.12.27	Eucalyptus reducta open forest to woodland on uplands and highlands on shallow granitic and rhyolitic soils	no concern
7.12.30	Corymbia citriodora +/- Eucalyptus portuensis woodland to open forest on granite and rhyolite	no concern
7.12.34	Eucalyptus portuensis and/or E. drepanophylla, +/- C. intermedia +/- C. citriodora, +/- E. granitica open woodland to open forest on uplands on granite	no concern
7.12.53	Corymbia clarksoniana +/- C. tessellaris, +/- Eucalyptus drepanophylla +/- C. intermedia open forest to woodland, or E. drepanophylla woodland, of moist to dry lowlands, foothills and uplands on granite and rhyolite	no concern
9.11.4	Eucalyptus crebra, Corymbia clarksoniana, C. citriodora subsp. citriodora +/- E. portuensis open forest on shallow soils on metamorphic hills and ranges	no concern
9.12.7	Eucalyptus cullenii +/- Corymbia leichhardtii +/- C. erythrophloia woodland on igneous rocks	no concern
9.5.9	Corymbia clarksoniana and/or Eucalyptus leptophleba and/or E. platyphylla woodland on plains	no concern

APPENDIX 2.

Wildlife species captured on camera traps at 11 key areas in the Wet Tropics (X=species present)

	Species name	Mt Windsor	Upper Daintree	Mt. Spurgeon	Kuranda NP	Koah	Herberton	Greater Ravenshoe	Yourka	Kirrama Range	Mt. Fox	Coane Range
MAMMALIA					*yet to be analysed*							
Metatheria												
Northern bettong	*Bettongia tropica*			X		X						
Rufous bettong	*Aepyprymnus refescens*	X					X	X	X	X	X	X
Northern quoll	*Dasyurus hallucatus*		X	X		X	X					
Spotted-tail quoll	*Dasyurus maculatus*	X	X									
Swamp wallaby	*Wallabia bicolor*			X		X	X	X	X	X	X	X
Agile wallaby	*Macropous agilis*					X	X		X	X	X	X
Whip-tail wallaby	*Macropus parryi*						X	X		X		X
Red-legged pademelon	*Thylogale stigmatica*		X	X		X						X
Common wallaroo	*Macropus robustus*					X			X	X		X
Eastern grey kangaroo	*Macropus giganteus*						X	X	X	X		X
Unknown macropod		X	X				X			X		
Allied rock wallaby	*Petrogale assimilis*											X

Mareeba rock wallaby	***Petrogale mareeba***						**X**					
Brush-tailed possum	*Trichosurus vulpecula*	X	X	X		X	X	X	X	X		X
Common ringtail possum	*Pseudocheirus peregrinus*									X		
Northern brown bandicoot	*Isoodon macrourus*		X	X		X	X	X	X	X		X
Bandicoot species unconfirmed	*Isoodon sp.*	X		X		X			X		X	
Cape York brown bandicoot	*Isoodon peninsulae*					X			X			
Long-nosed bandicoot	*Perameles nasuta*	X	X	X				X		X		X
Yellow-footed antechinus	*Antechinus flavipes*											X
Antechinus sp.	*Antechinus sp.*									X		
Sminthopsis sp.	*Sminthopsis sp.*								X			
Koala	*Phascolarctos cinereus*							X				
Monotremata								X				
Short-beaked echidna	*Tachyglossus aculeata*		X			X	X			X	X	X
Placental												

unidentified rodent		*X*	X	X								
Rattus sp.	*Rattus sp.*		X			X	X		X	X		X
Melomys sp.	*Melomys sp.*		X	X		X		X		X		X
Bush rat	*Rattus fuscipes*							X		X		
unidentified mouse						X			X		X	X
Giant white-tailed rat	*Uromys caudimaculatus*		X	X		X					X	
Introduced placental												
Wild dog or dingo	*Canis lupus*		X	X			X	X	X		X	X
Cow	*Bos taurus/indicus*	*X*	X	X				X	X	X	X	X
Feral pig	*Sus scrofa*	*X*	X	X				X	X	X	X	X
Feral cat	*Felis catus*						X	X	X			X
European rabbit	*Oryctolagus cuniculus*										X	
Horse	*Equus caballus*						X					
REPTILIA & AMPHIBIA												
unknown lizard		*X*	X						X			
Spotted tree monitor	*Varanus scalaris*		X									

Black-headed monitor	*Varanus tristis*							X			
Lace monitor	*Varanus varius*		X	X	X			X			X
Cane toad	*Rhinella marina*				X		X	X	X		
AVES											
unidentified bird			X			X					
Grey goshawk	*Accipiter novaehollandiae*		X								
Australian owlet-nightjar	*Aegotheles chrisoptus*		X					X	X		X
Scrub turkey	*Alectura lathami*	*X*	X	X		X					X
Brush cuckoo	*Cacomantis variolosus*		X								
Crow/raven	*Corvus sp.*		X				X	X	X	X	X
Olive-backed sunbird	*Nectarinia jugularis*		X								
Noisy pitta	*Pitta versicolor*		X	X							
Pheasant coucal	*Centropus phasianinus*			X			X	X	X		X
Pied currawong	*Strepera graculina*		X	X		X		X			X
Tawny frogmouth	*Podargus strigoides*		X					X			

Australian magpie	*Gymnorhina tibicen*	X	X	X		X			X
Pied butcherbird	*Cracticus nigrogularis*			X		X			
Grey butcherbird	*Cracticus torquatus*				X				
Emu	*Dromaius novaehollandiae*					X		X	
White-throated nightjar	*Eurostopodus mystacalis*		X			X			
Peaceful dove	*Geopelia placida*			X	X	X			
Noisy minor	*Manorina melanocephala*					X		X	
Wedge-tailed eagle	*Aquila audax*						X		
Grey shrike-thrush	*Colluricincla harmonica*						X		X
Quail	*Turnix sp.*					X		X	
Willie wagtail	*Rhipidura leucophrys*						X		
Dollarbird	*Eurystomus orientalis*				X				
Brown goshawk	*Accipiter fasciatus*			X					
Sulphur-crested cockatoo	*Cacatua galerita*			X					

Eastern yellow robin	*Eopsaltria australis*											X
Common bronzewing	*Phaps chalcoptera*											X
Brown treecreeper	*Climacteris Picumnus*									X		
TOTAL SPECIES	*73*	*11*	28	19	n/a	19	22	21	32	26	15	30

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WWF-Australia National Office

Level 1, 1 Smail St,
Ultimo NSW 2007
GPO Box 528,
Sydney NSW 2001

Tel:+1800 032 551
enquiries@wwf.org.au
@WWF_Australia
wwf.org.au